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D2.4 Intermediate report on programme progress and KPIs

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Abstract

This deliverable aims at:

- refining the 5G PPP KPIs definition considering the worldwide context on 5G
- defining reference test cases and measurement tools able to monitor the progress achieved towards the KPI targets
- drafting a strategy for evolutions in the second year of the program to encourage projects to quantify the progress achieved especially on performance KPIs

It shows that we are performing well on nearly all KPIs and even over performing on the private investments leveraging factor.

For next year, we should go further especially on the energy consumption KPI and on the quantification of the impact of Phase 1 projects technology impacts in order to disseminate powerful contributions in the world.

Document revision history

Version	Date	Description of change	List of contributor(s)
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v0.2	24/08/16	Initial draft	Jean-Sébastien Bedo
v0.3	31/08/16	Complete draft	Jean-Sébastien Bedo

[1] http://creativecommons.org/licenses/by-nc-nd/3.0/deed.en_US

Executive Summary

In this deliverable, we have refined the 4 performance, 3 business and 5 societal 5G PPP KPIs for Europe taking into account the evolution of 5G definitions in the world and the possible measurement methodologies at this state of play. Some of the market oriented KPIs need to be replaced by proxies at this stage because 5G is not mature enough to measure them directly before 2020. The main performance indicators identified in this way are the contribution to standardization bodies and the dissemination of projects through demonstrations / showcases at world events.

We have also summarized the cross project coordination activities which lead to a shared definition of synthetic 5G deployment scenarios and test environments shared by all projects. This gives us a first framework to monitor and quantify the progress on the various aspects of 5G for next years. We have a clear path to measure the progress on nearly all KPIs except for the energy consumption where the TB has already kick started some action which need to be strengthened in the second year of the programme.

We have also asked to 5G PPP Phase 1 projects to assess the progress achieved so far from their point of view on the different 5G PPP KPIs. From this exercise, we can conclude that the programme is progressing on all KPIs with a good pace after one year of activities. We are even exceeding by far our target on the leveraging factor for private investments. Indeed, the private sector is investing 10 to 30 times the amount of public money which is invested by European citizens and this will grow in the future.

This deliverable also drafts a strategy for evolutions in the second year of the program to encourage projects to share measurement tools and test facilities and to quantify the progress achieved especially on performance KPIs. One of the concrete next steps will be to communicate as soon as we get more quantitative measures on performance KPIs in order to compete with our international counterparts. Indeed, China for example has already communicated on throughput or latency figures in conferences and 5G and we need to demonstrate the ability of Europe to deliver the enablers which will have the most impact on 5G services.

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Abbreviations

EC	European Commission
KPI	Key Performance Indicator
3G PP	3rd Generation Partnership Project
5G PPP	5G Public Private Partnership
ETSI	European Telecommunication Standards Institute
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IRTF	Internet Research Task Force
ITU	International Telecommunication Union
MWC	Mobile World Congress
NGMN	Next Generation Mobile Networks
WP	Work Package

1 Introduction

D2.4 “Intermediate report on programme progress and KPIs” is an intermediate report on 5G PPP programme progress overseeing and KPIs monitoring activities performed by Euro-5G during the first year of the project.

Following Euro-5G objectives, this deliverable aims at:

- refining the KPIs definition and finding proxies to monitor them considering the worldwide context on 5G and the maturity of 5G technologies in 2016
- defining reference test cases able to demonstrate the fulfilment of the KPI targets
- drafting a strategy for evolutions in the second year of the program to encourage projects to share measurement tools and test facilities and to quantify the progress achieved especially on performance KPIs

It is composed of six main sections:

- Section 1 presents the introduction;
- Section 2 summarizes the requirements and performance targets that have been defined up to now in the world for 5G technologies of services with a focus on ITU and 3GPP
- Section 3 refines the definition of KPIs and proposes some proxies to monitor in an easier manner some KPIs which cannot be measure before 2020
- Section 4 presents the results of the coordination which has been done between projects on use cases and test scenarios towards a common performance progress measurement plan
- Section 5 details the self-assessment which has been made by 5G PPP Phase 1 projects on the achievements achieved so far on the programme KPIs
- Section 6 summarises the conclusions and drafts some next steps.

2 What are the worldwide 5G targets?

The objective of this section is to give an overview of the evolution of 5G targets in the world.

2.1 What is really 5G?

There is a worldwide effort on the further characterization of 5G use cases and related requirements (e.g. ITU, 3GPP, NGMN...) which has accelerated in 2015.

In early 2015, operators have kick started this activity with a vision paper from NGMN[2] which identified the following vision for 5G:

"5G is an end-to-end ecosystem to enable a fully mobile and connected society. It empowers value creation towards customers and partners, through existing and emerging use cases, delivered with consistent experience, and enabled by sustainable business models."

and the following 8 use case families in early 2015:

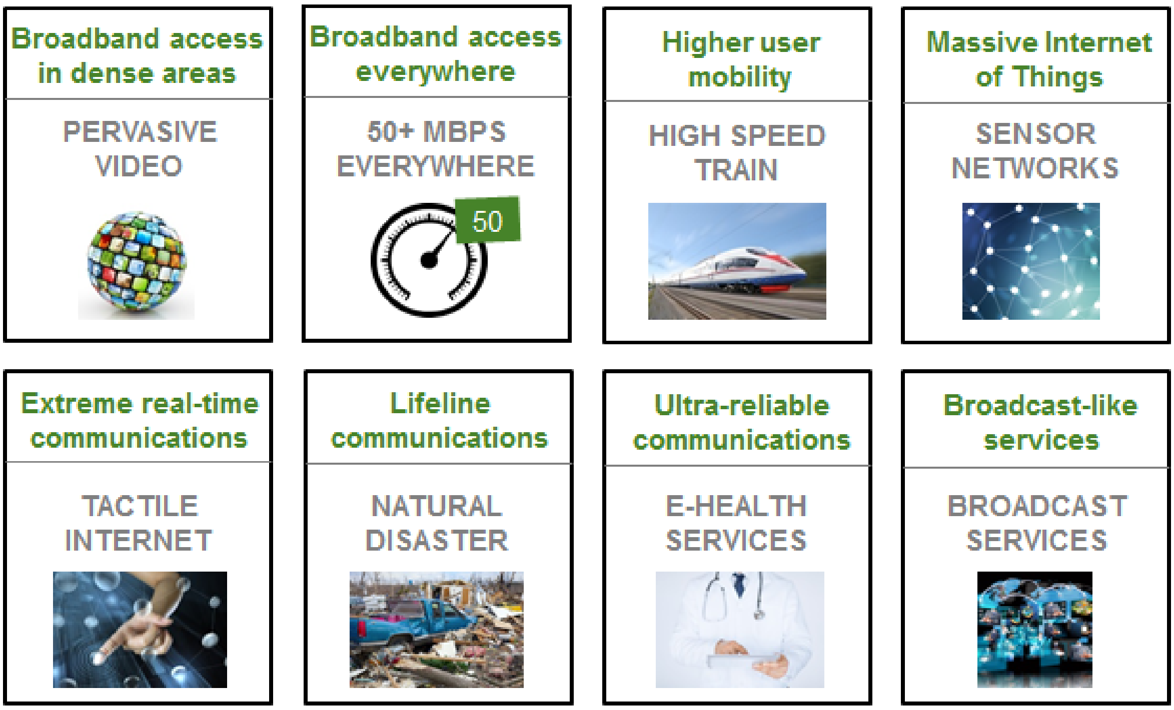

Figure 1: 5G use cases families

We will detail further in the following subsections the visions which were then developed by ITU and 3GPP, the main standardisation bodies for 5G.

During this period, the 5G Infrastructure Public Private Partnership (PPP) has also progressed on the identification of uses cases and requirements with a clear effort on verticals markets, e.g. the five white papers addressing Factories, Automotive, eHealth, Energy as well as Media and Entertainment[3].

[2] https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

[3] These whitepapers on vertical industries are available on 5G PPP website here: https://5g-ppp.eu/white-papers/.

2.2 KPIs at the ITU level

The roadmap for 5G (IMT-2020) at the ITU level is the following:

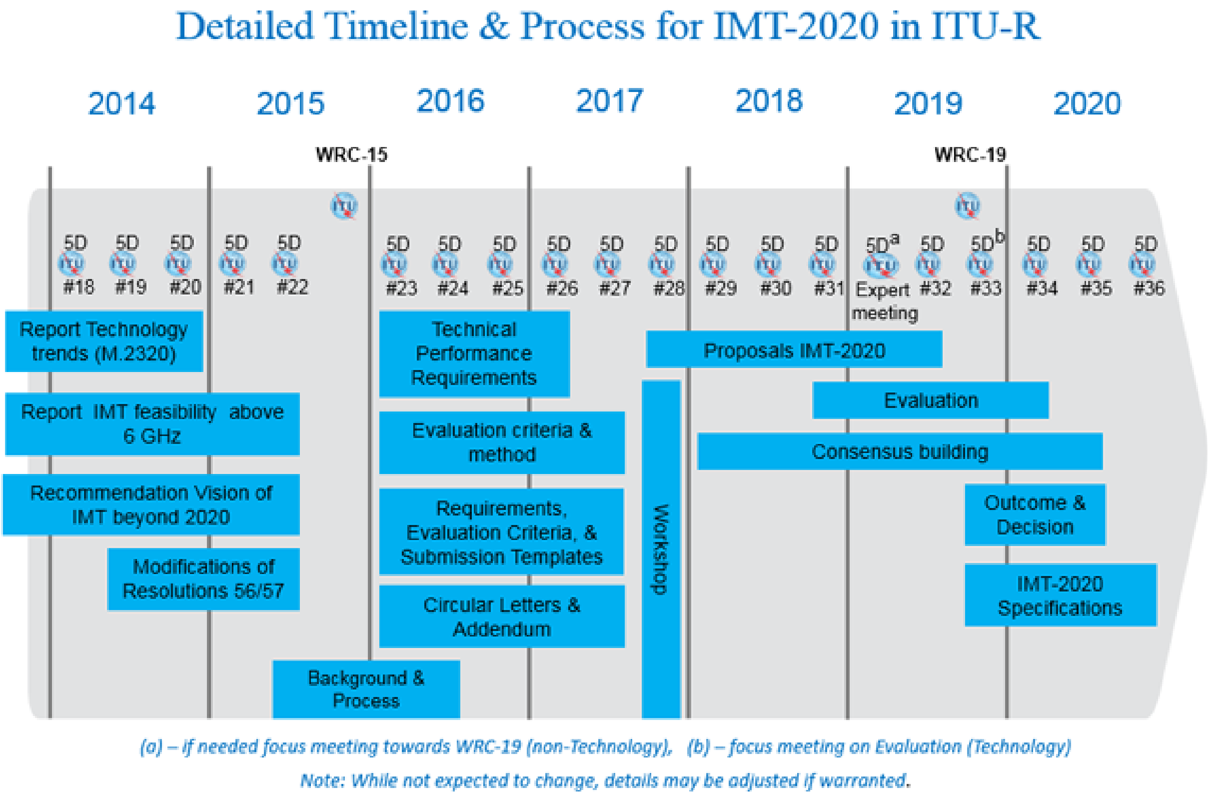

Figure 2: ITU roadmap for 5G

We can clearly see that 5G PPP Phase 1 projects will frame the requirements, evaluation criteria and methodologies but the selection of technologies for the standard and their evaluation will come later only during 5G PPP Phase 2.

The usage scenarios retained by the ITU for 5G are the following:

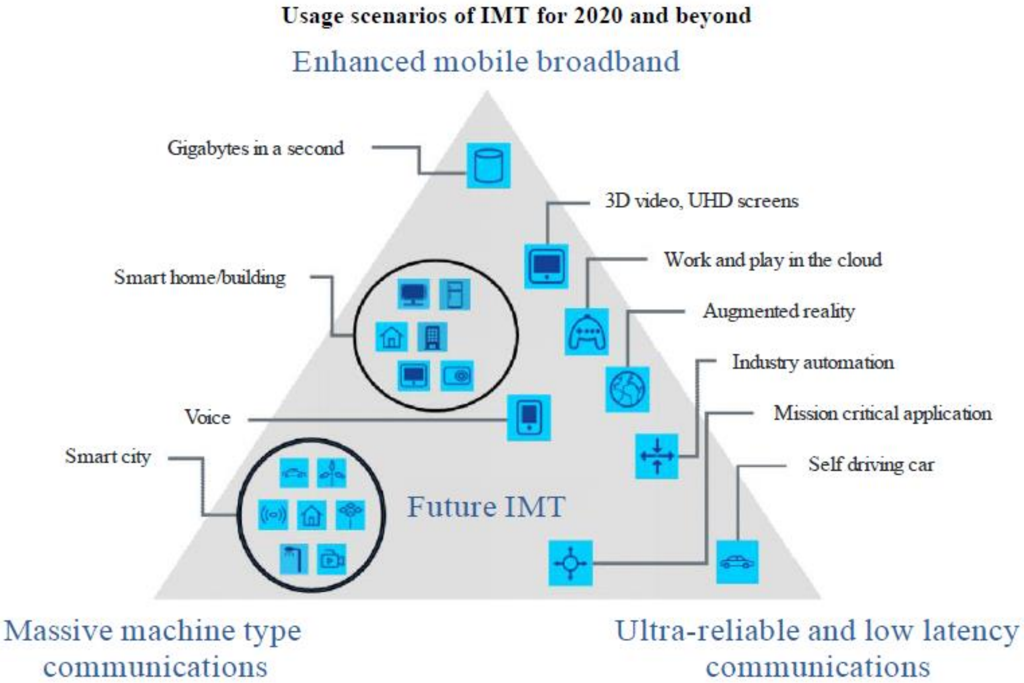

Figure 3: 5G usage scenarios ITU reference

These use cases lead to the following key KPIs:

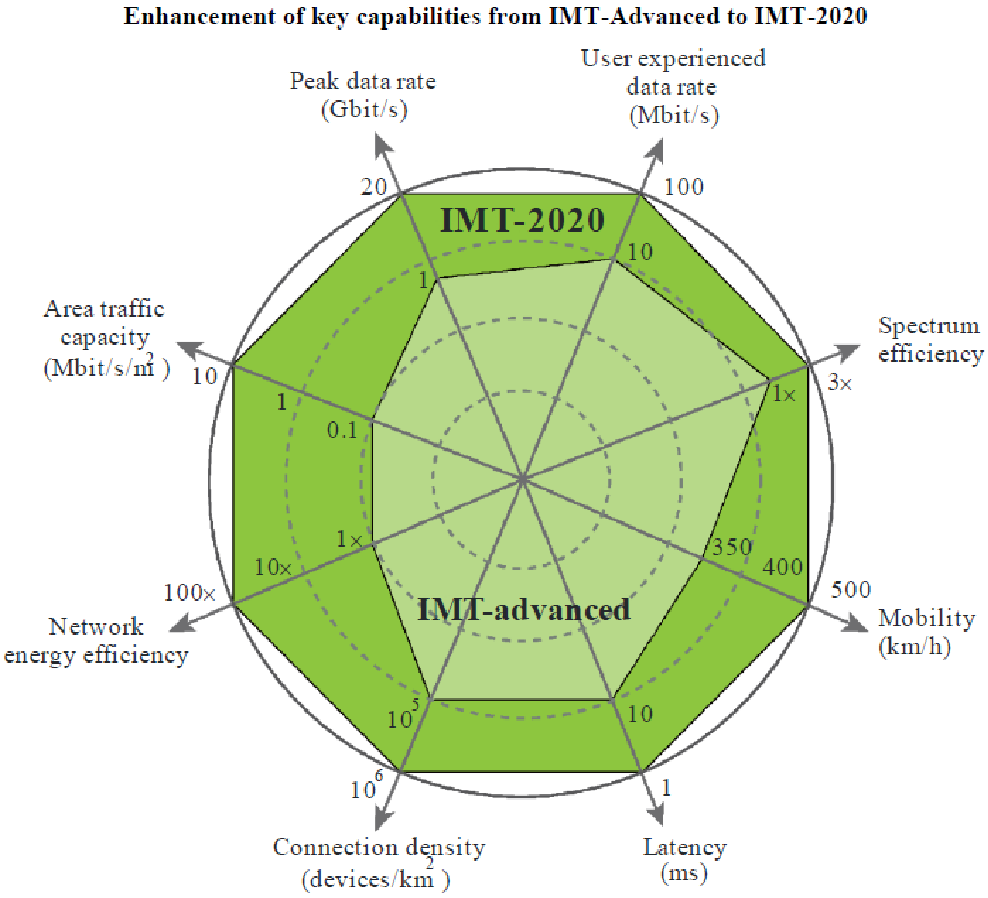

Figure 4: 5G requirements spider diagram

which are complemented by reliability, resilience, security and privacy, as well as operational lifetime for machine-type devices with a target of beyond 10 years without charge.

2.3 KPIs at the 3GPP level

A study has been launched at the 3GPP SA level about 5G service requirements. The objective is to develop high-level use cases and identify the related high-level potential requirements to enable 3GPP network operators to support the needs of new services and markets.

74 Use Cases have been identified in the study on New Services and Markets Technology Enablers (FS_SMARTER) [TR 22.891].

4 families of use cases have been identified:

- eMBB - Enhance mobile broadband which can be decomposed in 5 categories,
  - High Data Rates : This family focuses on identifying key scenarios from which eMBB primary data rate requirements for peak, experienced, downlink, uplink, etc. data rates can be derived, as well as associated requirements pertaining to latency when applicable with UEs relative speed to ground up to 10 km/h (pedestrian).
  - Higher Density: This family covers scenarios with system requirement for the transport of high volume of data traffic per area (traffic density) or transport of data for high number of connections (devices density or connection density) with UEs relative speed to ground up to 60 km/h (pedestrian or users moving on urban vehicle).
  - Deployment and Coverage: This family covers scenarios with system requirement

considering the deployment and coverage scenario e.g. indoor/outdoor, local area connectivity, wide area connectivity, with UEs relative speed to ground up to [120] km/h.

- Higher User Mobility: This family focuses on identifying key scenarios from which eMBB mobility requirements can be derived, with UEs relative speed to ground up to 1000 km/h.
- Devices with highly variable data rates: This family focuses on identifying key scenarios from which eMBB requirements can be derived, for UEs having multiple applications which exchange small amount of data and large amount of data.

- CC - Critical communication which can be decomposed in 6 categories,
  - Very low latency: Characterized by a very high system requirement for latency. It is essential to carry the messages very quickly between the sender and receiver (e.g. tactile internet).
  - Mission critical services: Communications that are critical and need a higher priority over other communications in the networks.
  - Higher reliability and lower latency: Characterized by a high system requirement for reliability and latency. In most cases the data rates are moderate, and what matters most is that the messages are transmitted quickly and reliably (Industrial control systems, Mobile Health Care, Real time control of vehicles, road traffic, accident prevention, Wide area monitoring and control systems for smart grids, Speech, audio and video in virtual and augmented reality…).
  - Higher availability: One typical area where this type of communication is needed is when the traditional cellular network is congested or damaged, or when its coverage is not wide enough.
  - Higher reliability, higher availability and lower latency: Characterized by a high system requirement for reliability, availability, and latency. In most cases the data rates are moderate, and what matters most is that the messages are transmitted quickly and reliably, and that the coverage is sufficiently wide.
  - Higher accuracy positioning: High positioning accuracy includes requirements that the location information is acquired quickly, is reliable, and is available.
- mIoT - Massive Internet of Things which covers the following aspects,
  - Operational aspects (lightweight device configuration, variable data size, Internet of Things security, farm machinery and leasing, one user with multiple devices, one device with multiple users, connection support by service provider, communication between devices with multi-vendors).
  - Connectivity aspects (device in direct 3GPP connection mode, in indirect 3GPP connection mode, in indirect 3GPP connection mode in the roaming case, in direct device connection mode, service continuity).
  - Resource efficiency aspects (mobility management, variable data size, discovery mechanisms…).
- NO - Network operation which covers flexibility in terms of mobility and performance envelope, scalability, network slicing, network capability exposure, broadcast, efficient content delivery, self-backhauling, multiple access support, migration, interworking and security.

An overview of the corresponding requirements can be found below.

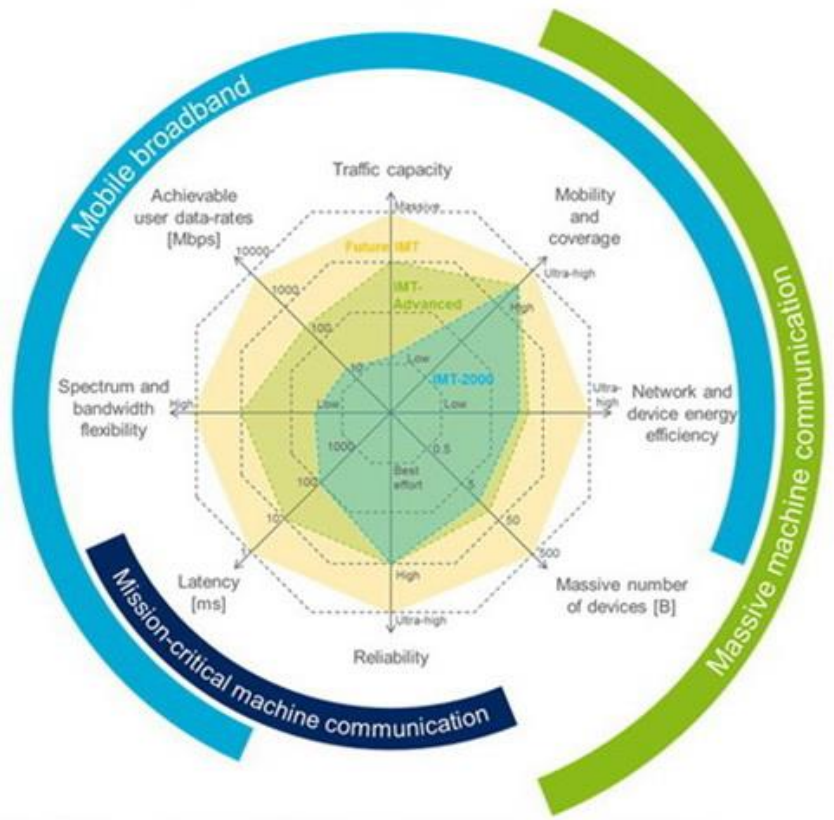

Figure 5: 3GPP SA requirments spider diagram

2.4 Conclusion

There is globally a large convergence on 5G targets in the world. There are divergences on the actual figures of the KPIs to be reached but globally the order of magnitude is the same.

However, the energy efficiency KPI is not so clear in the world. We can see that ITU is recommending an improvement of x100 while 3GPP is very vague (from middle to ultra-high efficiency).

Resilience, security and privacy are seen as important by all stakeholders but there is no real description of the way to measure them.

In the same vain, end-to-end services aspects such as creation time, scale-up, scale-down, capabilities exposure and so forth are explored very superficially by the different 5G fora.

3 5G PPP Key Performance Indicators description

The objective of this section is to refine the 5G PPP KPIs definition.

3.1 KPIs in the PPP contract

There are 3 KPIs related to business aspects:

- B1. Leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems in the order of 5 to 10 times
- B2. Target SME participation under this initiative commensurate with an allocation of 20% of the total public funding
- B3. Reach a global market share for 5G equipment & services delivered by European headquartered ICT companies at, or above, the reported 2011 level of 43% global market share in communication

There are 5 KPIs related to societal aspects:

- S1. Enabling advanced user controlled privacy
- S2. Reduction of energy consumption per service up to 90% (as compared to 2010)
- S3. European availability of a competitive industrial offer for 5G systems and technologies
- S4. Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications
- S5. Establishment and availability of 5G skills development curricula (in partnership with the EIT)

There are 4 performance KPIs:

- P1. Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010
- P2. Reducing the average service creation time cycle from 90 hours to 90 minutes
- P3. Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people
- P4. Creating a secure, reliable and dependable internet with a "zero perceived" downtime for services provision

3.2 Refinement of KPIs definition

3.2.1 Business related KPIs

- B1. Leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems in the order of 5 to 10 times

This KPI is rather difficult to assess. The first comment that we can make is that the refection on this KPI covers a couple of years. Indeed, investment in collaborative research now can be leveraged in very high investment in telecom infrastructures to support 5G services in 5 to 10 years from now. Indeed, telecom technology adoption follows the famous S curve with limited investment at the beginning and a faster pace when the first cities are covered by the new technology.

The methodology we propose to measure and monitor this KPI is based upon gathering the published public figures from annual reports for worldwide R&D expenses in the ICT sector. Then we need to define which proportion of the R&D spends of the ICT industry is 5G related. The easiest way to proceed to define this value is to issue a poll among industry players (including: equipment manufacturers, mobile network operators, test equipment manufacturers and device manufacturers, and chipset manufacturers). The proportions of 5G versus the total telecom R&D expenses will increase as 5G moves into full standardisation, development and production over the next few years. In order to identify an investment value specific for Europe, Euro-5G used a representative set of European key ICT players (Ericsson, Nokia, Huawei, Samsung, DT, Orange, TIM, Telefonica, Telenor, Intel, Sequans) which are contributing to 5G PPP programme. We propose to use the same set of players for further iterations..

- B2. Target SME participation under this initiative commensurate with an allocation of 20% of the total public funding

The measurement of this KPI is rather straightforward and is a direct output of the selections of projects made by the European Commission for 5G PPP calls. One has to consider that it is probable that we will increase the participation of SMEs as we are approaching to market products. Indeed, it is difficult for many SMEs to support multiple year research programmes without any revenue stream except public funding.

- B3. Reach a global market share for 5G equipment & services delivered by European headquartered ICT companies at, or above, the reported 2011 level of 43% global market share in communication

This KPI is very difficult to measure and monitor before 2020 when the market for 5G equipment will really start. As an indirect measurement, we could use the share of European manufacturers in 5G trials planned in 2018 in order to monitor progress before 2020. We could also count the number of proof of concepts developed and disseminated by 5G PPP projects.

Another indirect measurement for this KPI is the importance of joint contributions to standardisation bodies. Indeed, these contributions are direct outputs of 5G PPP projects and are helping the private side to coordinate on the products and services to invest in and to position their technologies and know-how in the worldwide landscape. This importance can be looked at in terms of patent portfolio for European players and number of joint contributions in standardisation bodies.

3.2.2 Societal KPIs

- S1. Enabling advanced user controlled privacy

Two projects are particularly focused on this KPI in 5G PPP Phase 1: 5G-ENSURE and CHARISMA. They have defined three main categories of enablers which need to be delivered to fulfil this very important KPI:

- anonymization and untrackability services to avoid the unwanted propagation of mobile network, device or localization identifiers
- privacy policy compliance engines working also at the application and device layer
- tenant isolation mechanisms to fully benefit from network slices without opening any security backdoor

We propose to monitor the existence and richness of these enablers to follow up on this KPI.

- S2. Reduction of energy consumption per service up to 90% (as compared to 2010)

From section 1, we can clearly see that this KPI is the most controversial in the world with different targets depending on the standardization bodies and measurement processes. Despite our efforts, we have not been able to converge on a single way to measure energy consumption in the various projects nor to find a proper reference for 2010 energy consumption. The CSA has proposed to reuse the tool machinery developed by GreenTouch (https://s3-us-west-2.amazonaws.com/belllabs-microsite-greentouch/index.html) consortium but we have not seen a frank adoption of this methodology by 5G PPP projects. As a result, for the moment we will ensure a monitoring of this KPI through various proxies: spectrum efficiency, mechanisms to activate cells only when necessary, specific protocols to decrease the consumption of connected objects, and hardware components consumption reduction.

- S3. European availability of a competitive industrial offer for 5G systems and technologies

This KPI is very close to B3 so we can reuse the proposed approach for B3 to monitor this KPI.

In addition, we could add in the monitoring process for this KPI aspects related to the existence and large coverage of a European infrastructure to deliver 5G services. From that perspective we could start from a very accurate knowledge on 5G technologies (realistic and quantified assessments of the maturity and performances of the different technological components) so as to estimate the total cost of ownership and rollout for different coverage targets for operators. Depending on the result, we could estimate the possible scenarios based on the perspective on revenue streams and regulatory evolutions in Europe.

Another important aspect for operators is to ensure that 5G technologies will serve the services ambitions of European operators in terms of capabilities. Indeed, the interests might be different depending on the regions in the world. European operators need to find business growth in the B2B market segment and in particular with partners in the vertical industries which are very strong in Europe (industry, energy…).

- S4. Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications

Compared to the beginning of the cPPP, the vision on future services has largely evolved and has been disseminated thanks to the Vision & Societal Challenges Working Group[4]. As a result, UHDTV and M2M maybe not the best services for 5G target. So we should reorient this KPI towards the stimulation of services for vertical industries in Europe. In particular, we should estimate the impact of 5G enabled services on efficiency and worldwide competitiveness in vertical industries (e.g. cost of renewables compared to traditional energy sources for energy…).

- S5. Establishment and availability of 5G skills development curricula (in partnership with the EIT)

We have not managed to engage with the EIT on this aspect. So we propose to focus our target on the establishment of curricula dedicated to 5G in Europe in order to increase skills in the domain. We propose to monitor this KPI by counting the number of available master degrees and other curricula in European universities as well as summer schools.

3.2.3 Performance KPIs

- P1. Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010

We propose to translate this generic KPI in 2 distinct KPIs inspired from ITU, 3GPP and projects reflexions:

- absorb 1 TB/s of traffic in a smart office or high speed train (corresponding to 10 TB/s/km² of wireless area capacity)
- reach a peak user data rate between 1 and 10 GB/s for specific deployment scenarios and use cases

- P2. Reducing the average service creation time cycle from 90 hours to 90 minutes

This KPI is rather difficult to measure since service creation time vary a lot already today depending on required services. For example, a SIM card activation can take a few hours allowing a new consumer to connect to the Internet very rapidly. On the opposite side, a corporate VPN can take several weeks to be fully activated because some fibres and physical equipment need to be installed on customer premises or within local exchanges.

As a result, we propose to monitor the following parameters:

- level of automation of service related processes (service fulfilment, service assurance, service negotiations …)

[4] https://5g-ppp.eu/wp-content/uploads/2016/02/BROCHURE_5PPP_BAT2_PL.pdf

- existence and range of an autonomic network management framework including the capability to reallocate resources very rapidly between services and users
- usage of Open Source, SDKs and DevOps to facilitate and speed up service developments

- P3. Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people

We propose to translate this generic KPI in 2 distinct KPIs inspired from ITU, 3GPP and projects reflexions:

- handle between 10.000 and 1000.000 devices per km² for specific deployment scenarios and use cases
- facilitate (technically and economically) the deployment and operation of a big number of small cells (tens of sites per km²)

- P4. Creating a secure, reliable and dependable internet with a "zero perceived" downtime for services provision

We propose to translate this generic KPI in 3 distinct KPIs inspired from ITU, 3GPP and projects reflexions:

- provide a latency between 1 and 10 ms depending on deployment scenarios and use cases (1 ms being for the air interface link)
- reach a reliability > 99% (meaning that a packet reaches the destination in the allowed latency budget in 99% of the cases) and even close to 99,999% for specific deployment scenarios and use cases
- reach an availability rate > 99% (meaning that the user equipment is covered by a 5G service more than 99% of the time of usages) for specific deployment scenarios and use cases

The security and privacy aspects are not easy to quantify so we will provide a qualitative monitoring of these aspects.

4 What are the tests which will show the achievement of 5G PPP performance KPIs?

This section will present reference test cases able to demonstrate the fulfilment of the KPI targets. It is based on METIS II cross project deliverable entitled “5G-PPP use cases and performance evaluation models”. We focus here only on the 3 of the performance KPIs (P1, P3 and P4) plus the energy efficiency KPI and we do not consider other societal KPIs or business KPIs.

In order to quantify how certain technical solutions would affect 5G PPP KPIs, specific evaluation metrics are needed. This section provides basic info on how to evaluate them through inspection, analysis or simulation.

- In case of evaluation through inspection the evaluation is based on statements
- In case of analytical procedure, the evaluation is to be based on calculations using the technical information provided by the technology component owner (methodology, algorithm, module or protocol that enables features of the 5G system is a technology component or enabler)
- Evaluations through simulations contain both system level simulations and link level simulations although it is expected that majority of solutions will be assessed using system level evaluation.

During the first year of 5G PPP programme, METIS II organized a joint activity between 5GPPP Phase 1 projects to share use cases, requirements, deployment scenarios and performance assessment methodologies between projects. The following table details some 5G characteristics and their assessment method as defined by this cross project activity:

Inspection (yes/no):	Analysis (calculation)	Simulations:
• Bandwidth and channel bandwidth scalability • Deployment in IMT bands • Operations above 6 GHz • Spectrum flexibility • Inter-system handover • Support for wide range of services	• Control plane latency • User plane latency • mMTC device energy consumption • Inter-system HO interruption time • Mobility interruption time • Peak data rate	• Experienced user throughput (bursty traffic) • Traffic volume density (bursty traffic) • Capacity (full buffer) • E2E latency • Reliability • mMTC device density • RAN energy efficiency • Supported velocity

Table 1: Assessment methodologies

For analysis, the cross project deliverable details the required steps which need to be taken into account for each quantity. For example, for user plane latency, 5 steps have been defined:

- Transmitter processing delay
- Frame alignment
- Synchronization
- Number of TTIs used for data packet transmission (includes UE scheduling request and access grant reception)
- HARQ retransmission
- Receiver processing delay

METIS II cross project activity went a step further on the performance assessment by simulations. This activity defined 4 synthetic deployment scenarios for 5G:

- indoor hotspot
- urban macro
- outdoor small cells
- rural macro and long distance

For each of these synthetic deployment scenarios, range of configurations covering all 5G PPP use cases were described for base station layout (hexagonal…), inter-site distance, antenna height, number of antennas elements & ports, antenna gain, transmit power, frequencies, and carrier bandwidth.

All use cases from 5G PPP Phase 1 projects were also reviewed to classify them along these 4 synthetic deployment scenarios and to define the following test parameters: number of user equipment per area, number of user equipment antenna elements and RF chains, user equipment height and antenna gain, maximum power, minimum distance between user equipment and base station, indoor / outdoor ratio, channel model, traffic and mobility models.

With this full set of parameters, each use case can be tested in similar conditions by different projects or with different technology settings to measure the impact of various architectural concepts or technology components developed within 5G PPP Phase 1 programme. These simulations and measurements will be conducted during the second year of the programme.

5 Progress achieved so far

This section is based on the self-assessment of the progress achieved so far on each KPI made by 5G PPP Phase 1 projects. The following table summarizes the contributions compiled in this section for each project:

	P1	P2	P3	P4	B1	B2	B3	S1	S2	S3	S4	S5
5G Crosshaul			x		x		x					
5G NORMA			x				x					x
5Gex		x								x		
5G-ENSURE				x				x				
5G XHaul	x					x						x
CHARISMA	x							x				
COGNET		x		x								
COHERENT	x					x				x		
FANTASTIC 5G			x						x		x	
Flex5GWare									x	x	x	
METIS II					x				x		x	
mmMagic					x		x				x	
SELFNET		x		x								
SESAME		x				x						
SPEED 5G	x		x			x						
SONATA		x								x		
SUPERFLUIDITY	x						x			x		
Virtuwind		x		x						x		

Table 2: Projects assessment of progress on 5G PPP KPIs

P1. Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010

5G-XHaul

On an architectural level, we have quantitatively investigated the implications of different functional splits on the transport network requirements. Based on the targeted 1000 x increase in wireless area capacity, the required data rates for three different functional splits were derived for different network segments. A reduction of FH (CPRI like) needed capacity of up to 200x by using appropriate functional splits, and up to 10x by using statistical multiplexing was found feasible.

Additionally, to utilize available network resources efficiently, we propose introducing four different transport classes. The transport classes correspond to typical latency/capacity coordinates matching both different 5G use cases (from tactile internet to eMBB) and the implementation options in the transport network. In the next year, several wireless and optical technologies will be developed in 5G-XHaul to address the requirements of these transport classes.

In the wireless domain, the 5G-XHaul project aims at innovations in increasing the capacity on the link (point-to-point (P2P)), multi-link (point-to-multipoint (P2MP)), and network levels.

We have developed a new beamforming mmWave frontend chip which can be used for line-of sight (LOS) MIMO transmission using optimally spaced antenna arrays. First measurements proove the correct function of the frontend chip. Furthermore, measurements of a LOS-MIMO transmission using arbitrary waveform generators (AWG) and vector signal analyzer (VSA) showed the feasibility of this approach. Depending on the number of streams a data rate of up to 100 Gbit/s is feasible.

For optical fibre transmission, an efficient architecture based on time-shared optical networks (TSON) and passive optical networks (WDM-PON) was developed and is also reflected in the white paper of the 5G-PPP architecture working group.

CHARISMA

CHARISMA has developed an innovative distributed hierarchical architecture, based around the Converged Aggregation Levels (CALs), which range from CAL3 (Central Office), CAL2 (Macro Base Station), CAL1 (Micro Base Station) to CAL0 (Access Gateway). The CALs allow an efficient approach to aggregating a higher density (i.e., towards the x1000 increase) in user equipment density. More specifically, the hierarchical topology enables more efficient management of a greater number of wireless devices connected to the CHARISMA architecture via its various CALs; thus increasing the wireless area capacity. In addition, during the 1st year of the project, CHARISMA has focussed on producing an ultra low latency architecture solution, achieved by: 1) use of distributed caching solutions, for low latency access times; 2) 60-GHz (mm-wave) final drops for large bandwidth data pipes (both increasing bandwidth capacity, as well as reducing data bottlenecks at the access point); 3) TrustNode router, featuring hierarchical 6TreeNode routing for accelerated routing; and 4) Accelerated Network Interface Card (NIC) located at the CALs, also acting in concert at each CAL to accelerate data transfer. Together, these ultra low latencies (towards the 1-ms KPI) will also enable new service capabilities and underpin new use case scenarios that will require both such ultra low latencies as well as high bandwidth throughputs.

COHERENT

COHERENT aims to develop a unified control and coordination framework for 5G heterogeneous radio access networks (RAN), with the emphasises on software defined networking (SDN) for RANs, efficient radio resource modelling and management in programmable RANs, and flexible spectrum management. In the first year of the project, COHERENT has made the concrete progress on **flexible RAN architecture design** (Deliverable D2.2), **radio resource abstraction, virtualization and management** (Deliverable D3.1) and **flexible spectrum management** (Deliverable D4.1). The achievements by COHERENT address 5G PPP KPI P1 from the following aspects: new RAN architecture to manage densified heterogeneous RAN, new methods based on RAN virtualization to improve radio resource utilization efficiency; network slicing support at RAN for varied vertical services; and flexible spectrum management and spectrum sharing to offer higher area capacity.

The flexible RAN architecture proposed by COHERENT introduces new logical centralized control and coordination network entity, RAN virtualization, flexible function split, and SDN based control principles into LTE/LTE-A, WiFi and emerging 5G networks, to realize a flexible and scalable hierarchical control framework for densified heterogeneous RAN (Deliverable D2.2). The concept of the network graph, which reflects the low layer reality of RAN by abstracted network views, is introduced to support radio resource virtualization and enable scalable fine-grain coordination among RAN entities for higher wireless area capacity. The architecture supports the network slicing at RAN for varied mobile services.

New radio resource management methods based on the new architecture are developed to support fine-grain radio resource allocation and node cooperation cross the cellular cells' boundary. The improved coordination methods are capable of improving the performance of coordinated multi-point transmission and reception (CoMP), multi-connectivity and other new cooperative functions in RAN. COHERENT has identified and been working on 11 key research topics which exploit the proposed architecture and network graph approach for wireless area capacity improvement and service enhancement (Deliverable D3.1).

COHERENT has proposed a **flexible spectrum management framework** for heterogeneous RAN therefore not only conventional spectrum management methods but also new spectrum access schemes, for instance, license shared access (LSA), could be integrated to provide more spectrum opportunities to end users. Moreover, the flexible duplex in LTE has been studied in the project. The flexible duplex has potential to improve the spectrum utilization efficiency in LTE/LTE-A. The first spectrum related results of COHERENT are included in Deliverable D4.1.

SUPERFLUIDITY

The current set of services that is achievable with Network Function Virtualisation (NFV) is limited by the composition mechanisms offered to construct VNF forwarding graphs (VNF-FGs). SUPERFLUIDITY is developing the Reusable Functional Block (RFB) concept as well as defining means to define service graphs recursively so as to compose services based on virtual network functions (VNFs) that goes beyond what can currently be achieved based on available standards. An RFB may be analogous to a traditional VNF or VNFC, implemented as a fully-fledged VM running on a hypervisor or in an OS container. An RFB can correspond to a small footprint Unikernel VM running in a specialised hypervisor. In the latter case, the execution environment is the hypervisor specialised in supporting lightweight VMs. RFBs can also be modules or components of special purpose execution environments, like extended finite state machines based on OpenFlow for packet processing, software routers, or radio signal processing chains.

Telefónica is pushing the RFB concept in the IRTF NFVRG as an initial sanity check, to be later integrated into the ETSI NFV work. Telefonica believes that it will allow to define and implement novel services based on previously defined and tested services in an agile way, very much in line with current DevOps approaches.

BT believes that in the next 2-3 years the worlds of cloud computing and virtualised network functions are coming together into a completely new model for telecommunications combining cloud services, network function virtualisation, and software defined networks. Entire enterprises will be able to run on virtualised servers, virtualised network functions, and virtualised network control services. The BT Vision is described by Howard Watson, our CEO of BT Technology, Service & Operations, at https://player.vimeo.com/video/166341115 (starts at 14 minutes). As part of this convergence, NFV has a critical role. BT has already launched our first commercial service that uses NFV (Cloud Connect Intelligence), with more in the pipeline. The fast and flexible deployment and modification of services is what is most attractive about NFV, including the promised DevOps approach – as this simplifies and automates the process from design of the new network service to its deployment. BT is feeding the results into our internal OSS/BSS developments.

NEC has worked on virtualisation execution environment minimalisation. By reducing the size of VMs to the minimal set of resources, it is then possible to have more workloads running on a node. For this, NEC has evaluated mapping workloads to containers and minimal Linux execution environments called TinyX. This work has also looked at profiling of the workload startup time and then reducing the elements that take most of the time. In Xen this has led to improvements in the control stack tools to reduce the startup time of the workloads.

NOKIA IL is working on optimizing the cloud utilization through optimizing and automating the infrastructure configurations, improving the placement algorithms based on rigorous hardware benchmarking, and task offloading to dedicated hardware (e.g., OVS offload to NICs). To allow those optimization, NOKIA IL rely on and extend OpenStack services and in particular Mistral work flow engine. Here, Mystral is a key component that facilitates the applications deployment and life cycle management. For example, orchestrating application scaling to obtain adequate application performance or alternatively better resource utilization.

OnApp has been working on hypervisor-level improvements and virtualisation optimisations to allow its MicroVisor platform to handle the scale of network functions expected for 5G. Fundamental to performance in a distributed platform, which is likely the way that hardware architectures will go, at least in the core network, is improving the network latency and throughput between guests. The network latency between guests on the same physical node and also to nodes that are hosted on different physical machines is very important for the overall performance of network functions and for service function chaining of RFBs that is envisaged in SUPERFLUIDITY. To this effect OnApp have been working on improving the network performance for 10-40GbE network interfaces and reducing the overhead in the virtualisation layers.

Nokia Bell-Labs France has been working on Cloud RAN to address capacity and coverage issues, while supporting mobile xHaul (Fronthaul and Backhaul) solutions as well as network self-optimisation and self-adaptation with software control and management through SDN and NFV. Centralising the processing in the Edge Cloud, one of the main feature in Cloud-RAN, open the door to implement a very powerful optimisation technique like the coordinated multipoint (COMP), Interference Cancellation scheme, improving the throughput of the system. The testbed hosted by Nokia FR supports a first Proof of concept of Cloud RAN demonstrating the fronthaul network and the deployment of the different RFBs composing the Core and the RAN. These RFBs are executed using containers technology. On the testbed, we tested the flexibility in the service deployment in the sense that each container could be deployed in a virtual machine or on bare metal, as it is the case in the compute Node 2 of Testbed #1, following the service requirement.

EBlink will contribute towards a wireless Fronthaul architecture to ease network deployment with more flexibility while increasing network capacity in dense area by developing µWave/mm-Wave wireless fronthaul to support CRAN network. EBlink will work with Nokia to make more efficient some techniques such as UL CoMP, ICIC, CSPC, CA etc. by enabling BBU pooling/virtualisation to reduce X2 delay and enable Gbps wireless links with a very small footprint and few impact on the environment. The project will bring a new technological step in terms of spectral efficiency. Thanks to the use of the high capacity and high spectral efficiency wireless Fronthaul link combined with different baseband functional split options, it will be possible to overcome the last distance gap where optical fibre connection is not always available and where the cost of installing it would be too high and the administrative process a lengthy one. By developing a new flexible fronthaul interface (XHAUL) that can support both CPRI and packet-based protocol (NGFI), the available resource can be used more efficiently and ensure a smooth transition from legacy network to 5G network. For a deployment based on distributed base stations architecture/Cloud-RAN, laying down optical fibre (Gbps links) from the network access point all the way up to the RRHs is often a challenge and consequently imposes significant limitations to bring capacity in dense areas. The wireless fronthaul will contribute to build local cloud RAN with high capacity centralised processing and low-cost distributed RHHs. Mobile operators can easily and cost-effectively install small-RRH for indoor coverage (iDAS) for outdoor coverage and capacity in dense urban areas that are hooked to baseband and backhaul resources. In summary it can be said that the EBlink solution will facilitate very dense deployments of wireless communication links via the local cloud RAN and at the same time will help to reduce network latency and cost since Local Cloud RAN will facilitate MEC at the edge of the mobile network, within the Radio Access Network (RAN) and in close proximity to mobile subscribers.

Unified Streaming will unleash the power of the SUPERFLUIDITY architecture to tailor it towards the needs of its clients in the Over the Top Video Streaming Industry. In doing this it will exploits its expertise in protocols and media standards such as those defined in MPEG and MPEG DASH industry Forum of which it is both a contributor and member. In particular it will provide its core multimedia functions such as trans multiplexing (serving both Apple and Samsung devices), Digital Rights Management (content protections), and personalization (ad insertion) at the edge of the network in virtualized superfluid compute instances. This is expected to highly increase the efficiency of over the top video streaming in access networks, benefiting from Radio Network information services. The SUPERFLUIDITY project provides a use case to demonstrate that using the Unified Streaming products Remix, Origin in the edge will help achieve this target KPI.

Speed 5G

Speed-5G implements extended-DSA (eDSA) concept towards achieving higher wireless capacity based on the following three functions:

1) better resource reuse along small-cell based ultra-densification;

2) traffic smart offload with the use of heterogeneous technologies; and

3) efficient use of all and any available spectrum resources through the use of dynamic and smart spectrum access.

To date, and considering above functions, MAC/RRM structures and interfaces have been designed and identified by SPEED-5G. In addition, a novel algorithm on MAC/RRM has been implemented to be operated in heterogeneous bands over the HetNet scenarios. A self-organizing MAC algorithm capable of optimizing autonomously has also been implemented for ultra dense small cell networks.

P2. Reducing the average service creation time cycle from 90 hours to 90 minutes

5Gex

How 5GEx addresses this? By defining an automatic multi-domain resource and service orchestration architecture, implementing it leveraging components from existing projects, and validating it in a large scale test-bed (the 5GEx sandbox) connecting 13 sites, including 4 operators providing the connectivity backbone.

First 9 months achievements? During the first 9 months of 5GEx's lifetime, the project has designed a multi-provider, multi-domain orchestration architecture enabling automatic end-to-end service composition across multiple domains. The solution defined three layers of services for automation: multi-provider value added connectivity, VNFaaS and resource Slice as a Service (SlaaS). The reduction in service creation is achieved via automations in domain discovery processes, bilateral business and service negotiations and fulfilment – assurance – billing for Network Services.

The project is now about to finish the implementation of its first prototype, an open-source proof of concept of a fully automated NFV service deployment from an NFV marketplace (based on the open source components developed by the EU FP7 T-NOVA project) to multi-provider NFV Infrastructures (based the open source framework developed within the EU FP7 UNIFY project). This prototype will be provided as a reference implementation and evaluation framework for the community.

The verification of the average service creation time cycle shall follow once the prototype is released and deployed. At that stage, testing over a sandbox deployed across Europe will begin. This testing will be used as the feedback loop to further improve and provide more concrete verification of the architecture and the overall project result goals.

COGNET

The orchestration functionality which will emerge from the CogNet project will help reduce the time required to create and build services as much of the functionality required to deliver a service, through set up, configuration, lifecycle management and performance management will be greatly simplified. Simplification through the use of technologies such as Software Defined Networking, Network Function Virtualisation, Service Function Chaining and associated standards and projects (MANO, SUPA, TOSCA, OpenDaylight, OpenStack,…) all of which allow the service "inherit" capabilities such as fault tolerance, scalability, flexibility and portability which would previously have to be developed specifically to support the service. In this CogNet is an enabler as it leverages the above technologies and helps coordinate all of these capabilities and ensure that the service always runs in an efficient and fault tolerant mode.

To date we do not yet have a working example of how we have achieved this KPI, however we hope to be able to demonstrate a service use cases within the second year of the project. One such potential case will demonstrate how a standalone SIP server can be dynamically transformed into a load balanced, scalable and fault tolerant service through incorporation within the CogNet framework with no additional configuration or programming work.

A means of measuring this may be to quantify the service creation in terms of how long it takes (over the time needed to program a service in single use mode) to deploy it as a load balanced, scalable and fault tolerant service, fully integrated with the network mgmt required to maintain this mode.

SELFNET

SELFNET focuses on significantly contributing to this P2 KPI through an autonomic network management framework that is able to provision a set of key innovative functionalities: automated (and thus speedy) physical and virtual infrastructures and services deployment, automated and enhanced network service monitoring and performance analysis, intelligence-based network management engine assure the quality of running services, and integrated management and orchestration of SDN/NFV Apps for on-demand service creation. Towards realising these functionalities, the following specific achievements can be highlighted after the first year of the project:

- SELFNET has established a detailed definition of the planned autonomic management framework with evolved standards-compliant architecture, components and their interfaces/APIs and essential work flows specified. (Deliverables 2.1 and 2.2)
- SELFNET has designed and prototyped an innovative, automated physical and virtual infrastructure and network service deployment system, which is notably compliant with the 5G Mobile Edge Computing (MEC) paradigm to benefit from localised cloudification and hence expedited service delivery. (Deliverable 2.4)
- SELFNET has designed and prototyped the Service Function Chaining (SFC) mechanism to enable on-demand automated service composition and provisioning. (Deliverable 2.4)
- SELFNET has designed and prototyped the mechanisms for the lifecycle and repository management of SDN and NFV Apps and for the on-boarding and access of these Apps, thereby paving the way for on-demand service deployment and operation. (Deliverables 2.3 and 3.1)
- SELFNET has designed and prototyped the network monitoring facilities to gather essential performance metrics and events from the running services and physical/virtual infrastructures, enabling that existing or potential network/service issues can be analysed and handled. (Deliverable 4.1)
- SELFNET has designed and prototyped initial network management intelligence based on an innovative Tactical Autonomic Language (TAL) specification, which defines the essential work flows of the autonomic behaviours to allow fast and improved decisions and actions to assure service provisioning. (Deliverable 5.1)

SESAME

A 5G network will have to advance towards a distributed and flexible high level architecture in order to support the increased data rates and low service creation times envisaged by new 5G technologies. On the service creation part, significant improvements have been already realized within SESAME project. SESAME deals with clusters of small cells that are enhanced with an integrated, low-cost micro-server so as to provide processing power and edge cloud capabilities at the network's edge. Therefore, as the platform under development is going to deliver network services as Virtual Network Functions (VNFs) for each operator, these services will be provided at low cost and with a low power consumption hardware.

During the first year of the project, a specific result that highlights the reduction of service creation time refers to the placement of a network specific VNF at the network's edge. Such a procedure requires:

- Steering data packets from the original route
- GTP De-encapsulation of data packets received at VNF environment
- Process of data from VNF (e.g., Deep Packet Inspection)
- Encapsulation of data packets and sending them towards their original destination

The above process has been already tested and validated in order to guarantee the smooth integration of the small cell with the resources of the attached micro-server. Therefore, the flexible design of the SESAME platform and the associated VNF functionality promotes a shared virtualised infrastructure, i.e., a cloud environment, right at the network's edge. This will allow multiple network services to be deployed at a lower time scale.

Virtuwind

The VirtuWind solution architecture is in progress to address programmability in the SDN and NFV network applied to industrial use case of Wind parks. There are different architecture components defined which cover auto-configuration of SDN/NFV devices during boot-up phase as well as reconfiguration of SDN/NFV devices during runtime. The north bound interface semantics is under definition which will enable SDN controller to parse the service request seamlessly facilitating the reduction of service creation time from some hours to few minutes. For later (project year 2&3)

performance comparison of the proposed SDN/NFV architecture with the existing one, VirtuWind consortium conducted "State of the Art" measurements and testing in the "Floe" wind park. The next measure in the year 2 is to finalize the VirtuWind solution architecture in order to reduce service deployment time from the current state of the art methods.

SONATA

SONATA project addresses the significant challenges associated with both the development and deployment of complex network services envisioned in 5G networks. SONATA is focused on Network Function Virtualization (NFV), a cornerstone of future software networks that influences heavily how they are built, deployed and managed.

SONATA is developing a NFV service platform for the operator, a supporting SDK for service developers and a DevOps workflow that connects these stakeholders together. The project is aligned with the MANO layer of the ETSI architecture.

It is well-known that software networks are an attractive upgrade for network operators of various sizes and scope, whether they are a large communication service provider (CSP) or an enterprise running their own network. The supporting business case includes lower CapEx on hardware procurement and upgrades; flexibility and alleviated vendor lock-in; reduced OpEx while increasing efficiency and ability to scale network operations; and potential for agile service development and improved time-to-market.

The contribution of SONATA towards reducing time-to-market for services based on NFV adoption and extension is two-fold: on one hand, offering a well-structured and NVF compatible SDK and Service Platform (SP) that allow service developers to easily develop and faster deploy networked services on top of telecom operators' resources, while on the other hand, promoting DevOps model to efficiently and seamlessly integrate service development and management operations of virtual network functions

Current average time to design and deploy new service over existing network is from 3-4 days in the fastest case up to 2 weeks depending on the complexity. SONATA results are directly impacting in the reduction of the necessary time to create and deploy a new service over networks. Its primary value proposition is to help realize the aforementioned NFV core business case as a chief component in the overall architecture (i.e. NFV orchestrator); alleviate NFV adopters' initial pain points revolving around multi-vendor complexity; and empower CSPs and supporting third-party developers with the workflow and tools needed for the agile service development and deployment envisioned for 5G networks.

Thus SONATA also targets the integration of service development and operations (DevOps model). The SONATA project enables the DevOps model for network services, by introducing tool chains that allow the handling of the different service's phases, including development, deployment, testing, monitoring, and operation.

P3. Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people

5G Crosshaul

The P3 KPI has a strong implication in the work performed by 5G Crosshaul. To acknowledge its importance, a use case specifically suited for this KPI has been selected; a dense urban environment, capable of huge traffic demand and, in particular, a very high number of connected devices.

The technologies identified in the project allows to implement the 5G Crosshaul network using any kind of medium (air, fiber, copper) on any kind of topology (mesh, tree, ting, linear) and deployment scenario (indoor/outdoor, small/macro-cells). According to a modular and multi-layer (circuit and packet) data plane architecture, these technologies can be integrated at different level, from L1 to L3. Together with a SDN, technology agnostic, control approach, this makes possible to avoid network overprovisioning and scale the TCO with network capacity and complexity, allowing a very capillary deployment. Moreover, the use of a standardized framing protocol makes possible to deal with any protocol split that may be adopted in 5G while using widespread Ethernet based forwarding elements.

The flexibility in bandwidth and connectivity resources is compatible with multi-tenancy and multi-domain scenarios, allowing the support of heterogeneous business models.

In addition, the technical workpackage dealing with control applications for the Crosshaul is also focusing on this specific scenario. The novel applications developed are focused on providing cost-efficient resource orchestration solutions to manage the integrated fronthaul and backhaul networks to facilitate very dense deployments of wireless and mobile networks including indoor and outdoor small cells as well as macro cell base stations. The goal of the resource management solutions is to reduce the overprovision of the network and to allow dynamic capacity and energy configuration of the network as well as moving available resources or virtual functions across the network, in order to support different degree of density of the network while minimize the overall energy consumption and CAPEX/OPEX.

Finally, we are specifically validating this KPI within the project demonstrations. The proofs-of-concept on the integrated fronthaul/backhaul will allow evaluating what are the most appropriate deployment options to offer the wireless link densities required in 5G networks. This entails appropriately serving both the high-rate 5G wireless access links and the deployment of wireless transport links to provide the appropriate capillarity in a cost-effective way. The project will evaluate in close to real scenarios with what combination of transport technologies the requirements of various 5G RAN splits are fulfilled, including analogue RoF, L1 PHY or PDCP-RLC splits. This results in a plethora of wired and wireless (e.g., microwave, mmwave, optical wireless) data plane solutions under a single control plane (XCI) along with network management applications for an efficient deployment of the 5G-Crosshaul network.

5G NORMA

It is known that a 1000-times improvement can only be achieved by an architecture that is scalable with an increasing number of base stations (densification), while radio spectrum efficiency will provide a relatively smaller contribution to this. 5G NORMA provides a 5G architecture that enables a cost-efficient densification approach and guarantees an improved energy-efficiency. Adaptability and, in particular, mobile network multi-tenancy concepts will be the key concepts here. 5G NORMA thus provides the means to introduce 5G innovations that allow for the 1000 times increase. Among the key 5G NORMA innovations that contribute to the flexibility which allows for introducing novel technologies are:

- As a result of the *centralized control* and having a global view of the network from 5G NORMA, we can implement control functions that allow for a better coordination of resources among the base stations and allocation of mobile terminals to different air interfaces, improving the overall performance in terms of capacity. 5G ORMA's flexible RAN architecture aims to maximize the coordination gain of a fully centralized control while still considering practical network limitation in the assignment of RAN functions. For example, a centralized and a distributed algorithm for multi-tenancy-aware optimized radio resource allocation were designed. The centralized outperforms the distributed scheme by more than 60 % (in the best case).
- From *mobile network multi-tenancy*, the 5G NORMA project enables an implementation- and cost-efficient framework for new advanced spectrum sharing concepts. We estimate that wireless spectrum utilization efficiency can be increased by at least a factor of 2-3. Indeed, based on previous studies within the EU FP7 R&D efforts, a flexible spectrum sharing scheme that adapts to the load fluctuations of different operators can provide multiplexing gains of this order of magnitude.
- We estimate that the *multi-service mechanisms* of 5G NORMA can provide a gain of a factor of 2. Indeed, by employing mechanisms that are specifically devised for a given traffic type we can be much more efficient. For instance, it is known that a suitable MAC protocol, adapted to the number of contending sources, can improve substantially the efficiency of a more generic one.

FANTASTIC 5G

FANTASTIC-5G has worked on several means to support the global efforts in achieving this target. Having to serve this high amount of nodes in a density has several impacts to the system requiring respective design considerations. We focus in the following on the ones being relevant for the project:

- Beside the sheer number of devices, the key aspect to be cared for is the highly differing requirements being connected to these devices (ranging from high end tablets to low-end sensors/actuators)
- The system has to provide high data rates per area in a consistent and ubiquitous manner
- Many of the devices only connect sporadically to the system, possibly leading to peaks of traffic
- The system design has to be highly energy efficient for allowing a very long lifetime for battery-powered wireless devices.

The project is focussed on designing a multi-service air interface for enabling the system to support the highly varying requirements the connected nodes are requesting for. Besides techniques that increase the overall spectral efficiency of the system (e.g. advanced modulation schemes like FQAM, non-orthogonal multiple access, mMIMO, D2D and interference coordination), and techniques that enable a flexible multi-service support (e.g. enhanced waveform designs that support varying configurations within a single band, flexible frame design that enables the use of different numerologies concurrently and a highly flexible radio resource management), the project investigates the following key techniques that are tailored toward handling a massive number of connections:

- dedicated FEC (e.g. to improve the links carrying very small payloads),
- efficient multiple access procedures including the design of the respective preamble space (for enabling the use of lightweight access protocols as given later),
- efficient multiple access protocols based on one-stage or two-stage principles (for reducing the overhead related to the transmission of small payloads in a sporadic manner),
- a third RRC state being tailored to this kind of communication links (for the devices to be able to switch to idle-mode without the need for executing the complete setup procedure reducing energy consumption and message exchanges),
- in-resource control channel designs (to avoid the control channel to be the bottleneck and to allow for more varying control channel formats formatted for the respective connection and to enable interference coordination mechanisms to be applied to the control channel).

More details can be found in the respective deliverables of the project (D3.1 and D4.1).

Speed 5G

Speed-5G contribution in increasing the density of connected devices will be achieved via following approaches:

1) increasing the overall simultaneously operated bandwidth (via the use of licensed and unlicensed spectrum at the same time);

2) allowing more users per spatial area (e.g., by supporting dynamic channel selection to mitigate interference);

3) adding small cells that can offload traffic; and finally

4) optimizing the medium access control protocol so that users can access the medium more efficiently (i.e., based on consideration of current traffic loads on channels, traffic types to support, different regulation regimes etc.).

Status: In order to support massive connection of many kinds of devices (e.g., wearable and MTC devices and smart phones), a novel algorithm considering IoT traffic types operating over a FBMC physical layer has been initially defined and has been under improvement for dense area scenario. Its performance will be evaluated via system-level simulations.

P4. Creating a secure, reliable and dependable internet with a "zero perceived" downtime for services provision

5G-ENSURE

5G-ENSURE project has analyzed several use cases covering a wide variety of deployments including, for example, the Internet of Things, Software Defined Networks and virtualization, ultra-reliable and standalone operations. The analysis has produced 31 security relevant use cases grouped in 11 security clusters [1] which highlight security issues inherited from current generation networks as well as security and privacy functionality needed to support the new scenarios introduced in 5G. Most of the clusters focus on the availability, reliability and integrity of the network and the supported services. The issues raised from the security analysis of these use cases have been used to understand the necessary solutions.

The result has been the identification of 22 security enablers which contribute on the creation of a reliable and secure network by covering the main 5G security areas/domains: Authentication, Authorization and Accountability (AAA); Privacy; Trust; Security Monitoring and Network management & virtualization isolation.

Each of these enablers is now either under maturation or development. The Technical Roadmap [2] indicates the initial set of enablers (Internet of Things (IoT), Fine-grained Authorization, Basic AAA, Privacy Enhanced Identity Protection, Device Identifier(s) Privacy, Trust Builder, Trust Metric, VNF Certification, System Security State Repository, Security Monitor for 5G Micro-Segments, Satellite Network Monitoring, Generic Collector Interface, Proactive Security Analysis and Remediation, Access Control Mechanisms, Component Interaction Audits, Bootstrapping Trust, Micro-segmentation). Their delivery is expected to be in September 2016 and it will be used to monitor the progress on the considered KPI. In addition most of the enablers are expected to be continued and/or completed in the context of the next release in August 2017. Another concrete action will be the delivery in October 2016 of the 5G security testbed, under setup within the project, that will be used to demonstrate and assess the enablers in the context of relevant use cases.

In the meantime the project is working on the definition of the 5G security architecture. The key objective is to built-in security mechanisms embedded within the network infrastructure, which may be used to create a secure reliable network and to support the requirements of the specific 5G services. The design of the 5G security architecture and the map of targeted security enablers to 5G architectural components will be another way to measure the progress of this KPI.

Therefore, at this stage we can assess that the 5G ENSURE project goes towards the fulfillment of the P4 KPI. The assessment will continue together with the development of the enablers and a final evaluation of the KPI fulfilment will be provided towards the end of the project’s life.

COGNET

Some of the CogNet research is focused on

- Network Security
- Network Resilience & Fault tolerance
- Scaling network resources according to predicted demand

All of these capabilities are focused on the use of Machine Learning to enable or improve existing methods of network management where issues are either identified and addressed before they become critical, the network is provisioned to a sufficient level to deal with both normal demand patterns but also unusual “once off” demand peaks. Security issues such as potentially malevolent users are identified through anomaly detection algorithms and isolated until they can be dealt with. These in turn will help provide a future network where the user can expect a higher level of QoS and security on their mobile or land based network than might be expected today.

CogNet has made significant progress in enabling these technologies through some of the research activities and demonstrators which are currently in development.

A potential measurement for such a KPI is to use an event simulator whereby a “with project technology” and “without project technology” are compared side by side. An estimate of the real world frequency of such events and the (perceptible) downtime that may occur if they needed to be manually managed versus automatically managed with associated minimal downtime could be used to calculate improvements.

What is a perceived downtime may be defined as a latency of over 100 milliseconds, or a drop in badwidth below certain thresholds, depending on the service being used (voice, data, video etc.)

A "with" perceived downtime of 1% versus a "without" perceived downtime of 5% would represent a a 400% ((5-1)/1) improvement.

SELFNET

SELFNET also expects to help in realising this P4 KPI mainly through the design and prototyping of three classes of representative use cases that demonstrate the self-organising network capabilities of the SELFNET framework. The three use cases address self-healing against existing or predicted network/service failures, self-protection against network/service security threats especially distributed denial of services, and self-optimisation to maintain or improve video application performances. Clearly, these capabilities can be directly explored to support this KPI in terms of strengthened network/service reliability, availability, security, and perceived quality. In the first year, the primary scenario in each use case class has been concentrated on and the following specific progress has been made regarding these use cases:

- SELFNET has defined the storylines and potential innovations/impacts of these three use cases including eight scenarios addressing essential requirements expressed by this KPI.
- SELFNET has defined in details the information models, work flows, and innovative Health of Network (HoN) metrics of the primary scenario in each use case category.
- SELFNET has designed and been prototyping the primary scenario in each use case category.

Virtuwind

The current state of the art security mechanisms in "Floe" wind park are developed based on evolution of technologies in the legacy systems. For applying existing as well as new security mechanisms in SDN/NFV environment, VirtuWind consortium identified certain KPIs which are followed in the VirtuWind architecture and are planned later on in the implementation. The industrial-grade QoS is the central part of the VirtuWind solution architecture. This means that there are architectural components for intra-domain use which are meant to provide guarantees for requested bandwidth, delay and jitter. For inter-domain use, currently 2 methods are identified and analysed in detail for SDN-based inter-domain SLA management.

B1. Leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems in the order of 5 to 10 times

5G Crosshaul

In order to make sure 5G-Crosshaul developments are in line with current companies' interests, the system architecture in 5G-Crosshaul and especially the XCI is aligned with the ETSI NFV architecture. Also, 5G-Crosshaul implements the relevant parts of the XCI as extensions of widely used SDN controllers. This keeps 5G-Crosshaul aligned with ongoing efforts for developing cloud-based network elements in both the core as well as the radio access network and it allows the big industries in 5G-Crosshaul to widen their current scope: experts in radio access network need to become cloud experts and vice versa.

In addition, all sorts of private companies are involved in the proofs-of-concept designed and developed in 5G-Crosshaul. This includes operators, big equipment vendors, and high-tech technology providers and SMEs, as well as IT and media companies. In this way, the complete value chain for the 5G-Crosshaul network is represented and the close-to-real scenarios under evaluation are expected create synergies among all these partners that are expected to serve as catalysers of further private investments either internally to the companies or in the framework of future collaborative projects.

METIS II

METIS-II consortium comprise major telecom vendors, biggest operators and leading wireless research universities in Europe, therefore have the unique capability to **drive consensus building** in the early stage of 5G standardization.

As a project with a strong focus on regulatory and standardization bodies, discussions inside METIS-II help to establish a **common viewpoint between European partners working jointly on 5G** and to streamline critical aspects of 5G standardization process. Such approach is invaluable taking into account short time to market of 5G and diverging viewpoints of the industry that may lead to difficult and long discussion on the standard specifications. Neutral environment provided by METIS-II foster establishment of most promising research directions, **knowledge sharing** between involved partners and transfer of the standard related ideas that are subject to critical analysis from academia, operator and vendors (Deliverable 2.2). Especially the last two group of **partners are expected to spend substantial investments on R&D in 5G during the next 5-8 years.** It should be highlighted that also technical solutions and concepts discussed and promoted in METIS-II, such as network slicing (Deliverable 5.1), large degree of harmonization for functionalities tailored for different services (Deliverable 4.1) or lean and future proof 5G RAN design (Deliverable 6.1), create a solid **background for new services**, business models and operations possible with 5G for both new and old cellular players.

Apart from consensus building inside the project, METIS-II **promotes and disseminates common viewpoints reached inside the project globally**, through workshops organized inside 5G-PPP and in leading conferences related to wireless research. Further dissemination of the knowledge obtained in the project is done through high quality and publicly available deliverables, numerous scientific publications or through commonly available 5G visualization tool platform developed in METIS-II (Deliverable 7.1).

mmMagic

The knowledge gained in the collaborative research carried out in mmMAGIC will greatly boost the technology readiness of the industry and SME partners for 5G and is expected to result in significant further investment by industry players in their internal R&D in particular in improving their capacity for innovation towards new products and services. It is also worth mentioning that besides its two year EC funded research activities the project has planned 6 month of pro-bono activity (3 months before the official start and 3 month after the end) and this is one way the project as a whole will leveraging the effect of EU funding.

Partners that are active in 3GPP leverage further the research from mmMAGIC in standardization and regulation. The results have been fed into 3GPP RAN1 and ITU-R working group 5D by mmMAGIC industry partners (14 contributions acknowledging or citing mmMAGIC, two contributions to ITU-R SG3).

Euro-5G

Within the Euro-5G project, as part of the monitoring of the programme parameters, iDate made an initial assessment of the 5G Research and Development investment based on the published annual report figures.

Leverage assessment methodology

At this point in time the refection covers a couple of years. The 5G-PPP funding for the first phase was about 70MEuro for bigger industry, which facilitated projects with a value of around 30MEuro per year – allowing for projects with different durations (between 24 to 26 months). The total funding budget for 5G PPP Call 1 was 125MEuro.

The methodology is based upon gathering the published public figures from annual reports for worldwide R&D expenses.

The challenge was then to assess the declared R&D figures of a representative set of Key ICT players and deduce which proportion of their R&D spend is 5G related. We also discussed if the 5G spend in Europe could be identified or at least assessed.

Conservative assumptions on what the 5G activities share of their worldwide R&D was – usually in the order of 10% and then further reduced that to reflect what European share of the 5G activities as part of the total R&D expenses could be – typically ending up with a figure of about 5% of global R&D. To further eliminate over-assessment risks and to give us a very conservative figure it was also considered the European 5G as 2% of Global R&D. These proportions of 5G research of total research expenses will increase as 5G moves into full standardisation, development and production over the next few years and future iterations of these assessments will take account of this.

For direct evaluation purposes, it was taken into account a representative set of players active in the 5G-PPP. For a second reference figure were considered a wider set of players in different aspects of the ICT sector including: equipment manufacturers, mobile network operators, test equipment manufacturers and device manufacturers, and chipset manufacturers.

First assessment of Leverage ratio for 2015

2015 published figures were used for the following 9 equipment vendors and operators, active in the 5G-PPP, as a first reference for the assessment: (figures in MEuro)

Organisation	2015 R&D	5G as 10% of Global R&D	European 5G as 5% of Global R&D	European 5G as 2% of Global R&D
Ericsson	3720	372	186	74
Nokia (inc ALU)	2127	213	107	43
Huawei	8630	863	432	173
Samsung	11797	1180	590	236
Deutsche Telekom	4429	443	222	89
Orange	726	72	36	15
TIM (Telecom Italia Mobile)	1700	170	85	34
Telefonica	1111*	111	56	22
Telenor	500	50	25	10
	33629	3474	1737	695

[5]

Table 3: Leverage factor first estimation

As it be seen from the table, even the most conservative assessment of 2% of the Global R&D spend being invested in 5G would result in **a leverage factor of 10 to 20** depending on whether you consider the whole 5G-PPP phase one investment or an annualised figure (70M or 30M p.a.).

First assessment of Leverage ratio for 2015 (expanded version)

Redoing the same exercise but increasing the sample to 12 organisations involved in the 5G-PPP with more diversified types of organisations, brings the following result:

Organisation	2015 R&D	5G as 10% of Global R&D	European 5G as 5% of Global R&D	European 5G as 2% of Global R&D
Ericsson	3720	372	186	74
Nokia (inc ALU)	2127	213	107	43
Huawei	8630	863	432	173
Samsung	11797	1180	590	236
Deutsche Telekom	4429	443	222	89
Orange	726	72	36	15
TIM (Telecom Italia Mobile)	1700	170	85	34
Telefonica	1111*	111	56	22
Telenor	500	50	25	10
Keysight Technologies -Anite	377	38	19	8
Rohde & Schwartz	238	24	12	5
Intel	10911	1091	546	218
Sequans	26	3	1	1
	33629	4629	2315	926

Table 4: Leverage factor extended estimation

[5] * 2014 figure

It now can be seen from the table, that the most conservative assessment of 2% of the Global R&D spend being invested in 5G would increase in **a leverage factor of 15 to 30** depending on whether you consider the whole 5G-PPP phase one investment or an annualised figure (70M or 30M p.a.).

Conclusion on Leverage ratio for 2015

From the above exercise, even allowing for the assumptions and generalisations, we can confidently state that the European ICT sector is achieving, and most probably exceeding, the planned level of investment leverage expected in the 5G-PPP Contractual Arrangement. If we were to extend this exercise to all the industrial partners of the 5G-PPP – approximately half of the 166 beneficiaries – we would considerably improve on the leverage ratios achieved.

B2. Target SME participation under this initiative commensurate with an allocation of 20% of the total public funding

5G-Xhaul

We have in 5G-XHaul a total of three SMEs, which are Blu Wireless Technology Ltd (BWT), Airrays GmbH (AIR) and TES-Electronic Solutions GmbH (TES). Thus, ca. 25% of the public funding is allocated to SME participation.

The SME partners are tightly integrated into the 5G-XHaul research and development activities. From all three partners we have received valuable contributions which can be the basis for innovative products.

BWT is focused on mmWave point-to-point (P2P) and point-to-multi-point (P2MP) communications system developments. BWT is evaluating whether the MAC simulation work, partially funded by the project, can be commercialized into an off-line tool.

Partner AIR is involved in the investigation of Sub-6-GHz Antenna modules which support different functional splits. AIR continues to work on a demonstrator platform of a massive MIMO radio unit. The architecture of this platform is influenced by the analysis of different functional splits between BBU and RU, which has been reported in deliverable D2.1. The platform forms the basis for subsequent product development.

The main contribution of TES is on mmWave beamforming antenna and frontend module development and design. This is a valuable IP which can be developed further into a product.

All three partners will be able to use the developed IP for creating innovative products after the completion of the project.

COHERENT

COHERENT consortium has 4 SMEs from 3 countries, with the total allocation of 26% budget from the public funding. 4 SMEs have made significant contributions to the project. The partner 4GCelleX leads the standardization work of the project in 3GPP, ETSI BRAN and ECC PT1. In the first project year, 21 contributions have been submitted to 3GPP. The partner EICT leads the architecture work. The first design of COHERENT architecture has been delivered in Deliverable D2.2. The partner CommAgility provides the expertise of the LTE protocol stack development to the project and contributes to the demonstration work. The partner FairSpectrum leads the spectrum trial work in the project and actively participates in the spectrum related work in different regulation bodies.

SESAME

Apart from benefits offered to existing market players, the SESAME approach allows new stakeholders to dynamically enter the network value chain (e.g., Virtual Network Operators, Premises/Land Owners, etc.). In addition, 5G network will enable operators to build diverse sets of business models and services. The consortium of SESAME includes three high-tech SMEs (Virtual Open Systems, Athonet, and Orion) and Incites (also a SME) an experienced player in the techno-economics field, which contribute to the technical roadmap and objectives in SESAME and are involved in the key technological component development and innovation aspects of the project. The SMEs are well positioned to leverage the technological expertise and exploit them within the 5G market space either through the consortium or as individual entities.

Furthermore, the depth of the technical and industrial participation allows the SMEs to work closely with the large players to gain valuable expertise, and further, the contribution to open standards and open source communities provides the opportunity to the SMEs to have better exploitation plans and commercialization potential from the technologies developed in SESAME. As for the last SME, i.e., Incites, that is involved in the business modelling and market analysis aspects, SESAME provides to them visibility to collaborate with several actors offering specific consulting services on the 5G virtualised small cells market. Overall, 16 % of the budget is committed to the SMEs and they contribute a total of 15 % of human resources in the project.

Speed 5G

There are 2 SMEs in SPEED-5G out of 10 partners in total. One of the SMEs is the project coordinator (Sistelbanda). The allocated funding is approximately 18%. This means that SPEED-5G contributes to the SME participation nearly exactly as targeted.

Euro 5G

A survey was organized to receive feedback from SMEs on 5G PPP Call 1 involvement processes. The results of the analysis of the SMEs participation in the first 5G PPP call are as follows:

- Most SMEs who responded are involved in NetWorld2020 and in H2020. This is not necessarily surprising as the survey was disseminated to the NetWorld2020 members and by the EC.

- Most SMEs (i.e. 58%) were not aware of the online brokerage service. 78% of SMEs who responded, stated that the proposal(s) they contributed was/were not registered on the PPP brokerage platform. The majority of SMEs (i.e. 67%) who used the brokerage platform to find proposal(s) and consortia declared that was not successful. In addition to this, just 3% of SMEs were invited to participate in 5G PPP proposal(s) thanks to a posting on the platform. This needs to be corrected and improved for the upcoming calls.

- A majority of SMEs (i.e. 56%) do not clearly understand the role of the 5G Infrastructure Association. However, a majority of SME (i.e. 62%) does understand the role of the NetWorld2020 ETP.

- 46% of SMEs were invited in a proposal by one or more partners in the consortium.

- Most SMEs were aware of the 20% target set by the EC for SME participation in the 5G PPP.

- The feedback / perception of the level of participation of SMEs is lower than reality i.e. a majority of responses indicate that there is an average of 10% participation of SMEs, while the actual figure is 17%.

- The SMEs who were not involved in a 5G PPP proposal, faced the following obstacles:
  - No specific technical interest in the PPP in 2013/2014 (8%)
  - H2020 and PPP complexity (16%)
  - No awareness of proposals in the area of interest (24%)
  - No clear understanding about the way to apply or join proposal (28%)
  - Attempts to join proposal(s) under preparation but not positive outcomes (24%).

The European Commission provided statistics for the participation of SMEs in 5G PPP Call 1.

The results of the analysis are as follows:

- In the 5G PPP Call 1 selected projects, 19,4% of beneficiaries – compared with the overall number of beneficiaries per project - are SMEs (57 SMEs among 294 beneficiaries). The share in budget (i.e. EC funding) is 17%.
  It is worth noting that, among the 294 organisations involved, there are beneficiaries (SMEs and non-SMEs) that participate in more than one project.

If we count the organisations that participate in more than one project, we obtain that 119 different non-SMEs organisations and 47 different SMEs are involved in the 5G PPP Call 1 selected projects. As result, 166 different organisations are involved in the Call 1.
If we refine the figures taking into account these numbers, the percentage of SMEs participation increase from 19,4% to 28%.

- In the proposals submitted to the 5G PPP Call 1, the participation of SMEs was 18% share in number of proposers- compared with the overall number of participants per proposal (192 SMEs among 1094 proposers) and 16% share in budget (i.e. EC funding).
  It is worth noting that, among the 1094 proposers, there are organisations (SMEs and non-SMEs) that participate in more than one proposal.
  If we count the organisations that submitted more than one proposal, we obtain that 406 different non-SMEs organisations and 126 different SMEs participated in the 5G PPP Call 1 proposal phase. As result, 532 different organisations submitted one or more proposals.
  If we refine the figures taking into account these numbers, the percentage of SMEs participation increase from 18% to 24%.

B3. Reach a global market share for 5G equipment & services delivered by European headquartered ICT companies at, or above, the reported 2011 level of 43% global market share in communication

5G Crosshaul

Major system vendors (Ericsson, Nokia, NEC, Interdigital) and operators (Telefonica, Orange and TIM) are active partners of 5G-Crosshaul, seeing in this project a big opportunity to remove a serious bottleneck for the 5G success, that is the design of a transport network that can accommodate the required user capacity, density and service performance. This will actually open new business opportunities, revitalizing, reshaping and moving back to Europe the telecom and datacom market with new generation products and higher production volumes.

SDN and NFV are still seen as key enabling technologies for 5G networks. The development and proofs of concepts on the XFEs and the XCI will allow the large vendors – Ericsson, Nokia, and NEC – to leverage the results to increase their market share in global communication infrastructure.

SMEs of the project are focused on the development of applications for network management as well as deployment of new services such as media distribution, TV broadcasting, and ubiquitous cloud services, etc. Both equipment vendors (Ericsson, Nokia and NEC) and service providers (e.g. ATOS, VISONA) will leverage the results into their future products, in order to improve the product features and to increase their market share in communication infrastructure on 5G transport. The participation of several European Operators (Telefonica, Orange and Telecom Italia) guarantees all the best for a solid partnership in order to reach a better market share both in services and equipment delivery.

The Proof-of-Concepts produced by the project will allow developing novel concepts and evaluating them in close-to-real scenarios so as to realize competitive products for a future integrated 5G-Crosshaul network. The resulting competitive products will contribute to increase the market share of European companies on 5G-related technologies, particularly on 5G transport.

5G NORMA

- 5G NORMA industry partners contributed to IETF, IEEE, 3GPP, BBF, NGMN
- Overall, 22 standards contributions
- 5G NORMA actively contributed to the patent portfolio of involved partners
- 5G NORMA partners actively provided research results to their business groups in order to exploit project results

mmMagic

mmMAGIC is addressing a key technology area of 5G PPP’s holistic plan to drive innovative communication research targeting solutions that meet the needs for 2020 and beyond for massive increase in network capacity and user throughput.

The results and solutions developed in the project are expected to be implemented in future products and services of the vendors, preparing them to meet the 2020 and beyond requirements of the European and global market for telecommunication infrastructure equipment and devices, as well as the underlying semiconductor products and solutions, such as single-chip platforms and 5G modems.

Results from mmMAGIC will help operators to define an evolution strategy towards 5G and will help them avoid undertaking short term decisions that may preclude or impair the adoption of mm-wave based network solutions. It will also provide operator with realistic and quantified assessments of the maturity of the different technological.

The know-how gained in the collaborative research carried out in mmMAGIC in first year has boosted the technology readiness of European headquartered communication networks vendors in mmMAGIC (Ericsson, Alcatel-Lucent, Nokia) have together a very large global market share, and the innovation achieved within mmMAGIC is expected to give them a head-start in the race to 5G standards and future products operating in high frequency bands, thereby helping them to improve their future share of 5G infrastructure.

From mmMAGIC, the European operators (Orange, Telefonica) are obtaining realistic and quantified assessments of the maturity of the different technological components that will be required in order to have the whole system available, facilitating also the identification of cooperation opportunities with vendors to help speed up their 5G service deployment. In the longer term, our system will enable many of the foreseen 5G services and vertical applications which require large bandwidth, provide superior quality of experience for the end user (higher data rates, ubiquitous availability, very low delays), hence creating significantly new revenues streams for operators and service providers.

SUPERFLUIDITY

The SUPERFLUIDITY consortium includes industrial partners that make use of the collateral with their customers to demonstrate the feasibility of 5G use cases and solution paths to major technical challenges.

NOKIA is a one of the leading telecom vendor with expected huge impact on the 5G market. CloudBand products, developed by NOKIA IL, are in the heart of NOKIA portfolio, where all NOKIA's VNFs are designed and optimize to work with. SUPERFLUIDITY concepts are well within CloudBand path to 5G, and as such will have impact on all NOKIA's product.

ONAPP, as an SME, is fully adopting the approaches recommended in SUPERFLUIDITY for its next generation Cloud platforms. Work at the Emerging Technology Department has been focused on getting an optimal platform for RFBs and Virtual Network Functions. At the time of writing, the work is still at an early stage for being production ready but it is fully envisaged that OnApp will be offering some products by the end of the SUPERFLUIDITY project that offer RFB / VNF support.

Unified Streaming as an SME will adopt the approaches recommended in SUPERFLUIDITY for deploying its much used streaming software for its clients. In doing so it hopes to unleash the 5G enabled video streaming components that will run at the edge network near the RAN. Further, the scalability offered by cloud computing and virtualized network instances will benefit video streaming in virtualized infrastructure, which Unified Streaming expects to be a key paradigm for the future of video streaming. Unified Streaming hopes to be a key player in delivering this 5G service, working with its clients worldwide.

To increase the global market share, Telcaria plans to reduce costs by combining SDN and NFV into their products and services for software-based telecom operators and ICT solutions integration at request, and therefore increasing added value by service differentiation. One of the main areas in which Telcaria foresees exploitation potential of SUPERFLUIDITY is the advances in technologies for integrating heterogeneous wireless networks (up to RAN level) and in architectures to optimise the reuse of functionality across heterogeneous access technologies for 5G.

S1. Enabling advanced user controlled privacy

5G-ENSURE

Users' privacy is an aspect of great importance for the 5G systems, and therefore a primary topic for the project that has dedicated a whole task to it.
To address this KPI, the 5G-ENSURE has started with the identification of 8 use cases concerning the user privacy. These have been used to understand the required enhancements and to drive the specifications of 5 privacy enablers. Their focus is to give to users more privacy by providing, both at

the network and infrastructure level and at service or application level, enhanced security mechanisms like confidentiality to subscriber and device identities, untrackability of the user location, unlinkability between the user subscription information and the device identity and services for anonymization capabilities. Moreover, in order to give more users control to their privacy, privacy policy compliance verification mechanisms have been proposed at the application level and at device-side.
For example, a public key-based solution for the encryption of long terms identifiers is proposed, in order to totally avoid sending IMSIs in clear text as is now the case in 3G and 4G networks. Furthermore, solutions for IMSI pseudonymization are proposed both at the network side and device side. Privacy-Enhanced AAA is the topic of still another enabler, while enhanced privacy techniques for non 3GPP access to the 5G network are also proposed in a dedicated enabler.

Currently two of these enablers are under development and will be released in September.
Some actions have been starting to promote the privacy solutions in various standardizations bodies (3GPP, ETSI TC CYBER)

Therefore, at this stage we can assess that the 5G ENSURE project goes towards the fulfillment of the S1 KPI. The assessment will continue together with the development of the enablers and a final evaluation of the KPI fulfilment will be provided towards the end of the project's life.

CHARISMA

CHARISMA has been developing the basis for a virtualised security infrastructure with additional open access capability. Both the open access and multi-tenancy provisioning require appropriate tenant isolation and end-user privacy; in addition, the virtualisation of many of the network functions (VNFs), and also virtualised security functions (VSFs) allow a greater degree of control both by the network operator (MVNO, VNO) as well as network provider (NP) and/or service provider (SP), and also the actual end-user, to control their use of the network resources. Privacy and security can be provisioned as a network service, which can be virtualised (e.g., as VNF), for optimally efficient exploitation. Towards the achievement of control, management and orchestration (CMO) of the virtualised network resources and security functions, CHARISMA has implemented the following components: Service Policy Manager, Service Monitoring and Analytics, Open Access Manager, virtualised infrastructure (VI) security, VI monitoring, and VSFs. The CHARISMA v-security solution targets virtualised security in terms of automated security management and VSFs, with the former being realised with the help of Service Policy Manager and Service Monitoring & Analytics modules, with support from VI security and VI monitoring; whereas the latter are implemented as VNFs which can be automatically provisioned through an orchestrator and virtualised infrastructure manager (VIM) in an NFV environment. CHARISMA addresses the multi-tenancy using its Open Access Manager component, which not only solves virtual network operator (VNO) resource sharing, but also enables dynamic resource allocation and segmentation with the same NFs (Network Functions) used by end users and customer premises equipment (CPEs).

S2. Reduction of energy consumption per service up to 90% (as compared to 2010)

FANTASTIC 5G

Energy consumption is one of the main components of the operational costs (OPEX) for the operation of mobile networks. FANTASTIC-5G is working on different topics supporting the system to be more energy efficient and many components helping to improve P3 (see above) are applicable here as well, as reducing the energy consumption is one aspect of P3. We are specifically working on several fronts:

- increasing the spectral efficiency so that more users/traffic can be served with the same equipment. This includes techniques such as mMIMO, NOMA, inter-cell coordinated rank adaptation, network based interference coordination and a highly flexible radio resource management,
- enhancing the performance of cell edge users so that base stations can limit their transmitted power. This includes system level integration of mMIMO for increasing coverage, advanced modulations such as FQAM, network based interference coordination and intra- and inter-cell coordinated power boosting, muting, and combining,

- increasing the battery life of low end devices by several techniques, including efficient multiple access procedures and protocols based on one-stage or two-stage principles (see P3),
- reducing the energy consumption of the infrastructure by inter-cell coordination mechanisms of small cells to be activated/deactivated (to support high capacities when required and only when required), and by D2D mechanisms (to allow an energy efficient offloading of traffic),

Energy efficiency is one of the main KPIs that are to be assessed in system level simulations of Fantastic-5G project during the second year.

Flex5GWare

On chip frequency generation

From a system perspective the frequency generation should not be the limiting factor for the overall system energy KPI targets. The fabricated 19 GHz PLL consumes 13 mW, which is SotA performance with a VCO FOM of -185dBc/Hz.

Active SIW antennas with integrated power amplifiers for the 20-40 GHz band

Antenna design with high radiation efficiency co-integrated with an efficient PA design, together showing low parasitic losses. The standalone components show promising results. The 28 GHz Doherty PA combines excellent Psat, gain, and power added efficiency at both max and 6 dB back-off compared to reported SotA. The SIW antenna demonstrates a maximum radiation efficiency of 85%. To be implemented and measured during the second year of the project.

PAPR reduction and power amplifier pre-distortion

The energy efficiency improvement is achieved via the PAPR reduction technique and power amplifier digital predistortion. Algorithm development and simulations are ongoing for PAPR and DPD. However, at this stage it is difficult to assess the expected energy efficiency improvement as the testbed activity will start during year 2.

High-Speed Low Power LDPC Decoder

An optimized LDPC decoder architecture in terms of power consumption has been developed in order to improve energy efficiency performance with respect to SotA. Exact improvement results will be available during year 2.

HW/SW function split on SoC prototyping board for energy aware communications

The energy consumption will be measured for different configurations of the distribution of HW accelerated and SW functions across different network elements and for various values of the wireless communication parameters. Significant energy reduction is expected when changing across the different network configurations, but energy measurements will be available during year 2.

Reconfigurable and programmable radio platform (terminal side) and SW programming performed and injected by the network

The Dynamic Functional Recomposition module performs a cognitive dynamic HW/SW partitioning, providing the optimal decision on the HW or SW implementation of the eNodeB functions targeting energy consumption minimization. In this case, power consumption reduction of up to 34 mW per function can be achieved.

Flexible resource allocation in CRAN/vRAN platform

Energy savings achievable through the switching off of a small cell when it is unused.

METIS II

METIS-II addresses this KPI through development of 5G features such as lean control plane design, radio resource management exploiting dynamic activation/deactivation of network nodes or through work on enablers for RAN network slicing and native D2D support.

Using **lean control plane design** 5G network can minimize ‘always on’ transmissions allowing DTX cycles in regular RAN operations (Deliverable 6.1). Here METIS-II proposes several enhancements, such as system information distribution using self-contained transmissions or clean-slate design of reference and broadcast signals.

In 5G, the notion of radio resource can be extended to power consumption dimension. For this reason **radio resource management schemes** developed in (Deliverable 5.1), such as multi-cell coordination in ultra-dense network or dynamic traffic steering concept, exploit dynamic cell switch on/off mechanisms. With this way forward, certain QoS level of a radio transmission and reduction of the overall network power consumption can be obtained at the same time.

Radio resource management developed by METIS-II, e.g. multi-dimensional resource management for 5G and legacy air interfaces, as well as air interface variant agnostic resource abstraction model for virtualized RAN (Deliverable 5.1) provide enablers for efficient exploitation of **network slicing** in RAN domain. Through network slicing and underlying mechanisms such as virtualization, smaller network infrastructure is needed to cater for diverse requirements of different 5G services. This in return leads to the reduction of the overall power consumption of access infrastructure.

Finally, **native support of D2D** transmission allows energy efficient information exchange between users in proximity, offloading network elements directly involved in such transmissions in legacy systems. To create native support of D2D transmission, METIS-II account for D2D in design of holistic radio resource management (Deliverable 5.1) or initial access and mobility solutions (Deliverable 6.1).

It is worth to underline that network energy efficiency is one of the KPIs that is planned to be assessed in METIS-II 5G evaluation process (Deliverable 2.1).

S3. European availability of a competitive industrial offer for 5G systems and technologies

5Gex

How 5GEx addresses this? The 5GEx architecture will allow a much faster and agile service deployment across multiple domains, bootstrapping a new way of collaboration between operators regarding 5G infrastructure and NFV services. The 5G Exchange will enable operators to buy, sell, and integrate infrastructure and NFV services, enabling one-stop shopping for their customers.

First 9 months achievements? In these first 9 month, the 5GEX sandbox has been designed and deployed. This will enable the experimentation and validation of the devised mechanisms, architecture, and business model in practice. This sandbox is composed of the different operator’s labs and networks. Since one of the project goals is to open the sandbox to other participants outside the consortium, enabling a platform to allow testing of multi-domain services, the project has already started to analyze the mechanisms to open up the sandbox, towards making it easier (and ultimately, feasible) to do so.

COHERENT

COHERENT investigates new RAN architecture, spectrum management, network slicing and softwarization at RAN for flexible, scalable, cost efficient control and coordination solutions for 5G mobile networks. The COHERENT partners have been actively cooperating with other 5G PPP projects through 5G PPP working groups and adopting diverse technical inputs into the project work. Led by the partner 4GCelleX, the partners of COHERENT have actively participating in standardization and regulation work in 3GPP, ETSI and ECC. The COHERENT partners have submitted 21 joint contributions to 3GPP SA1, RAN1, RAN2 and RAN3, to prompt the COHERENT related work, including RAN architecture, 5G use cases, and other key findings from the project. The COHERENT partner has submitted joint contributions with the industry partners from other 5G PPP projects to 3GPP.

Flex5GWare

On chip frequency generation

28nm CMOS (fully depleted SOI) is selected as a low cost, high volume technology option to comply with industry baseline. Given the simulated and measured performance, it is clearly shown that CMOS is a feasible option and that the cost target (similar BOM as in 4G devices with superior performance) is well met.

Active SIW antennas with integrated power amplifiers for the 20-40 GHz band

Small dimensions of mm-wave wavelength allow for the realization of small footprint antennas. Antenna on low profile substrate and compact HW implementation due to co-design. Reduction of size/cost by 57 %.

Full duplex FBMC transceiver

Reuse of the same bandwidth for UL and DL. At least 50 % average data rate increase is expected from the technology using the same spectrum.

Flexible resource allocation in CRAN/vRAN platform

Increase of the user (and also cell) throughput using the same available spectrum thanks to the application of the CoMP technique.

Multi-Chain MIMO Transmitter

Increase the number of available transmitters for a more accurate spatial spectrum reuse, which enhances the user data rate using the same spectrum. In addition, the multi-chain MIMO transmitter facilitates massive-MIMO system, which implies that spatial multiplexing can be exploited supporting an increased number of users using the same spectrum.

Virtuwind

Europe is still leader in green renewable energy. To maintain the lead position, the wind energy specifically should be at the same cost level as compared to conventional energy resources. VirtuWind has done Techno-Economic analysis of typical architectures in wind parks and envisioned savings due to application of SDN and NFV technologies in communication networks of wind parks. The KPIs were identified to check the savings potential. The architecture developed so far in VirtuWind project is able to support industrial-grade QoS. The next step in year 2 will be to implement such an architecture which will eventually bring savings in the industrial use case such a wind parks.

VirtuWind showed its first project demo at the Mobile World Congress 2016 which fetched good attention from the EU policy makers, international research and commercial entities. VirtuWind is also planning its second demo at the 5G Global event in Rome in November 2016.

In addition VirtuWind conducted a workshop on exploitation to elaborate how the developed technology can be used in adjacent businesses. Therefore, the draft of the business model given in the proposal was used as blueprint and is going to be extended towards other domains in ongoing work (using the business model canvas method).

SUPERFLUIDITY

The SUPERFLUIDITY consortium includes key actors at different standards defining organisations (SDOs) (i.e. ETSI NFV ISG, ETSI MEC ISG) and initiatives (i.e. OSM) that are currently shaping the 5G network.

BT is one of the companies that created the original work at ETSI and created the concept of network virtualisation, and we continue to play a leading role. Where the SUPERFLUIDITY results have implications for standards, BT will discuss this within the project, as a form of socialisation, and then help bring the results to the relevant standards bodies and support their progress. BT believes that standardisation is key in the telecoms field, and certainly in the NFV space, in order to ensure interoperability and allow us to source components from different / multiple vendors.

Telefónica and BT have leadership roles at ETSI NFV ISG; BT is Rapporteur for the End-to-end Processes Work Item and plays a key role in the ISG’s initiative to bring together the Information Models of many SDOs and industry groups. In addition, BT is involved in other bodies such as: Next Generation Mobile Networks Alliance, which is a service provider alliance that puts in joint requirements into SDOs; OSM (Open Source MANO – founding member, vice chair, and chair of the End User Advisory Group); and the TMF’s ZOOM project (Zero-touch Orchestration, Operations and Management).

Telefonica is chairing the TSC of the ETSI NFV ISG. With regards to OSM, Telefónica is chairing the board. In addition, Telefónica is a member of the User Advisory Board of OpenDaylight. Currently there are a large number of open source projects relevant to NFV, some of which are competitors – at the moment we believe this is reasonable, as it is encouraging innovation and filling gaps in proprietary implementations.

CloudBand of NOKIA IL is developing an NFV platform composed of Infrastructure Software, Application Management, and Cloud Network Director. Enhancing CloudBand platform with SUPERFLUIDITY concepts and particularly with support for RFBs is part of CloudBand path to 5G. Extending Cloudband management and orchestration products to the MEC domain is yet another goal in CloudBand roadmap. This will allow CloudBand to bring a leading NFV platform ready for 5G application demand. In addition to Cloudband product goals, NOKIA IL is an active contributor to OpenStack, leveraging it as a leading virtual infrastructure manager for NFV deployments, by that fostering the whole NFV industry. In OpenStack we are working with the community to bridge the gaps between OpenStack and the ETSI NFV community. For example, we contributed to Heat to allow better support for NFV deployment. Furthermore, CloudBand initiated a new OpenStack project, named Vitrage, which was recently approved under the OpenStack tent, developing a platform for monitoring correlation and more specifically, root cause analysis. Vitrage is expected to provides triggers and inputs for fast scale and migration operation that are facilitated by the SUPERFLUIDITY architecture. In addition to OpenStack, and OPNFV, NOKIA IL also operates within TOSCA to define the VNF and NS descriptors.

ONAPP is an SME that provides an IaaS solution to 3,000+ customers. As the leading public cloud provider in terms of number of licensed customers (1 in 3), ONAPP offers the possibility of exposing new 5G services and solutions to a large customer base. Particularly relevant from SUPERFLUIDITY are the innovations into managing large numbers of small, virtualised work environments that can be tied together to form high performance services. Being able to provide fluid resources across the datacentre and cloud access points through its ONAPP Cloud and ONAPP CDN platforms are the core business areas of ONAPP and as such any improvements in this space, as proposed by SUPERFLUIDITY will be advantageous for ONAPP's customers and the respective end-users. ONAPP has an exploitation plan that has been detailed, but aside from those specific exploitation activities, ONAPP will benefit from providing the latest 5G systems and technologies as a market leader with continued innovation. Many of ONAPP's customers that are based in Europe have multiple European data centres and so will benefit from the technologies that are being promoted by SUPERFLUIDITY.

Unified Streaming is an SME software company that provides OTT (over the top) streaming software to over 200+ customers including large companies in the media industry such as BBC iplayer, RTL, etc. Beyond that, its software is also used outside of Europe such as HBO (USA) and Foxtel (Australia), Globo.com (Australia). The Unified Origin is a flagship product that provides DRM, Late Trans-muxing, Streaming manifest generation that is particularly well suited towards offering in a 5G environment. Unified streaming will be an exemplary super user of the SUPERFLUIDITY deploying its software in edge cloud, virtualized environment, as a key offering an exemplary 5G environment that will bear many of the concepts from SUPERFLUIDITY.

SONATA

SONATA aims at boosting the adoption of software networks in European industry. This is achieved not only by technical achievements, e.g. the integration of SONATA SDK with service orchestrator but also via the definition of a roadmap, highlighting business opportunities arising from the adoption of extended NFV technologies proposed by SONATA.

The NFV MANO field is crowding quickly, and over 20 comparable solutions are available in the market. Each vendor has its strategy to integrate a software network orchestrator in its solution. The SONATA enhanced MANO framework documented that was designed and developed during this first year provides as solid base to support the required flexibility. The SONATA architecture is in line with the current ETSI NFV standards, but proposes enhancements wherever needed. The project is also using common industry standards, with solutions based on TOSCA. Several are the reasons of why following common industry standards is a good practice but, for SONATA, the most important is the possibility of influencing those standards.

The SONATA Service Platform (SP) has been delivered to the public in a GitHub repository under permissive, open source Apache v2.0 license in July 2016 - https://github.com/sonata-nfv. A continuous integration and continuous delivery (CI/CD) methodology was elaborated, as well as the tools and processes used to drive the software development in a DevOps approach that is at the very core of the SONATA development cycle. The highly flexible micro-service based project structure, were all different service components run inside Docker containers, enabled great progress amongst individual SDK or SP components. The project website is also a point of reference for the code availability and all related documentation: www.sonata-nfv.eu

One of the main pillars in which SONATA exploitation plan is founded on is its open source strategy. There are many reasons that support this strategy. Many factors and interests influenced this decision and the two key ones were: uptake maximization of SONATA solution and also easy integration into larger solutions. SONATA project is committed to maintain a public roadmap during the entire development process.

As mentioned the first public release of SONATA has been delivered in the summer of 2016. Then a qualified version will be delivered in M19. In moth 25, the final release of the SONATA platform will be public. However, SONATA recognizes that simply hosting an open source code on a public repository is not enough to pursue a successful exploitation strategy. To create the widest impact possible with the open source project, the consortium have been actively promoting collaboration and trying to influence the main key open source communities. SONATA is already collaborating with several Open Source communities. Among them, OpenStack and Open Source MANO (OSM) deserve special mention.

S4. Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications

FANTASTIC 5G

FANTASTIC-5G targets to enable the system to support the various anticipated services (such as eMBB services alike U-HDTV streaming and M2M applications) being part of the 5G ecosystem in a parallel manner with highest efficiency. The project targets to avoid the need of using dedicated RANs for each single service opening up the opportunity of making use of synergies and reducing overall costs and energy consumption. Target is to design a single multi-service air interface being able to be flexibly (on resource level) configured according to the respective connection (i.e. what service the connection is to convey and the respective link characteristics). With making this vision a reality new (and classical) players of mobile communications are able to implement their service into the communication system with being able to make use of economy of scale (both in terms of number of devices and number of supported use cases) and to make use of the high degree of coverage 5G is about to support.

Flex5GWare

In very broad terms, in this first year, Flex5Gware has detailed the specification of the interfaces, modules, and services, to support a flexible and reconfigurable SW-driven operation for 5G Radio Access Technologies (RATs) taking into account sensor-retrieved context information. This specification builds on the functionality provided by digital HW, which depends on the corresponding technology considered, and extends it by specifying HW abstractions and building blocks to enable the orchestration of services and the development of new ones, supporting, among others, real-time re-configuration of the PHY parameters of RATs, Medium Access Control (MAC) protocol extensions, and distributed optimization schemes.

In particular, among other definitions, the specification described above includes a sensor API, which can enable sensor-based M2M applications. This is so because a generic back-end has been developed in order to dynamically select and configure the more appropriate communication means and communication protocols, so as to deal with the given requirements based on, e.g., M2M/IoT application goals and current context (e.g., latency, throughput and energy efficiency for the case of sensor networks).

METIS II

METIS-II stimulate new services of high societal value through providing overall 5G RAN design that supports different (and sometimes contradictive) transmission requirements and through development of individual technology components directly addressing needs of new services identified in [3].

Overall 5G RAN design presented in (Deliverable 2.2) is highly scalable (in terms of throughput, operating frequency, number of devices or connections), supports network slicing and software configurability, which makes this concept flexible, future proof and ready for accommodation of new services whose requirements are not precisely defined yet. Proposed overall 5G RAN design introduces new 5G air interface through tight integration with LTE-A evolution (Deliverable 6.1) that allows economically justified introduction of services, with requirements different than originally posed to 4G. Same holds for METIS-II activities on **spectrum** that touches upon coexistence of legacy services and 5G, as well as feasibility analysis for propagation on frequencies foreseen for 5G (Deliverable 3.1). 5G RAN design proposed by METIS-II is built on top of METIS-II concepts for **harmonized air interface designs** (Deliverable 4.1), which take into account flexible numerology and different frame structures needed for varying KPIs of future services (low delays, high reliability or device energy efficiency, etc.). Similarly, **overarching resource management functionality framework** (Deliverable 5.1) allows smart distribution of available radio resources in optimized manner to meet above-mentioned KPIs. Finally, partners involved in METIS-II aim at providing **techno-economic feasibility evaluation** of the 5G scenarios and test cases against the technical solutions developed in the project, to perform qualitative and quantitative assessment. This is especially relevant from the perspective of novel 5G scenarios related to ultra-reliable MTC or massive MTC. First findings from these activities will be available in deliverable D1.2 planned for 1Q2017.

On top of above mentioned activities that try to provide a holistic solution for multiplicity of services foreseen for 5G, METIS-II develops also **individual technical solutions** tailored toward specific service types. Extension of RRC state machine to RRC connected inactive (e.g. for nomadic MTC devices), D2D for mMTC (allowing ubiquitous and energy efficient MTC connectivity) or context management (for tailored and user optimized content handling) are just a few examples to mention.

mmMagic

- Multi-frequency measurements with omnidirectional and directional antennas for different environments, as well as dedicated measurements on human blockage, wall diffuse scattering, traffic impact and channel sounder validation, have been carried out, and have resulted in mmMAGIC initial channel model The channel model is made available to end-users as an open source simulator, for technology community for evaluation and design of 5G mm-wave systems.
- Extensive and in-depth research and design has been carried out in the air interface topics at mm-wave frequencies, including waveforms, channel codes, novel reliable and efficient HARQ methods, an frame structure and numerology design has been looked into considering KPIs such as throughput, robustness, latency and mobility support, as well as design principles targeting at different use cases and requirements. Four subframe structures, with the possibility of free configuration to enable flexible time division multiplexing, have been proposed, in addition to one specific frame structure to enable efficient backhauling operation, by allowing a specific resource for backhaul uplink and downlink, and access downlink.
- mmMAGIC is contributing to standardization and regulation of the technologies used for such future services (14 contributions in 3GPP acknowledging or citing mmMAGIC and two contributions to ITU-R SG3). The development of globally accepted standards and regulation will ensure interoperability and economies of scale with affordable cost for system deployment and end users.
- mmMAGIC technologies, therefore, are strongly contributing to global 5G standards to fulfil very high data rates (10 GBps) and 1000X capacity increase requirements, resulting in enabling and simulating new 5G services such as U-HDTV and Virtual Reality.
- Further work is in progress on examining techno-economic viability of offering such services to 5G users, and this will be reported in second year.

S5. Establishment and availability of 5G skills development curricula (in partnership with the EIT)

5G NORMA

All 5G NORMA's academic partners have been involved in various activities, e.g.

- 5G NORMA summer school has been organized in London, 20-22 June 2016, at King's College
- Project key technologies and results have been included in M.Sc. programmes
- Ph.D. students are involved in the project and offer M.Sc. theses in the scope of NORMA

In detail,

- University Carlos III de Madrid has leveraged 5G NORMA in order to improve its research and academic standing. Some key 5G technologies addressed in 5G NORMA, such as network slicing, orchestration and multi-tenancy, have been inserted in the program of the Master of Telematics Engineering (courses on "Wireless Communications" and "Mobile Networks"). Moreover, three PhD theses and a number of M.Sc theses are being conducted. This will contribute to the formation of engineers with a strong background on such key future technologies. Moreover, UC3M has leveraged 5GNORMA to strengthen its leadership in the scientific community, with a special focus on multi-tenancy, and to peform some direct industrial collaborations.
- The Technical University of Kaiserslautern strives to use 5G NORMA, its results and key technologies to elevate its academic standing. Lectures of our Masters' program have used the results of 5G NORMA to enrich their educational value, bringing at the edge research and technology to the current generation of students. 5G NORMA topics like "QoE in Mobile Networks" and "5G mm-wave Technologies" have also been addressed in academic seminars that are part of our programs. The research of multiple PhD students in the TU Kaiserslautern have being influenced by the key technologies and results from 5G NORMA. Some topics being explored are mobility of virtual network functions, routing augmented with QoE, inter RAT multi-connectivity, and congestion reduction in mMTC.

5G XHaul

Academic partners, active in the consortium, are University of Thessaly, University of Bristol, and University of Dresden. All three academic partners have included aspects of 5G research in their curricula on wireless and optical communications. Furthermore, the Research Institutes IHP and i2CAT use their cooperation and strong links to Humboldt-University Berlin (HU-B) and Universitat Politècnica de Catalunya (UPC), respectively, for introducing 5G-research in the curricula of those universities. At the Computer Science Department of HUB, some concepts on mmWave communications, beamforming and localization were introduced in the M.Sc. course "Wireless Broadband Communications Systems". At UPC, some of the architectural concepts discussed within 5G-XHaul where introduced in the subject "Mobilitat, Xaxres i Serveis" ("Mobility Networks and Services"), (MXS), a 3rd course subject in the degree of Telematics Engineering offered in the EETAC of the UPC.

Furthermore, our Partner TU-Dresden (TUD) organized a summer school "5G Lab Germany Summer School on Wireless & Networks" from 16.-23.09.2015 with strong focus on 5G Mobile Communications.

NetWorld2020

On April 28, 2016, The 5G Infrastructure Association requested the NetWorld2020 Members active in the Academic and Research domains to provide information on the 5G skills development curricula they established and/or that they plan to establish. We detail below the feedback we have received.

University of Florence, Italy

Department of Information Engineering

http://www.dinfo.unifi.it/changelang-eng.html

Two courses related to 5G are offered:

Basic Telecommunication networks (undergraduate course): it includes 2 CFU (Crediti Formativi Universitari)[6] on sensor networks

Wireless communications (graduate curse): it includes 2 CFU on 5G architecture and protocols

University of Padova, Italy

Department of Information Engineering, Telecommunications engineering curriculum

http://www.dei.unipd.it/en/

http://en.didattica.unipd.it/offerta/2015/IN/IN0524/2008

The following 5G-related courses are offered:

INTERNET OF THINGS AND SMART CITIES

ADVANCED COMMUNICATION TECHNIQUES

NETWORK ANALYSIS AND SIMULATION

WIRELESS SYSTEMS AND NETWORKS

Aalto University, Finland

School of Electrical Engineering, Department of Communications and Networking

http://comnet.aalto.fi/en/

The Department of Communications and Networking is a key partner in the Finnish national 5G research program and its project TAKE-5. Partners include Nokia, Ericsson and Huawei.
It also participates in multiple 5G related EU-projects.

The following 5G related courses are offered:

1. Trends in Communications Engineering Research
2. Radio Resource and Spectrum Management
3. Mobile Communication Systems
4. Routing and SDN

University Carlos III of Madrid, Spain

Department of Telematic Engineering

http://www.it.uc3m.es/vi/

A specific degree in NFV/SDN, very oriented to the control plane of 5G networks is offered:

MASTER AND SPECIALIST IN NFV AND SDN

[6] Useful references:

http://ec.europa.eu/education/ects/ects_en.htm
https://en.wikipedia.org/wiki/European_Credit_Transfer_and_Accumulation_System

Tampere University of Technology, Finland

Department of Electronics and Communications Engineering

http://www.tut.fi/en/home

The following 5G related courses are offered:

1. 5G Mobile Communications
2. Radio Architectures and Signal Processing - Special emphasis in the course is on the RF performance and transceiver signal processing requirements and solutions for LTE/LTE-Advanced and 5G mobile communication network devices.
3. Multicarrier and Multiantenna Techniques

Chalmers University of Technology, Gothenburg - Sweden

Department of Signals and Systems

http://www.chalmers.se/en/departments/s2/Pages/default.aspx

The University continuously integrates new knowledge gained by its research and participation in EU projects into their curricula and courses.

In relation to 5G, it has participated in the EU FP7 METIS project and is currently participating in the H2020 5GPPP mmMAGIC project.

The knowledge from these projects has been integrated in the current courses of the Master Program on Communication Engineering. The course Wireless Networks has a special focus on 5G, including lectures on 5G research and invitation of several prominent researchers from industry within the 5G community in Sweden and Europe.

Institut Mines-Télécom (Telecom Bretagne, Telecom ParisTech, Telecom SudParis)
https://www.mines-telecom.fr/en/

The offered postgraduate education programmes related to 5G are:

Telecom Bretagne

1. Master of Science (MSc) in Design and Engineering of Communication Networks (DECN)
2. Master of Science (MSc) in Telecommunication Systems Engineering (TSE)
3. PhD programmes in Signals and Communications, Electronic Engineering, Networks engineering. Additional information available at: https://www.telecom-bretagne.eu/studies/phd/

Telecom SudParis

1. Master in Communication networks & services

Telecom ParisTech

1. Master in Mobile Communications

2. Master in Advanced communication networks (ACN) (Jointly operated by Telecom-ParisTech and Ecole Polytechnique, in collaboration with Université Paris Sud within the Université Paris-Saclay

3. Master in Telecommunication Architecture Services Oriented
Information and Communication Science and technology Doctoral School (ED STIC) - Université Paris Saclay

A number of courses for professionals is also offered: http://www.telecom-evolution.fr/fr/domaines/reseaux-dinfrastructure-operateur#3322

6 Conclusions

From the self-assessment exercise conducted by 5G PPP Phase 1 projects, we can derive the following summary table:

KPI	Topics	Results
P1. Providing 1000 times higher wireless area capacity	more cells (smaller and heterogeneous)	developments of enablers have started but quantification and techno economics aspects are missing
	better spectral efficiency	developments of enablers have started but quantification is missing
	new spectrum	mmWave is well addressed, new spectrum management schemes also
	functions to reduce / aggregate traffic	first results are there in the fronthaul segment with a reduction of x200
P2. Reducing service creation from 90 hours to 90 minutes	Rule based automation of processes	developments of enablers have started in all domains (assurance and fulfillment), a sandbox is available but real life testing need to take place
	Machine learning based autonomics	developments of the framework is done, test on some use cases need to be conducted
	Replacement of physical deployments by VNFs placement	developments of enablers on VNFs placement are numerous but quantification of the impact is to be done
P3. Deployments to connect over 7 trillion wireless devices	Energy efficiency for low battery devices	developments of enablers on function placement and cell edge improvements have started but quantification is not envisaged
	More users per spatial area	developments of enablers have started in the domain of interference mitigation and efficient multiple access have started but quantification is to be done
	Optimisation for different requirements	enhanced waveforms and flexible frame design have been developed to fit the needs of mMTC and uMTC
P4. Creating a secure, reliable and dependable internet	Development of use cases	has been done by the relevant projects and enable to define a testbed for further evaluation
	Development of enablers	enablers including machine learning techniques have been developed but not yet tested in terms of impact on use cases
	Architecture "security by design"	has been initiated but need further work within the Security WG
B1. Leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems in the order of 5 to 10 times		First estimations indicate a leverage factor between 10 and 30 well above the target which is 5 whereas we can foresee further acceleration on private investment on 5G from European players
B2. Target SME participation under this initiative commensurate with an allocation of 20% of the total public funding		Within Phase 1 projects 19,4% of beneficiaries are SMEs 17% of funding is dedicated to SMEs
B3. Reach a global market share for 5G equipment & services delivered by European headquartered ICT companies at, or above, the		Phase 1 projects have delivered 96 contributions to 5G oriented standardisation bodies putting Europe at the forefront of contributions to

reported 2011 level of 43% global market share in communication	define the worldwide 5G standard.
S1. Enabling advanced user controlled privacy	We can estimate that a share of 2 out of 3 of the identified privacy enablers for Phase 1 have been developed at this stage.
S2. Reduction of energy consumption per service up to 90% (as compared to 2010)	This KPI is very difficult to monitor and there is no agreed measurement tools between Phase 1 projects for the moment. However, we already have some good results on the antenna hardware side with a mawimum radiation efficiency of 85% already achieved.
S3. European availability of a competitive industrial offer for 5G systems and technologies	Phase 1 projects have been the showcase of European industry at MWC 2016 and they will deliver an even higher dissemination impact at next Global 5G Event in Rome with more than 13 booths. Several sandboxs have been developed and some have been opened to third parties so that our international counterparts and vertical industries can start experimenting of future 5G services.
S4. Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications	Lots of projects are working on the possibility to have several services supported by a single infrastructure which will bring huge economies of scale. Beyond that, Virtuwind has initiated a techno economics model to estimate the savings brought by 5G in the introduction of renewables in the smart grid. Quantification results will follow and should be completed by other vertical industries.
S5. Establishment and availability of 5G skills development curricula (in partnership with the EIT)	Masters and courses have already been settled on 5G at least: 7 in Finland 7 in France 6 in Italy 1 in Spain 1 in Sweden

Table 5: Executive summary of progress on 5G PPP KPIs

So the programme is progressing on all KPIs with a good pace after one year of activities. We are even exceeding by far our target on the leveraging factor for private investments.

We have a clear path to measure the progress on nearly all KPIs in the second year of Phase 1 projects through test cases and / or testbeds except for the energy consumption where the TB has already kick started some action which need to be strengthened in the second year of the programme.

Some of the KPIs (like B3, S3 and S4) need to be replaced by proxies at this stage because 5G is not mature enough to measure them directly. These proxies like the contribution to standardization bodies and the dissemination of projects through demos at world events are however very encouraging for the European industry.

One of the concrete next steps will be to communicate as soon as we get more quantitative measures on performance KPIs in order to compete with our international counterparts. Indeed, China for example has already communicated on throughput or latency figures in conferences and 5G and we need to demonstrate the ability of Europe to deliver the enablers which will have the most impact on 5G services.

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