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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 2017. Further evolutions will be covered in the planned revisions of the document.

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 2017, 15 months after the start of the project.

Before entering into 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 develop 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).

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 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.

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.

In the long term the project plans to cover functionality to support heterogeneous networking, including functionalities such as Wi-Fi offloading or dual connectivity. These actions are tackled in Year 2 of the project in task 4.1.

Finally, it is the intention of the consortium to keep on monitoring the evolution of 5G aspects throughout the project. An update of this deliverable will be published by March 2018 (Project Month 27).

Contents

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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 test bed relevance. Focusing on a target without taking into account the 5G evolution would limit the chance of being successful from a test bed exploitation perspective.

In this report (finalized - March 2017), we describe the evolution states that took place between the project submission (summer 2015) and March 2017. 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.

Finally, the consortium intends to review this document and adapt its content in 12 months from its publication (March 2018).

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.

In order 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 NarrowBand-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 are capable of measuring the time difference between some 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.

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 1.4 MHz 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 1.4 MHz, 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 20 MHz. 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 868 MHz (as defined by ETSI and CEPT) as well as the 902 MHz 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.

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 [6].

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*” [7].

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" [7] 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 [8], the latest Wi-Fi Alliance Certification Program Roadmap [9] published in October 2016 has postponed the program launch to be in mid-2019.

The final revision of this deliverable in the context of TRIANGLE will track the compliance of this milestone.

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 [10].

ETSI is currently leading the development of the interoperability test specifications (TS-0013) that is 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.

So far oneM2M has not defined a certification program, or a testing scheme, but ETSI is also supervising the development of the certification program. oneM2M is not certifying any products or services.

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 certified more than 2000 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 [12]) 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.

In particular, 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.

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)” [13] event covered the full range of requirements that will feed TSG RAN work items for the next 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.

Highlights from the short-term roadmap of 5G studies in TSG RAN:

- Scenarios and requirements for Next Generation Access Technologies
  - Completed on December 2016
  - Latest progress in TR 38.913
- Channel model frequency spectrum above 6 GHz
  - Completed on June 2016
  - New channel model described in TR 38.900
- Study on new radio access technology
  - Target completion in March 2017
  - Working groups evaluating technology solutions for New Radio

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, has published a technical report for the work item on Multi-Standard Radio (MSR) [14]. 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)) [15].
- TS 36.875 (Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Extension of dual connectivity in E-UTRAN) [16].
- TS 36.331 (Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC)) [17].
- TS 36.412 (Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)) [18].
- TS 36.465 (Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and Wireless LAN (WLAN); Xw interface user plane protocol) [19].

3GPP RAN2 has recently released a technical report called “Study on New Radio Access Technology” [19]. 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.

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)” [20] 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. Otherwise, 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.

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“ [21] depicts the system description for IP flow mobility and seamless WLAN offload. In March 2017, a new version of 3GPP TS 23.261 has been published, adapting LTE WLAN offloading specification to Release 14.

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” [22]. 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 [23] recently updated in February 2017 under version 0.0.4.

The 3GPP Work Item description that introduced LAA (RP-141664) defined fair coexistence in terms familiar to the Wi-Fi Alliance: “that LAA should not impact Wi-Fi services (data, video and voice services) more than an additional Wi-Fi network on the same carrier” [24]. Pass/fail criteria will be based upon a comparison the results of tests of the impact of LAA on Wi-Fi with baseline measurements of the impact of Wi-Fi on Wi-Fi.

The final revision of this deliverable in the context of TRIANGLE will track the further revisions of the TR 36.789.

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 [6].

Their major work in 2015 has been to develop the document “Coexistence Guidelines for LTE in Unlicensed Spectrum Studies” [25]. 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" [25] 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" [26]. 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" [26] is 1.1 and was released on December 21st, 2016.

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 millimetre-wave frequency bands is one of the most promising technologies. As a matter of fact, 3GPP is working on a new study item [27] to define a new radio. This work is still at very early stages and is targeting Release 14 and further. The usage scenarios to cover include eMBB (enhanced Mobile Broadband), eMTC (enhanced Machine Type Communication) and URLLC (ultra reliable and low latency communications).

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 likely in the millimetre-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. Millimetre 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 millimetre 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.

Relevant vendors have already developed several technology demonstrators of mmWave radio access solutions. Qualcomm presented a demonstration of a mmWave design for 5G, by using one mmWave Base Station and one UE [28]. This demonstration performed intelligent beam forming and beam tracking techniques that provided relatively stable SNR, even under UE movement and changing RF channel conditions.

Samsung presented some 5G innovations during MWC 2016, including platforms with mmWave and Multi-Link solutions [29]. Research conducted so far has resulted in the belief that millimetre bands are ideally suited for 5G, an environment of high-density small cells.

Interestingly the FCC has issued a "Notice of Inquiry" on the Use of Spectrum Bands Above 24 GHz For Mobile Radio Services [30]. According to Samsung [31], "The Notice of Inquiry reflects the Commission's keen understanding of 5G and seeks input on important questions about the spectrum and technical rules needed to make 5G succeed". In addition, there are relevant initiatives in the USA on the use of millimetre bands by the major telecom operators.

Verizon for example has applied for a 6-month license, starting April 2016, to perform trials in the 27.5-28.5 GHz band.

AT&T has presented a filling to perform trials in the following bands: 3.4-3.6 GHz, 3.7-4.2 GHz, 14.5-17.35 GHz and 27.5-28.5 GHz.

T-Mobile has also joined the research activities and has presented a filling application to perform tests in the 28 GHz and 39 GHz bands.

All these initiatives target basic research on the characterization of propagation in these bands. Relevant vendors such as Ericsson, Nokia, Intel, Samsung and Qualcomm are playing relevant roles in these activities.

Currently frequency bands for mobile communications are highly fragmented, creating significant challenges for equipment manufacturing. Because of a lack of common band plans among regulatory administrations, a complex set of regulations and requirements for mobile devices has emerged. Fragmentation of spectrum resources will become a particular problem when deploying 5G services. An agreement on the use of millimetre bands is highly desirable. The latest World Radiocommunication Conference (WRC-15) decided to include studies in the agenda for the next WRC in 2019 for the identification of bands above 6 GHz to counteract the difficulties encountered in finding more spectrum in the below 6 GHz bands, and allow technology to meet demand for greater capacity.

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 D2.3 “Report on 5G evolution” [M3, M15, M27], 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 two or more eNodeBs 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”. Additionally, this task foresees the use of Wi-Fi technology on the data plane, whereas that control plane remains in LTE eNodeB.

- Wi-Fi offloading capability will be included 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. Currently the testbed core network has been expanded to support the ANDSF and ePDG to provide non-3GPP untrusted access to the testbed and the data transport has been tested with the a client prototype. There is no commercial ePDG Android support yet in the marked, TRIANGLE will keep track on the appearance of such devices. The consortium will also explore possible architectures to enable the control of the UE perceived power from Wi-Fi Access Points.
- 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 cell, 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.

- December 2017:1st 5G version targeted (eMBB, low latency)
  - Complete Stage-3 (definition of switching and signalling capabilities needed to support services defined in stage 1) of all L1 and L2-User-Plan for both Non-standalone and Standalone.
- March 2018: intermediate implementable version for Non-standalone 5G-NR
- 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 be 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 [32]. NFV MANO splits the architecture in three main functional blocks: the NFV orchestrator, the VNF Manager and the VIM.

3GPP has adopted this architecture [33] and in the technical report TR 32.842 [34] the impact of the architecture in the 3GPP standards is analyzed. The SA5 group [35] is including the following tasks in release 14: management concept [36], 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 [37] and has already generated some specifications [38].

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 [39]. The RFC 7426 [40] 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 [41].

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 [42].

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 [43]. 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 [44].

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 Base Band 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 [45].

A new project funded by NGMN that is currently active is “C-RAN evolution” [46]. This project covers C-RAN architectures, CoMP support and performance and multi RAT joint radio optimization (MRJRO).

4.6.3 3GPP

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 [45].

In [46] 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) gives 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 [34].

Based on the conclusions of the study [34], 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. 3GPP TR 23.714 [47] 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) [48], 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.

The current SDN in TRIANGLE has been deployed to introduce the effect that this technology could have in the backhaul network, assuming a domain change (this is the backhaul network is controlled by a third party) but also leaving the possibility of enforcing QoS in the 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 Rx interface) and QoS enforcement in the queues of the SDN switches.

Regarding NFV, an extension regarding the use of orchestrators in the testbed has been selected in the first open call wave.

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 will be implemented as part of Task 4.2, which has started at M13. We are now looking into it as it seems there are still questions open.

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 [49].

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) [50], 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 [51].

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 [52], with further enhancements to support additional V2X operational scenarios to follow, in release 14, targeting completion during March 2017.

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.

The latest conformance test specification is to be published by ETSI in March 2017 for C-ITS Decentralized Environmental Notification Basic Service (DEN) [54] and for for Cooperative Awareness Basic Service (CA) [55].

Regarding the actual deployment, the European Commission in [56] 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*” [6].

Their major work in 2015 has been to develop the document “Market Needs and Use Cases” (MN&UC) [6]. 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 smart phone ownership.

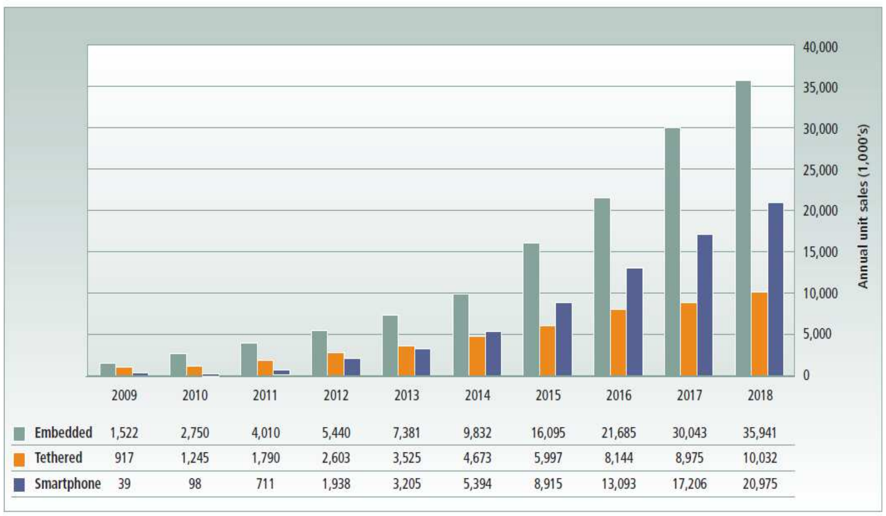

Figure 1 - In-Car Applications Unit Sales

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” [57] 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 that has 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 [6] 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 [58] 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.

Their plans for 2017 are to complete the “Gaps Analysis” and the “Recommended Practices” documents, and also write some white papers about BT/Wi-Fi coexistence, MirrorLink using Miracast and other topics.

5.4 Impact on TRIANGLE

The TRIANGLE consortium members has been monitoring the definition of automotive applications which are candidate to be integrated in the scope of 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 [59] 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. 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. 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, and MEC (Mobile Edge Computing) gateways.

6 5G Test Beds

6.1 Commercial "5G" Testbeds and technologies

A number of 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 is hosting the 2018 Winter Olympics (SKT)
- Russia is hosting the 2018 World Cup (MegaFon)
- Japan is 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 Verizon 5G Technology Forum

The Verizon 5G Technology Forum [59] 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 is planning to start a ‘5G’service to pilot customers in 11 markets in the US in mid-2017 [60].

6.3 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 [61].

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 beginning next year.

6.4 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 [61].

6.5 Ericsson and Nokia

The radio testbeds developed by Ericsson and Nokia (In particular after the recent acquisition [63]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:

- AT&T has also announced plans for a limited 5G rollout known as “5G Evolution” in late 2017 [63].
- China Mobile is planning large–scale pre-commercial trials in 2019 [64].
- SK Telecom has already made some demonstrations of “5G” network slicing [65] and opened a new 5G Innovation Centre with partnerships involving Nokia, Ericsson, Intel and Samsung.

6.6 Telecom Infra Project (TIP)

TIP is a new Open Source wireless initiative lead by Facebook and supported by a number of companies including operators, infrastructure providers, and both chip and equipment manufacturers [62]. 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 [68] 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 [69].

6.7 5G Field Tests

The telecommunication operators who have claimed to have run 5G field test are [70]:

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

6.8 European Government backed 5G Initiatives

Several European governments have announced support for supporting 5G Testbeds and deployments. Examples of these include in the Netherlands [65] and Italy [66] 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 [67] 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

6.9 Impact on TRIANGLE

Since 5G is not a ratified standard, 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 demonstrators and, as such, are not interoperable or standardised in any way. 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 is 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 radio communication.

In early 2012, ITU-R embarked on a programme 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 [64].

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.

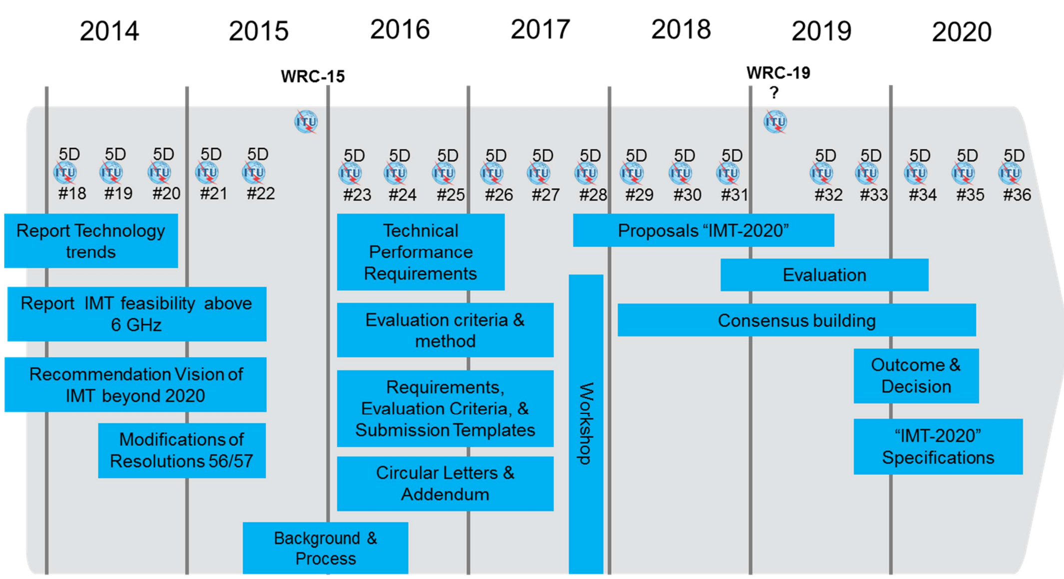

Figure 2 - Detailed Timeline & Process For IMT-2020 in ITU-R [65]

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

- In the 2016-2017 timeframe, WP 5D will define, in detail, the performance requirements and evaluation criteria and methodology for the assessment of new IMT terrestrial radio interface.
- WP 5D plans to hold a workshop in late 2017 that will allow for an explanation and discussion on performance requirements and evaluation criteria and methodology for candidate technologies for “IMT-2020” that has been developed by WP 5D, as well as to provide an opportunity for presentations by potential proponents for “IMT-2020” in an informal setting.

- 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 plans to start 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.

The last revision of this deliverable, in the scope of TRIANGLE, will track the completion of the work abovementioned.

7.1.2 Ongoing Work: Development of Performance Requirements

Currently ITU-R WP 5D is in the stage of developing the minimum performance requirements. 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 will start a discussion process between the ITU-T and the External Organizations that is planned to end 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 [75].

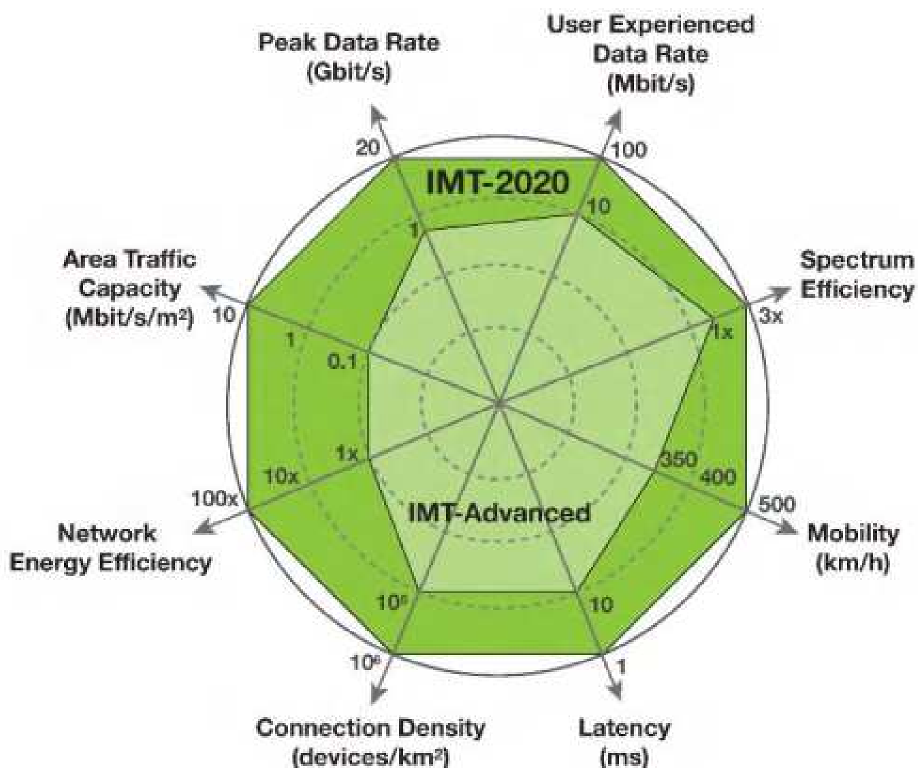

Figure 3 - Enhancement of key capabilities form IMT-Advanced to IMT-2020 [64]

ITU-R WP 5D states 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. This may be revised in the light of future studies.

Report ITU-R M. [IMT-2020. TECH PERF REQ is currently under active development and the last contribution accounted at the publication date of this deliverable was on February 7th.

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. Currently, release 12 is being finalized. Focus is now, gradually shifting, on which enhancements to include in the next release, release 13. The intention is to finalize release 13 by March of 2016. According to 3GPP, start of the "5G" work shall not impact release 13 work and schedule [67]. A study phase for 5G is expected to be included in release 14, but most observers do not expect to see 5G specifications to emerge until release 15 in the 2018 timeframe, and full requirements by the end of 2019, just in time to present to ITU.

Release 14 will mark 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 [67] is depicted below.

Figure 4 - Tentative 3GPP timeline for 5G [68]

3GPP RAN kicked off its development of the next generation 3GPP cellular technology with the 5G Workshop in September 2015 [69]. 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 [70][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.

- Views on 5G New RAT in 3GPP [71]

> 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 [72]

[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/

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.

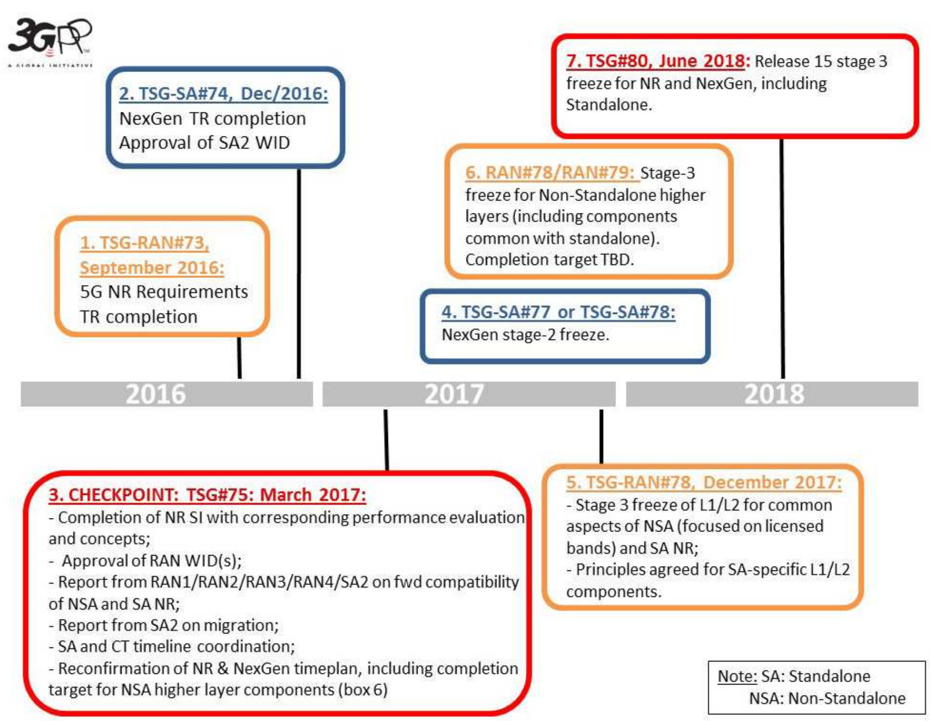

Figure 5 - 3GPP Planned Released within TRIANGLE timeline

The current status of the 3GPP releases is summarized in Annex 1 and Annex 2.

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 [73]. 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.

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 [74].

In 2017 ETSI will organize a workshop on "Multimedia Quality in Virtual, Augmented or other Realities" which would try to cover the latest developments in this area especially under QoS and QoE aspects. This event will be closely tracked in TRIANGLE because both VR and AR applications are inside the scope of the test specification being currently developed by the consortium.

ETSI will organize in 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.

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 [75].

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.

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” [76].

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 [77].

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 [78] and therefore its role will be key for the adoption of the 5G technologies by the industry players (manufacturers, operators and laboratories).

7.8 Impact on TRIANGLE

Various members of TRIANGLE are members of WFA, ETSI, 3GPP, GCF and they 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.

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.

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. 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 two meetings in 2016.

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

[7] 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.

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

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

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

[11] 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.

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

[13] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/37900.htm.

[14] 3GPP. [Online]. Available: http://www.3gpp.org/dynareport/36300.htm.

[15] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/36875.htm.

[16] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/36331.htm.

[17] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/36413.htm.

[18] 3GPP, 2015 December. [Online]. Available: http://www.3gpp.org/dynareport/36465.htm.

[19] 3. RAN2, "Study on New Radio Access Technology. 38.804, v1.0.0," 2017-03.

[20] 3GPP. [Online]. Available: http://www.3gpp.org/dynareport/36847.htm.

[21] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/23261.htm.

[22] 3GPP. [Online]. Available: http://www.3gpp.org/dynareport/36889.htm.

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

[24] 3GPP, “RP-141664 Study on Licensed-Assisted Access using LTE”.

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

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

[27] 3GPP, 2016. [Online]. Available: http://www.3gpp.org/DynaReport/38913.htm.

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

[29] 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.

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

[31] FCC, “GN Docket No. 14-177”.

[32] 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.

[33] 3GPP, October 2015. [Online]. Available: http://www.3gpp.org/news-events/3gpp-news/1738-sa5_nfv_study.

[34] 3GPP, September 2015. [Online]. Available: http://www.3gpp.org/DynaReport/32842.htm.

[35] 3GPP, August 2015. [Online]. Available: http://www.3gpp.org/specifications-groups/sa-plenary/sa5-telecom-management.

[36] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/28500.htm.

[37] 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.

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

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

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

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

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

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

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

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

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

[47] 3GPP, February 2016. [Online]. Available: http://www.3gpp.org/DynaReport/23714.htm.

[48] 3GPP, February 2016. [Online]. Available: http://www.3gpp.org/DynaReport/23711.htm.

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

[50] 3GPP, “Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description,” 2015.

[51] 5G-PPP, October 2015. [Online]. Available: https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf.

[52] 3GPP, “RP-161788 V2V Work Item Completion,” 2016.

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

[54] 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.

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

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

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

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

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

[60] 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.

[61] 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 .

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

[63] 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/.

[64] 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.

[65] 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.

[66] 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.

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

[68] 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.

[69] 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/.

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

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

[72] 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.

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

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

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

[76] 3GPP, ““5G” timeline in 3GPP,” 2015.

[77] 3GPP, March 2015. [Online]. Available: http://www.3gpp.org/news-events/3gpp-news/1674-timeline_5g.

[78] 3GPP, “Report of 3GPP RAN workshop on "5G",” September, 2015.

[79] 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.

[80] 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.

[81] 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 .

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

[83] 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.

[84] 5G-PPP, [Online]. Available: https://5g-ppp.eu.

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

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

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

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

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

[90] 3GPP. [Online]. Available: https://portal.3gpp.org/desktopmodules/WorkItem/WorkItemDetails.aspx?workitemId=660174.

[91] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/36331.htm.

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

[93] 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.

10 Annex 1. 3GPP Release 13 Status

Source: Work Plan 3GPP version February 7th 2017.

Multi-Broadcast Single Frequency Network (MBSFN) Minimization of Drive Tests (MDT) enhancement	0%
Mission Critical Push To Talk over LTE (MCPTT)	90%
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%
Study on Lawful Interception Service Evolution	10%
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	97%
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	66%
Elevation Beamforming/Full-Dimension (FD) MIMO for LTE	100%
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	100%
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	53%
LTE-WLAN RAN Level Integration supporting legacy WLAN	100%
Indoor Positioning enhancements for UTRA and LTE	74%
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%
Service Requirements Maintenance for Machine-Type Communications (MTC)	100%
Cellular (Narrowband) Internet of Things	89%
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	93%
EGPRS Access Security Enhancements in relation to Cellular IoT	99%
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%
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%
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 IMS Enhanced Spoofed Call Prevention and Detection	30%
Study on Compliance of 3GPP SA5 specifications to the NGMN NGCOR	60%
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	75%
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	99%
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 on LTE 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	30%
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 February 07th 2017.

Study on Scenarios and Requirements for Next Generation Access Technologies	100%
Mission Critical Improvements	49%
Protocol enhancements for MCPTT over LTE	6%
LTE support for V2X services	62%
Support for V2V services based on LTE sidelink	48%
Non-IP for Cellular Internet of Things (CIoT) for 2G/3G-GPRS(EC-EGPRS)	100%
Further enhanced MTC for LTE	26%
Enhancements of NB-IoT	26%
AT Commands for CIoT	95%
Extended architecture support for Cellular Internet of Things	57%
Radio Interface Enhancements for Extended Coverage GSM for support of Cellular Internet of Things	35%
Battery Efficient Security for very low Throughput MTC Devices	0%
New band support for Rel-14 Narrowband Internet of Things (NB-IOT)	99%
Enhancements of Dedicated Core Networks selection mechanism	59%
Addition of band 25 and 26 to LTE MTC cat.0	0%
Addition of bands 25 and 40 to LTE MTC cat.1	0%
Study on Management aspects of selected IoT-related features	5%
EIR check for WLAN access to EPC	100%
Support of EAP Re-authentication Protocol for WLAN Interworking	73%
Phase 2 of the Support of Emergency services over WLAN	99%
T-ADS supporting WLAN Access	100%
Enhanced LTE-WLAN Aggregation (LWA)	75%
Evolution to and Interworking with eCall in IMS	83%
Password based service activation for IMS Multimedia Telephony service	9%
IMS Signalling Activated Trace	28%
UE Conformance Test Aspects – IMS for Converged IP Communications	0%
User Controlled Spoofed Call Treatment	41%
Enhancement for TV service	60%
MBMS Transport Protocol and APIs	70%
Multimedia Priority Service Modifications	100%
Lawful Interception Rel-14	10%
SIP Reason header extension	25%
Enhancements to User Location Reporting Support	100%
Diameter Load Control Mechanism	98%
Diameter Base Protocol Specification Update	3%
Enhancements to Multi-stream Multiparty Conferencing Media Handling	50%
Deleted - CT aspects of (or "Enhancements of") MTSI Extension on Multi-stream	100%

Control and User Plane Separation of EPC nodes	61%
OAM14 Rel-14 Operations, Administration, Maintenance and Provisioning (OAM&P)	72%
Development of super-wideband and fullband P.835	75%
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	45%
SCC AS Restoration	100%
Paging Policy Enhancements and Procedure	100%
Enhancement to Flexible Mobile Service Steering	100%
Unlicensed Spectrum Offloading System	100%
Media Handling Extensions of IMS-based Telepresence	50%
Improved Streaming QoE Reporting in 3GPP	65%
New GPRS algorithms for EASE	70%
S8 Home Routing Architecture for VoLTE	83%
Improvements of awareness of user location change	74%
Service Domain Centralization	100%
Sponsored data connectivity improvements	85%
Stage-3 SAE Protocol Development - Phase 5	80%
Group based enhancements in the network capability exposure functions	100%
Robust Call Setup for VoLTE subscriber in LTE	77%
Extension of UE Delay test methods and requirements	50%
Improved operator control using new UE configuration parameters	45%
Shared Subscription Data Update	100%
Security Assurance Specification for PGW network product class	40%
Security Assurance Specification for eNB network product class	5%
Rel-14 Charging	47%
Determination of Completeness of Charging Information in IMS	8%
Enhanced LAA for LTE	35%
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	0%
LTE 2.6 GHz FDD Supplemental DL band (2570-2620 MHz) and LTE Carrier Aggregation (2DL/1UL) with Band 3 for region 1	100%
Multi-Band Base Station testing with three or more bands	99%
Performance enhancements for high speed scenario in LTE	61%
Remote UE access via relay UE	100%
Further Indoor Positioning Enhancements for UTRA and LTE	56%

Signalling reduction to enable light connection for LTE	41%
Radiated performance requirements for the verification of multi-antenna reception of UEs in LTE	16%
Enhancements on Full-Dimension (FD) MIMO for LTE	32%
Further mobility enhancements in LTE	90%
Uplink Capacity Enhancements for LTE	34%
L2 latency reduction techniques for LTE	100%
eMBMS enhancements for LTE	32%
SRS (sounding reference signal) switching between LTE component carriers	43%
Downlink Multiuser Superposition Transmission for LTE	38%
IMS Stage-3 IETF Protocol Alignment	35%
Multi-Carrier Enhancements for UMTS	100%
Citizens Broadband Radio Service (CBRS) 3.5GHz band for LTE in the United States	80%
LTE Band 41 UE power class 2 operation	89%
LTE UE Total Radiated Power (TRP) and Total Radiated Sensitivity (TRS) and UTRA Hand Phantom related UE TRP and TRS Requirements	70%
Dedicated Core Networks for GERAN	100%
Positioning Enhancements for GERAN	50%
Quality of Experience (QoE) Measurement Collection for streaming services in UTRAN	89%
Flexible eNB-ID and Cell-ID in E-UTRAN	90%
Security Assurance Specification for 3GPP network products	96%
4 receiver (4Rx) antenna ports with Carrier Aggregation (CA) for LTE downlink (DL)	44%
Introduction of new band support for 4Rx antenna ports for LTE	0%
Requirements for a new UE category with single receiver based on Category 1 for LTE	37%
Enhanced LTE WLAN Radio Level Integration with IPsec Tunnel (eLWIP)	60%
(Small) Technical Enhancements and Improvements for Rel-14	100%
(Small) Test Technical Enhancements and Improvements for Rel-14	0%
Rel-14 LTE Carrier Aggregation	90%
Rel-14 LTE Advanced inter-band Carrier Aggregation	63%
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 Overload Control for Diameter Charging Applications	10%
Study on forward compatibility for 3GPP Diameter Charging Applications	10%
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%

Study on OAM support for assessment of energy efficiency in mobile access networks	80%
Study on OAM aspects of SON for AAS-based deployments	70%
Study on SON for eCoMP for LTE	40%
Deleted - Study on SON for eCoMP for LTE	100%
Study on UICC power optimization for MTC	71%
Study on Implementation for the Partitioning of Itf-N	40%
Study on Server and Network Assisted DASH for 3GPP	100%
Study on UE characteristics and performance for Video	30%
Study on MBMS usage for mission critical communication services	95%
Study on Energy Efficiency Aspects of 3GPP Standards	0%
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	85%
Study on Context Aware Service Delivery in RAN for LTE	70%
Study on further enhancements to Coordinated Multi-Point (CoMP) Operation for LTE	80%
Study on Determination of Completeness of Charging Information in IMS	100%
Study on Interactivity Support for 3GPP-based Streaming and Download Services	80%
Study on Enhanced Acoustic Test Specifications	80%
Study on User Services Enhancements in 3GPP for TV Services	60%
Study on MBMS usage and codecs for MCPTT call and MC Video Service	60%
Study on MBMS Extensions for Provisioning and Content Ingestion	50%
Study on Technical Requirements for a new secure platform for 3GPP applications	15%
Study on global application of LTE Band 11 and of LTE Band 21 UEs	100%
Study on Downlink MIMO for GERAN	100%
Study on Management Aspects of Next Generation Network architecture and features	10%
Study on Management and Orchestration Architecture of Next Generation Network and Service	10%
Study on management and orchestration of network slicing for next generation network	25%
Release 14 studies on 5G MObile Network for Advanced communications	72%
Study on Stage 1 for New Services and Markets Technology Enablers	98%
Study on Architecture and Security for next Generation System	100%
Study on Architecture and Security for Next Generation System	45%
Study on New Radio (NR) Access Technology	55%
Study on Network Assistance for Network Synchronization in LTE	100%

12 Annex 3. 3GPP Release 15 Status

Source: Work Plan 3GPP version February 07th 2017.

5G System - Phase 1	0%
New Services and Markets Technology Enablers	75%
Inclusion of WLAN direct discovery technologies as an alternative for ProSe direct discovery	100%
Enhanced Calling Name Service	100%
Server and Network Assisted DASH for 3GPP Multimedia Services	0%
LTE Measurement Gap Enhancement	27%
Enhancements of Base Station (BS) RF and EMC requirements for Active Antenna System (AAS)	8%
Shortened TTI and processing time for LTE	4%
Enhanced CRS and SU-MIMO Interference Mitigation Performance Requirements for LTE	30%
450MHz E-UTRA FDD Band for LTE PPDR and PMR/PAMR in Europe	0%
E-UTRA 700MHz in Europe for Broadband-PPDR (Public Protection and Disaster Relief)	0%
FDD operating band in the L-band for LTE	0%
LTE Extended 1.5 GHz SDL band (1427 – 1518 MHz) and LTE Carrier Aggregation (2DL/1UL) with Band 20	0%
Add UE Power Class 2 to band 41 intra-band contiguous LTE Carrier Aggregation	0%
Addition of Power Class 1 UE to bands B3/B20/B28 for LTE	15%
TDD operating band in the L-band for LTE	0%
Study on management aspects of virtualized network functions that are part of the NR	5%
Study on enhancements of Public Warning System	5%
Study on mission critical system migration and interconnect between MCPTT systems	48%
Study on Mission Critical Communication Interworking between LTE and non-LTE Systems	22%
Study on Enhancement of 3GPP support for V2X services	95%
Study on architecture enhancements to ProSe UE-to-Network Relay	5%
Study on unlicensed spectrum offloading system enhancements	10%
Study on enhanced VoLTE performance	5%
Study on Complementary Features for Voice services over WLAN	10%
Study on Enhanced Isolated E-UTRAN Operation for Public Safety	15%
Study on Future Railway Mobile Communication System	40%
Study on Maritime Communication Services over 3GPP system	10%
Study on LTE bandwidth flexibility enhancements	50%
Study on Provision of Access to Local Operator Services	75%
Study on Enhancement of LTE for Efficient delivery of Streaming Service	0%
Study on a RESTful HTTP-based Solution Set	5%
Study on interference cancellation receiver for LTE BS	35%
Study on Management Enhancement of CUPS of EPC Nodes	0%
Study on Policy and Charging for Volume Based Charging	0%
Study on uplink data compression in LTE	0%

Study on channel model for frequency spectrum above 6 GHz	100%
Study on further enhancements to LTE Device to Device (D2D), UE to network relays for IoT (Internet of Things) and wearables	15%
Study on Virtual Reality	45%

13 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.