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5G-MoNArch
Project No. 761445

5G Mobile Network Architecture

for diverse services, use cases, and applications in 5G and beyond

Deliverable 7.2

Final report on dissemination, standards, and exploitation plan

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Abstract: This document provides the final reporting of the various dissemination activities conducted by 5G-MoNArch within the project runtime together with the initiatives towards the standards. The report furthermore provides the exploitation plans of the project partner organisations summarising the expected further use of the project results. Finally, the report provides a technical summary of the 5G-MoNArch contributions to the IMT-2020 evaluation conducted within 5G-PPP.

Keywords: dissemination, standardisation, exploitation plan, public relations, 5G-PPP, 3GPP, ETSI publications, workshops, events, IMT-2020

Executive Summary

This deliverable is the final report on all 5G-MoNArch Work Package 7 activities on dissemination, standardisation and exploitation.

In the first part of this document the activities regarding the dissemination of project results to the general public and the scientific and industrial communities are described. This includes a description of the Public Relations framework targeting the general public, consisting of the project website and the postings in social media as well as the presence of the project at major events such as the Mobile World Congress, but in particular the two dissemination two events of the project, organised at the testbed locations in Turin and Hamburg in May and June 2019. With respect to the dissemination towards the scientific and industrial communities, a detailed overview about publications made at conferences, in journals and magazines, presentations of project members, e.g., through invited talks or panels, and workshops organised by the project is provided. This includes the presence of the project at the EuCNC conferences.

This first part of the document furthermore lists the contributions to standards bodies and industry fora, informs about the patent applications, and describes the numerous activities of the project within the 5G-PPP framework, including the contributions to boards and working groups, and the cooperation with other research projects. For all these dissemination-related activities, an impact summary on each category is provided at the end of each chapter.

Finally, this first part gives the exploitation plans as foreseen by the project partners, highlighting the already achieved and the planned impact of the project's activities within the individual partner organisations.

In the second part of this document, a summary of the results on the activities conducted within 5G-MoNArch on the European contributions to the ITU-R IMT-2020 New Radio evaluation is provided, focusing on the simulator setup and calibration as well as on the achieved simulation results. These activities, coordinated through the 5G-PPP IMT-2020 evaluation working group, were hosted by Work Package 7 despite their technical characteristic.

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INTRODUCTION

This deliverable provides the report on the dissemination, including standardisation impact, and exploitation activities of 5G-MoNArch project at the end of the two years of activity.

In particular emphasised are the activities being part of the project's Public Relations framework, implemented through numerous information channels (website, social media) towards the general public and the scientific and industrial communities, contributions to several large events such as Mobile World Congress, and the specific project dissemination events organised to present the two testbeds about Touristic City and Smart Sea Port.

A second main part of the document is on the dissemination of the project's results towards the scientific community, including a complete list of all publications to conferences, journals and magazines as well as talks and presentations given by project members at various events. This part includes furthermore a summary reporting of the contributions of 5G-MoNArch to the EuCNC conferences, and the workshops and special sessions that have been organised by 5G-MoNArch in order to leverage discussions within the scientific community on core technical aspects of the project work. Being part of the 5th Generation Public Private Partnership (5G-PPP), 5G-MoNArch has been strongly involved into the cooperative 5G-PPP work in boards and Working Groups (WGs) and had several direct cooperative efforts with other research project, which are reported.

Third, this report provides an overview about the strong impact generated by the project to standards bodies and industry fora, highlighted in particular through the more than one hundred contributions to the 3rd Generation Partnership Project (3GPP) and European Telecommunication Standards Institute (ETSI) standardisation meetings during the project runtime. A second footprint indicating the high relevance and timeliness of the research work is the number of 17 patent applications generated by the project partners on the investigated topics, which are reported as well.

Finally, this document provides a technical summary of the work conducted within the project on the second-stage evaluation of the International Mobile Telecommunications standard 2020 (IMT-2020) – 5G New Radio (NR), which is coordinated by the International Telecommunications Union, Radiocommunications Sector (ITU-R). 5G-MoNArch contributed to the simulation-based evaluation of IMT-2020 concepts as member of the 5G-PPP WG, which executes the corresponding European efforts on behalf of the 5G Infrastructure Association (5G-IA).

Structure of the document

The deliverable is separated into two parts.

Part 1 of this document is dedicated to the dissemination activities towards the general public and the scientific and industrial communities, which include the activities dedicated to impact standardisation, related to the possible introduction of future products and services, and to the exploitation activities performed by the partners as a result of their participation to the project.

Part 2 of this document, consisting of Chapter 9, provides a summary of the activities and technical results conducted for the IMT-2020 evaluation, which were hosted under Work Package 7 of 5G-MoNArch.

PART 1: DISSEMINATION, STANDARDISATION AND EXPLOITATION

This first part of the document provides an overview and a summary of the activities conducted within Work Package 7 (WP7) of 5G-MoNArch with respect to disseminating its research and development results, the contributions to standardisation bodies, and finally the exploitation plans of each partner organisation.

- Chapter 1 is about the dissemination to the general public, as a way to set up a Public Relations framework for the whole project.
- Chapter 2 follows with the information about the impact towards standardisation bodies, the patent applications driven by project partners, and connections to industrial fora.
- Chapter 3 provides a summary of the cooperation with other European research projects and the relations with the 5G-PPP.
- Chapter 4 delves into the scientific dissemination achievements.
- Chapter 5 is a report on the two large dissemination events that took place in Turin and in Hamburg focussing on the public dissemination of the project's two testbeds.
- Chapter 6 provides the details on the exploitation plans of the overall project and the particular activities conducted by the 5G-MoNArch partner organisation.
- Chapter 7 a summarises and concludes on the dissemination, standardisation and exploitation activities of 5G-MoNArch.

In order to conduct the different dissemination activities envisaged within 5G-MoNArch, the following committees were created under the umbrella of WP7 in order to supervise the dissemination of the project at various fronts:

- *General dissemination team*: This team was composed by the WP7 leader, the Project Coordinator, the Innovation Manager and the all the responsible persons for Public Relations (PR) in the respective companies, and took care of the non-technical dissemination, including the publication of press releases, general videos, presence in mass media, etc.
- *Standardisation team*: This team was composed by the WP7 leader, the Innovation Manager, the Technical Manager and one standardisation responsible for each large company and took care of supervising the standardisation activities and identifying suitable bodies and groups where to 5G-MoNArch's contributions could be useful.
- *Dissemination and innovation team*: This team was composed by the WP7 leader, the Innovation Manager, the Technical Manager and one innovation responsible from key partners. The goal of this team was to identify proper dissemination measures and protection of Intellectual Property Rights (IPR) in order to promote the commercial exploitation of the concepts developed in the project.
- *Verticals and stakeholders*: In order to reach the different stakeholders targeted by the developed 5G-MoNArch technologies, with special focus on verticals, the following team was appointed: The Innovation Manager, the Technical Project Manager, the responsible project member for the techno-economic analysis (WP6) and one representative for each of the two verticals involved in 5G-MoNArch.

List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
5G	5th Generation mobile wireless communication system
5G-IA	5G Infrastructure Association
5G-MoNArch	5G Mobile Network Architecture
5G-PPP	5G Public Private Partnership
AI	Artificial Intelligence
APN	Access Point Name
AR	Augmented Reality
CN	Core Network
CR	Change Request
CSA	Coordination and Support Action
DL	Downlink
DoW	Description of Work
E2E	End-to-End
eMBB	enhanced Mobile Broadband
ENI	Experiential Network Intelligence
ETSI	European Telecommunications Standards Institute
FR	Frequency Range
GDPR	General Data Protection Regulation
GLOMO	Global Mobile
GoB	Grid of Beam
GSM	Global System for Mobile Communications
GSMA	GSM Association
GST	Generic Slice Template
IMS	IP Multimedia Subsystem
IMT-2020	International Mobile Telecommunications standard 2020
InH	Indoor Hotspot
IoT	Internet of Things
IPR	Intellectual Property Rights
ITU-R	International Telecommunications Union – Radiocommunications Sector
KPI	Key Performance Indicator
KTA	Key Technology Area
LTE	Long Term Evolution
MDAS	Management data analytics service
ML	Machine Learning
mMTC	Massive Machine Type Communication
MWC	Mobile World Congress
NEST	Network Slicing Taskforce
NGMN	Next Generation Mobile Networks
NR	New Radio
NRM	Network Resource Model
PR	Public Relationship
RAN	Radio Access Network
RRM	Radio Resource Management
SB	Steering Board
SDN	Software Defined Networking
SDK	Suite Developer Toolkit

SDO	Standard Development Organisation
SI	Study Item
SLS	System Level Simulator/Simulations
SMF	Session Management Function
SON	Self-organising networks
TB	Technical Board
TRxPs	Transmission Reception Points
TSG	Technical Specification Group
TXRUs	Transceiver Units
RMa	Rural
UL	Uplink
Uma	Dense Urban
UMTS	Universal Mobile Telecommunications System
UPF	User Plane Function
V2X	Vehicular to Everything
WAN	Wide Area Network
WG	Working Group
WPx	Work Package number x [1..7]
ZSM	Zero touch network and Service Management

1 Dissemination to the general public

The 5G-MoNArch project focuses on disseminating its results and achievements to three main groups: the general public; the scientific community; and institutions such as Standard Development Organisations (SDOs) like the 3rd Generation Partnership Project (3GPP), research and industrial fora, and the 5th Generation Public Private Partnership (5G-PPP). In this section, we will list all the channels used to reach the general public, provide updates about what was written in [5GM-D71], as well as summarised the impact they had in the lifetime of the project.

This set of dissemination activities has been particularly managed during the whole project period and especially in the second year as means to create a clear public relations framework, in order to distribute in the best possible way, the project results and its public dissemination activities to the general public. Furthermore, the project has organised two events to present to the general public the results of the two testbeds (described in [5GM-D52]) in Turin and in Hamburg, as it is reported in Chapter 5.

1.1 Public website

The central contact point with the general public is the public website (https://5g-monarch.eu/). It is built using WordPress, and it acts as the main repository for dissemination information – including all public deliverables – and news about the project. Other social media channels always referred to the website.

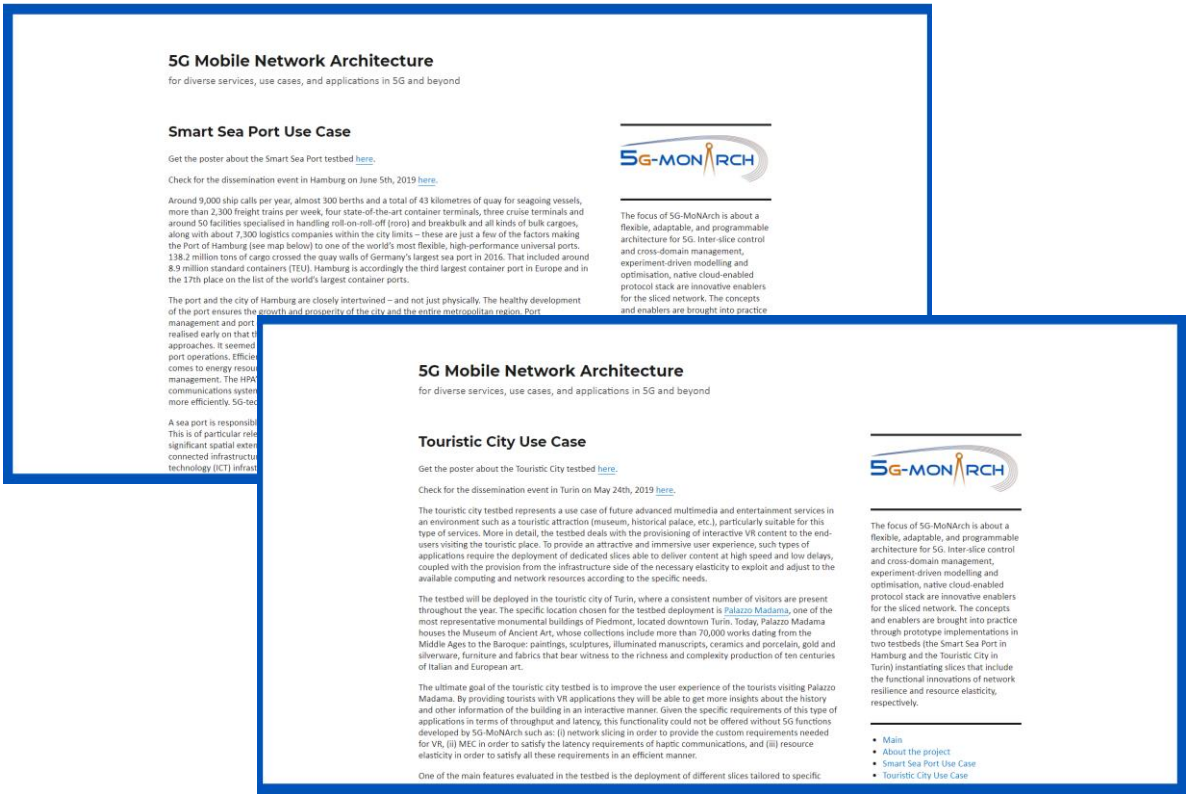

Figure 1-1: 5G-MoNArch page for the Smart Sea Port and Touristic City use cases

The overall organisation of the website remained rather similar since the beginning of the project, as described in [5GM-D71]. All significant changes are listed below.

- Two new pages, one describing the Smart Sea Port use case, another describing the Touristic City use case, were added, see a screenshot in Figure 1-1. They both contain a summary of the use case, including motivation, technical innovations, goals, a description of the implemented applications, and links to related material.

- The website page about Events and Publications was expanded (see Figure 1-2), including now information about the two project events (cf. Chapter 5):
  - The event in Turin on May 24th, 2019, with the focus on live presenting the Touristic City testbed to the public, and a dedicated workshop for stakeholders
  - The event in Hamburg on June 5th, 2019, with the focus on live presenting the Smart Sea Port testbed together with the core results of the technical project work as well as the verification and validation results to the public
- To allow visitors to register for the events a temporary page with a registration form had been published, where for each registered person a confirmation e-mail was automatically sent to a dedicated mailbox. This page was deleted after the registration period had expired.
- To provide a summary of the events to the visitors and facilitate access to the posters shown, two additional pages (one for each event) has been added. The information provided corresponds to the summary descriptions provided in Chapter 5.
- Finally, due to the changes to the handling of data privacy brought with the introduction of the General Data Protection Regulation (GDPR) by the European Union, a section was added detailing the website's privacy policy according to the GDPR.

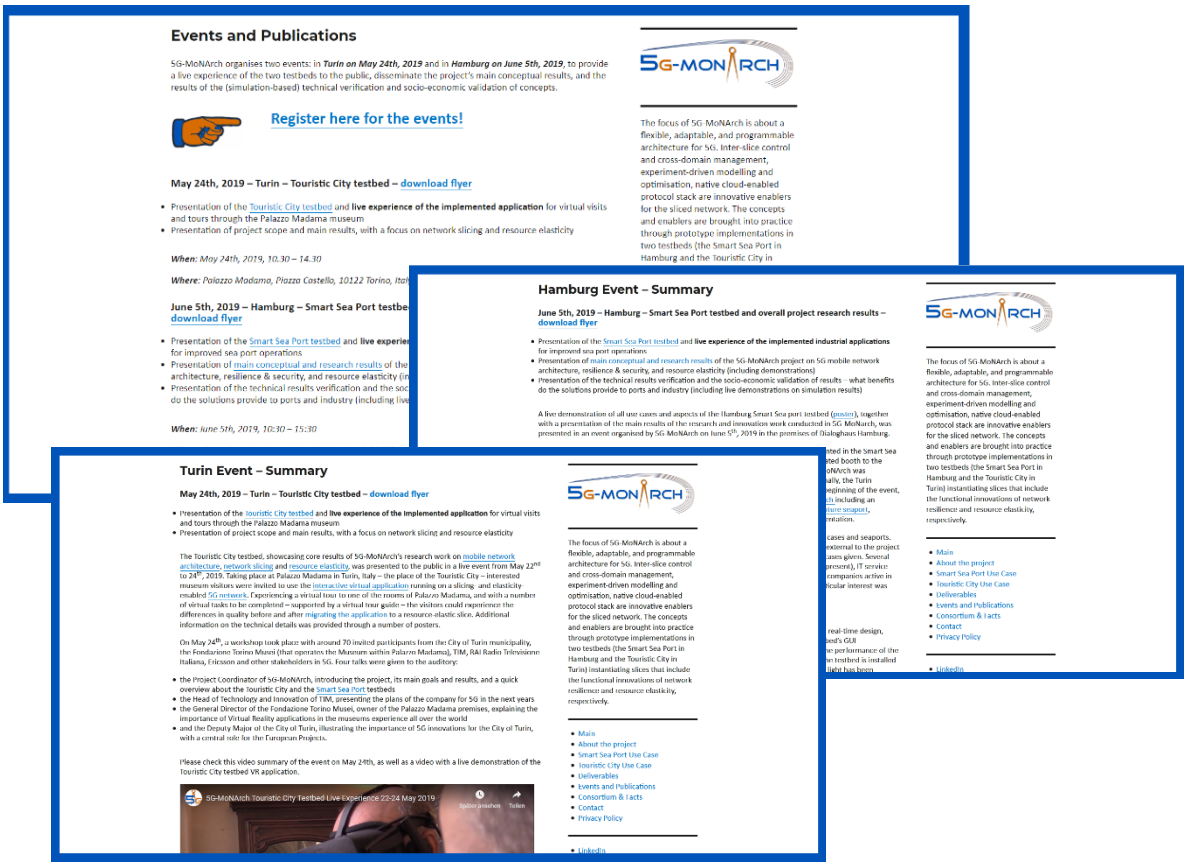

Figure 1-2: Updated Events and Publications page with link to registration, and summary pages for the events in Turin and Hamburg

1.2 Social media channels

Besides the public website, the project participates in three social media platforms – Twitter, LinkedIn and YouTube. They are used complement the website since they can reach different groups, spread news directly and quickly, or allow for hosting of material too cumbersome for the website.

- Twitter – https://twitter.com/5g_monarch

  - The Twitter account promotes news about the project easily and quickly. These news include newly released deliverables, participation in conferences, new videos, promotion of our events, etc…
- LinkedIn - https://www.linkedin.com/in/5g-monarch/
  - LinkedIn is a social network for professionals and companies, so it reaches another type of public from other venues. In particular the project's participation to main events such as the ICT 2018 conference, MWC, and the organisation of the project events were announced on LinkedIn.
- YouTube - https://www.youtube.com/channel/UCnwNJv-nxvxWGOcdjD0ZZ7Q
  - All video material produced by 5G-MoNArch goes into the YouTube channel. This is done both because the public website would not have the capability to host various HD videos, and because YouTube is the most popular video sharing platform worldwide, making it easier to disseminate our video material.

1.3 Press releases and presence in mass media

The various partner companies of the 5G-MoNArch project issue press releases to promote certain project achievements, which can then be considered another type of dissemination channel to the general public. It is worth highlighting that a number of the project press releases and activities had substantial impact on the mass media, reaching national level newspapers and TV channels in countries such as Germany and Spain. This has contributed to provide a great visibility of the project to the general, non-technical, audience.

In the following, we provide a list of press releases issued throughout the project runtime, along with their impact on mass media when appropriate, and partner websites that were regularly updated during the course of the project runtime.

Press releases

- Nokia announced the project start with a press release in August 2017, describing the cornerstones of the project setup and objectives. This press release gained quite some attendance and was cited in several international tech news sites and blogs. The original press release is available at: http://www.nokia.com/en_int/news/releases/2017/08/22/nokia-drives-key-european-research-project-5g-monarch-to-bring-5g-mobile-network-architecture-from-concept-to-real-world
- Huawei issued a press release in September 2017 focusing on its role as WP2 lead in 5G-MoNArch: http://www.huawei.com/en/press-events/news/2017/9/Huawei-Joins-5G-MoNArch
- The finalisation of the initial infrastructure setup for the Hamburg Smart Sea Port testbed was jointly announced in press releases issued through Hamburg Port Authority, Deutsche Telekom and Nokia in February 2018. The focus in these press releases was on the use cases and services to be shown and tested in Hamburg, and they gained a considerable international attendance, also due to the fact that 5G-MoNArch provides one of the first real-world testbeds for industrial use cases in Europe. The original press releases can be found online:
  - https://www.hamburg-port-authority.de/en/press-latest-news/new-communication-standard-5g-industrial-environment-trial-platform-launched-in-the-port-of-hamburg/
  - https://www.telekom.com/en/media/media-information/archive/research-platform-for-5g-513988
  - https://www.nokia.com/en_int/news/releases/2018/02/02/nokia-deutsche-telekom-and-hamburg-port-authority-collaborate-in-5g-research-in-industrial-environment
- UC3M launched a press release for Mobile World Congress in February 2018 regarding their commitments to 5G development, including the contributions to 5G-MoNArch: https://www.uc3m.es/ss/Satellite/UC3MInstitucional/en/Detalle/Comunicacion_C/1371246358819/1371215537949/UC3M_and_IMDEA_Networks_commit_to_5G_development_at_Mobile_World_Congress_2018

- The Hamburg Chamber of Commerce mentioned the 5G-MoNArch as one of the key drivers to bring the Hamburg Port forward through the implementation of new technologies and 5G in particular (July 2018 - in German) - http://hamburger-wirtschaft.de/pdf/072018/16/index.html
- A joint press release of HPA, Deutsche Telekom and Nokia released on November 6th, 2018, called "Port of Hamburg: 5G applications pass field test / 5G bewährt sich beim Praxistest im Hamburger Hafen" with clear reference to 5G-MoNArch as the joint basis for the cooperation and the testbed implementation; these press releases were launched after a stakeholder workshop together with a press event that took place in Hamburg in the premises of HPA
    - https://www.nokia.com/about-us/news/releases/2018/11/06/port-of-hamburg-5g-applications-pass-field-test/
    - https://www.hamburg-port-authority.de/de/aktuelles-presse/neuer-kommunikationsstandard-5g-bewaehrt-sich-beim-praxistest-im-hamburger-hafen-hpa-nokia-und-deutsche-telekom-und-ziehen-positives-zwischenfazit/
    - https://www.telekom.com/en/media/media-information/archive/port-of-hamburg-5g-applications-pass-field-test-551178
- The above press release and event was strongly reflected in German and international media, see some selected references below:
    - https://www.heise.de/newsticker/meldung/5G-Mobilfunk-im-Feldversuch-Telekom-Nokia-und-Hamburger-Hafen-praesentieren-erste-Ergebnisse-4213839.html
    - https://www.welt.de/regionales/hamburg/article183338782/Schnelles-Mobilfunk-Signal-5G-steht-stabil-Projekt.html?wtrid=onsite.onsitesearch
    - https://www.hafen-hamburg.de/de/presse/media/video/neuer-mobilfunkstandard-5g-im-hamburger-hafen---37979
    - https://www.teltarif.de/netzausbau-5g-hamburg-hafen-hpa-telekom-nokia/news/74578.html
- TIM issued a press release on May 14th, 2019 through the 5G-MoNArch website publicising the Turin Touristic City event. This press release was then disseminated in various 5G-PPP dissemination channels (website, LinkedIn Group and Twitter account).
    - http://5g-monarch.eu/wp-content/uploads/2019/05/5G-MoNArch-Touristic-City-Testbed-Live-Experience-press-release.pdf
    - https://5g-ppp.eu/5g-monarch-touristic-city-testbed-in-turin-may-22-23-2019/
- UC3M released a press release on the creation of the first 5G master's degree, with the participation of important European industrial players in the field. This activity was related to 5G-MoNArch as well as the other 5G projects where UC3M is involved, and had a very substantial impact on national media in Spain:
    - This news appeared in the following newspapers: 'El confidencial', 'La Vanguardia', 'Expansión', 'ABC'.
    - The news also had impact on important press agencies such as 'EFE' and 'europa press'.
    - The news was also published by 'Intereconomica' in the radio station.
    - Finally, it is worth highlighting that the project had also impact on specialised media around
- After the Turin Touristic City testbed event (May 24th, 2019), TIM published a press release in Italian discussing the event and the 5G-MoNArch project.
    - https://www.telecomitalia.com/tit/it/innovazione/la-rete-5G-in-italia/5G-MoNArch.html?utm_source=NewsletterInnovazione&utm_medium=email&utm_campaign=NewsletterInnovazione_155
- After the Hamburg event on June 5th, 2019, Deutsche Telekom published a press release on the finalisation of the Smart Sea Port testbed implementation
    - https://www.telekom.com/en/media/media-information/archive/port-of-hamburg-is-ready-for-5g-574536

Partner websites

- Hamburg Port Authority maintains a topic website on "5G Practical Test" which provides a brief description of 5G-MoNArch and links to the project website: https://www.hamburg-port-authority.de/en/themenseiten/monarch-5g/
- NOMOR Research links to the project from their website: http://nomor.de/resources/research-projects/5gmonarch-eu/
- Real Wireless posted the launch of 5G-MoNArch on their website: https://www.real-wireless.com/5g-monarch-started/
- Real Wireless posted "Introduction to 5G Mobile Network Architecture – 5G-MoNArch" in June 2018 - https://www.real-wireless.com/introduction-to-5g-mobile-network-architecture-5g-monarch/
- Real Wireless posted articles on their website regarding 5G-MoNArch participation at MWC 2019 (https://www.real-wireless.com/5g-monarch-testbed-wins-at-glomos-2019/) and also the testbed events (https://www.real-wireless.com/5g-monarch-testbed-events/)
- NOMOR Research posted the completion of the calibration of 5G System Level Simulator as part of the 5G IA's ITU IMT-2020 Evaluation on their website in November 2018 - http://nomor.de/2018/nomor-research-completed-calibration-of-5g-system-level-simulator-as-part-of-the-5g-ias-itu-imt-2020-evaluation/

1.4 Videos prepared by the project

Throughout the project lifetime, we produced several videos to disseminate the overview and the achievements obtained by 5G-MoNArch.

- 5G-MoNArch video For MWC 2018 (https://www.youtube.com/watch?v=KZPODVPv2qA): in this video we describe in an intuitive way the project objectives and the main enabler. It was originally shown at the Mobile World Congress 2018.
- 5G-MoNArch project introduction and goals (https://www.youtube.com/watch?v=y6b9FNniPuQ): in this video, built up of several interviews to the most relevant people in the project, we thoroughly describe the project ideas and concept.
- 5G-MoNArch touristic city testbed – Exploiting vertical and MNO needs (https://www.youtube.com/watch?v=oGbKNjIbOTI): in this video we interview the relevant verticals from the Touristic City testbed (i.e., Fondazione Torino Musei and the Municipality of Turin) to have their point of view on the technology developed by the project.
- 5G-MoNArch Touristic City testbed demonstration - VR application (https://www.youtube.com/watch?v=hLCkgdOhVJ4): this video includes the Virtual Reality experience as showcased in Turin during the public event.
- 5G-MoNArch Touristic City Testbed Live Experience 22-24 May 2019
- (www.youtube.com/watch?v=L-5XzBvAZyY): this video consists of a video summary of the Turin Touristic City event. It shows shorts segments of the presentations and of the visitors interacting with the various demonstrations (such as the VR application).

1.5 5G-MoNArch participation in the Mobile World Congress 2019

5G-MoNArch is one of the few projects being selected by 5G-PPP to be present twice at the Mobile World Congress, 2018 [5GM-D71] as well as 2019. While the focus in 2018 was mainly on providing a brief insight into the overall project activities, supported by flyers and a dedicatedly produced video, the 5G-MoNArch presence in 2019 was predominantly dedicated to the Hamburg Smart Sea Port testbed.

Being invited by the 5G Infrastructure Association to present at their booth in Hall 7 of the MWC, 5G-MoNArch provided a live experience of the Hamburg Smart Sea Port testbed one the one hand through the slice lifecycle management tool (cf. [5GM-D52]), which allows to design, create, deploy and manage network slices for different use cases in the live testbed. Furthermore, the sensor measurements of the

"improved pollution control" were shown, with the values acquired by the air quality sensors installed on the HPA barges together with some statistical KPIs could be live monitored. The 5G-MoNArch presence was completed by a number of presentations on the conducted research work, and the technical background and setup of the Smart Sea Port testbed. Furthermore, some videos on the project approach were shown.

There was a very high interest by MWC visitors in the 5G-MoNArch presence. Representatives of various industries (including mobile network operators, IT integrators, software companies, car manufacturers), universities and research institutes, regulators (e.g., the French and British regulation authorities), the European Commission and governments, representatives for smart city environments, but also analysts and even TV stations could gain insight into the presented results and the live testbed. The received feedback was very welcome by the validation and verification tasks within WP6 as well as for innovation management in WP1. For this reason, several questions for the different type of visitors had been prepared.

A main highlight of the MWC 2019 presence of 5G-MoNArch was winning the 2019 Global Mobile (GLOMO) 5G Industry Partnership Award, for the cooperation between Hamburg Port Authority, Deutsche Telekom and Nokia to deploy the Smart Sea Port testbed in Hamburg [MWC19], see pictures in Figure 1-3. This spotlighted not only the awarded partners but the overall project, as the judges explicitly mentioned that network slicing is seen as challenging in complex and changing environments, but that the approach of having a field trial and not only a lab trial was important for the scoring. This particularly supports the overall approach and setup of the 5G-MoNArch project as such.

Figure 1-3: Impressions of 5G-MoNArch presence at MWC 2019

1.6 European ICT event Vienna 2018

The European ICT 2018: Imagine Digital – Connect Europe event, organised by the European Commission in Vienna, Austria, from December 4-6, 2018, is a research and innovation event with the main purpose to interconnect research with society and industry, in order to leverage the digital

transformation. 5G-MoNArch contributed to this event on the one hand with a presence at the booth of the 5G Infrastructure Association (5G-IA), through posters, project videos, and flyers (see some pictures in Figure 1-4). The core contribution was by a networking session on "Network Slicing: 5G's new opportunities for industry and media", see https://ec.europa.eu/digital-single-market/events/cf/ict2018/item-display.cfm?id=22056, with the goal to present network slicing as a key technology coming with 5G, and to showcase the opportunities of end-to-end network slicing together with the flexible 5G network architecture for future businesses and industry. With some short pitches on the 5G-MoNArch approach and solutions, but also on the use cases implemented in the two testbeds, the participants of the sessions – stakeholders from industry and research – were particularly asked for their feedback, requirements, and expected opportunities of network slicing for their future business and work. The discussion during the event as well as the feedback forms provided to the visitors provided valuable feedback to 5G-MoNArch in particular with respect to gathering further input to the techno-economic analysis conducted with Work Package 6, but also to the project's innovation management process.

The received and summarised feedback of all participants was finally published in the form of an anonymised slide set on the 5G-MoNArch website [5GM-I18].

Figure 1-4: 5G-MoNArch presence at the European ICT event in Vienna, 2018

1.7 Impact summary

To provide a quantifiable metric of the impact generated by the dissemination activities of 5G-MoNArch towards the general public, this section provides several statistics and numbers in particular on the access of visitors to the website and the social channels.

- **Twitter**: The current status of the project's account, as of June 30th, 2019:
  - The account tweeted 58 times during the project runtime.
  - 78 other accounts are followed by 5G-MoNArch, including other research projects, 5G-PPP projects, researchers and major 5G events.
  - 5G-MoNArch has 332 followers and 23 likes.
- **LinkedIn**: The LinkedIn account has 209 contacts as of June 30th, 2019.
- **YouTube**: the YouTube channel has uploaded five videos as of June 30th, 2019. They include one short overview video for MWC 2018, a longer professionally edited 6 minutes video introducing the project and detailing the project's goals, and three recent videos going into detail about the Touristic City testbed in Turin. In total they reached a number of more than 880 views. Note that a number of videos on the Smart Sea Port testbed in Hamburg were produced and published by the Hamburg Port Authority on YouTube, but these were not counted for the statistics.
- **Website**: the impact of the website can be measured using page views, unique sessions and the amount of data sent to the requesters. A page view represents one time that a page was viewed by any user. A unique session measures access to the website by a user with unique IP address, including file downloads with a direct link. Sessions are the better means for estimating the number of unique visitors to the website. Finally, the amount of data sent includes all data provided by the website to the requester, including the web page, pictures, and downloaded files (e.g., deliverables, reports, flyers, posters, or publications).

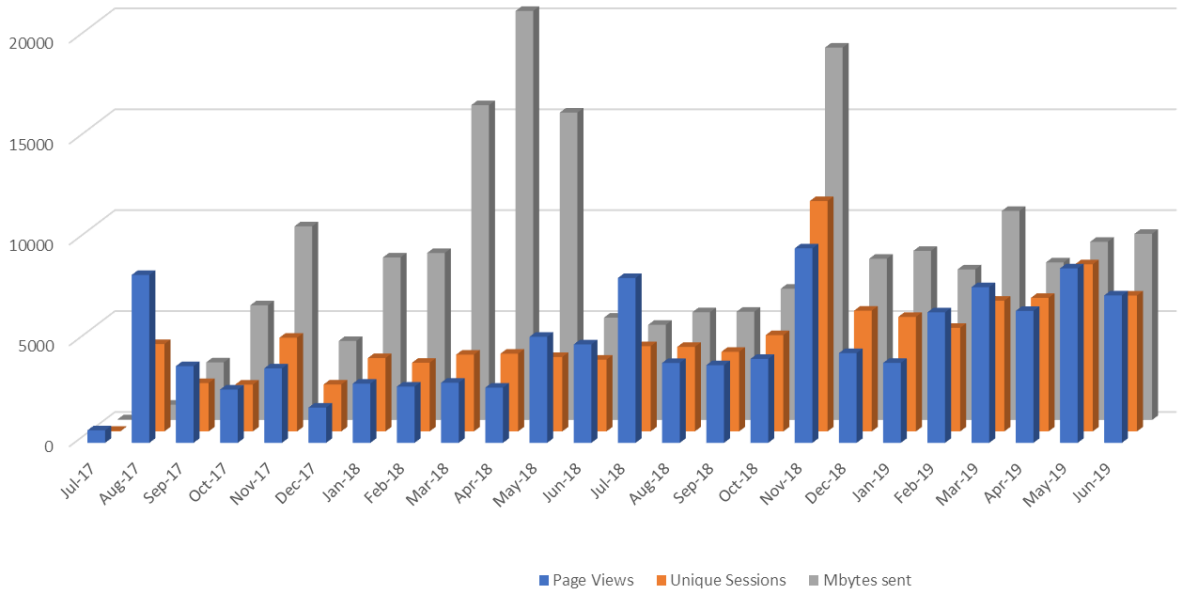

Figure 1-5: 5G-MoNArch website statistics

Statistics about the page view and sessions numbers of 5G-MoNArch website can be seen in Figure 1-4. As of as of June 30st, 2019, the total number of page views was 117243, the total number of unique sessions was 111422, and the total amount of data downloaded from the web page was almost 196 GByte. Even though it's possible to see that the project consistently and gradually attracted more attention, three periods of higher interest can be highlighted:

- An initial burst coming from the beginning of the project in August 2017, with the first version of the website going online and the corresponding announcement in social media and within the 5G-PPP community.
- A series of high downloaded data, but also a clear increase in the page views and unique sessions in the first and second quarters of 2018, was likely the result of the availability and announcement of the first two project videos which could be downloaded from the webpage,

and the availability first release of technical deliverables from WP2, 3, 4 and 6 ([5GM-D22], [5GM-D31], [5GM-D41] and [5GM-D62]) from the webpage. The participation of 5G-MoNArch at MWC 2018 which took place end of February 2018, and the participation at EuCNC in June 2018 together with the corresponding announcements, but also the distribution of direct links to the deliverables and videos contributed this peak.

- November 2018 represents the month with the highest number of sessions and page views (11417 and 9638, respectively) but also a high download rate. This can be attributed to the stakeholder workshop organised by 5G-MonArch partners HPA, Deutsche Telekom and Nokia o November 6th, 2018. Furthermore, the preparation and announcement of the networking session at the EU ICT event in Vienna (early December 2018) as well as the participation in a 5GXcast workshop on 3GPP's submission towards IMT-2020 have strongly contributed in particular to the peaks in page views and unique sessions. Finally, the release of the first Touristic City testbed video, which could be downloaded, clearly had a strong impact to the high amount of data downloaded.
- The last months of 5G-MoNArch were overall very strong in particular regarding the page views and unique sessions. This had various reasons: (i) the 5G-MoNArch participation at MWC 2019 which took place end of February, including the corresponding announcements on the webpage; (ii) the announcement of the two project events in Turin (May 24th, 2019) and Hamburg (June 5th, 2019) brought many visitors to the website; (iii) the participation at EuCNC in June 2019 which had a high visibility in the scientific community; and finally, (iv) the publication of the final technical deliverables by WP2, 3 and 4 ([5GM-D23], [5GM-D32] and [5GM-D42]) on the website in April and May. However, since the final versions of the Touristic City testbed videos was not downloadable, but only embedded in the website, there was no corresponding increase visible at the amount of transferred data.

In summary the overall impact of the dissemination to the general public in terms of quantitative measures is reported in Table 1-1.

Table 1-1: Overall results for the dissemination to general public

Public website https://5g-monarch.eu		• 111422 unique sessions (total number of visits) • 117243 page views • 196 GByte of downloaded data
Social channels	Twitter	• 58 tweets • 78 followed accounts • 332 followers • 32 likes
	YouTube	• 5 project videos • 880 views
	LinkedIn	• 209 contacts
Press releases		13 (issued by 4 partners)
Partner websites		3 websites of partner companies with regular updates
Contributions to international events and conferences	MWC 2018	• 1 stand at the Mobile World Capital Barcelona booth • 3 presentations at different booths
	IEEE ICC 2018	• 1 workshop (5GArch)
	EuCNC 2018[1]	• 1 booth • 2 special sessions

[1] Please find a more detailed description on the 5G-MoNArch contributions to EuCNC 2018 and 2019 in the chapter on dissemination towards the scientific community, Section 4.3

	EU ICT event 2018	• 2 project videos • booth presence (5G-IA) • 1 networking session
	MWC 2019	• 1 stand at the 5G-IA booth
	EuCNC 2019	• 1 large booth • 1 workshop

2 Standards, patents and industry fora

The goal of Work Package 7 is twofold: (i) facilitate the exploitation of 5G-MoNArch results, and (ii) create awareness of the project, its objectives and results. Several activities have been carried out to present the project through the most appropriate communication channels. In this section, we cover the following activities foreseen in the Grant Agreement of the project:

- Monitoring, alignment with, and contribution to the work of relevant standardisation bodies and fora for the definition of the future 5G access and core architecture.
- Identification of project results relevant to those relevant standardisation bodies as well as internal coordination within industrial project partners to bring those results to the standards meetings and work for their approval.
- Interactions with the 5G-PPP ecosystem, other related 5G projects (within and outside 5G-PPP) as well as proper 5G industrial and research activities.

Furthermore, 5G-MoNArch is committed to the 5G-PPP ecosystem. In that respect, it has performed appointments of representatives to joint Working Groups (WGs) to provide technical contributions to (and, on occasionally, edition of) deliverables and reports of the WGs.

Another important aspect in terms of dissemination is the commitment in the patents filing, stating in the most effective way the degree of innovation of the activities performed in the project. A specific section reports in this chapter the patents' activities in 5G-MoNArch.

2.1 SDOs and fora

2.1.1 Standardisation bodies

As it has been already stated in the Deliverable D7.1 [5GM-D71] 5G-MoNArch has a specific objective to be committed to contribute to standardisation activities as means to apply to commercial products the findings in the innovative topics dealt with in the project. In order to achieve this objective, the project has promoted the achieved project results to the relevant standard bodies and industry fora, which would contribute to facilitating the future exploitation of these results.

Third Generation Partnership Project (3GPP)

5G-MoNArch has covered a substantial number of technologies that are addressed by different SDOs, where a large number of 5G-MoNArch innovations have been introduced. It is confirmed, as already mentioned in the first year of activities, that among the various SDOs that have been targeted, the most relevant one has been the 3rd Generation Partnership Project (3GPP), which defines the basis of the most widely used mobile network technologies, i.e., GSM, UMTS, and LTE. The following Working Groups have been found to be of relevance to the project: SA2, which identifies the main functions and entities of the network, how these entities are linked to each other, and the information they exchange, SA5, which specifies the requirements, architecture and solutions for provisioning and management of the network (RAN, CN, IMS) and its services, RAN3, which deals with the interface descriptions within the RAN and to other network domains as well as RAN1 and RAN2, dealing with more RAN-related aspects that are also relevant to the project.

From the different activities of the above mentioned WGs, 5G-MoNArch targeted the 3GPP study and work items listed in Table 2-1 where various technical contributions have been made.

Of particular relevance is the SA2 "Study of enablers for Network Automation for 5G (FS_eNA)", which has aimed to study and specify how to collect data and how to feedback data analytics to the network functions. Both slice specific data and non-slice specific data can be collected to generate data analytics and feed back to the network functions for per slice/cross slice decision. As highlighted in [5GM-D23], numerous 5G-MoNArch contributions within the integrated data analytics framework and service-based architecture design have been already accepted by 3GPP SA2 and been captured by the related specification. In addition, within the framework of 5G-MoNArch integrated data analytics, technical contributions have been made to 3GPP SA5, where the 5G-MoNArch big data analytics module has been in part accepted as the management data analytics service (MDAS). Another relevant ISG has been the ETSI Zero touch network and Service Management (ZSM), which is looking into the

simplification of the network slice management via automation. 5G-MoNArch has made technical contributions to ETSI ZSM focussing on the integrated data analytics and service-based architecture/service-based interface. With regards to 3GPP RAN3, 5G-MoNArch focus has been on the RAN support of network slicing and slice-adaptive self-organising networks (SON).

With respect to details on the contributions towards 3GPP standards we refer to the technical results descriptions provided in the 5G-MoNArch deliverables from WP2 (Overall mobile networks architecture: [5GM-D22], [5GM-D23]), WP3 (Resilience and security: [5GM-D31], [5GM-D32]), and WP4 (Resource elasticity: [5GM-D41], [5GM-D42]).

Table 2-1: Targeted SI/WIs for 5G-MoNArch

ID No.	Release	Name	Target WG	SI/WI description
760047	Rel-16	Study of enablers for Network Automation for 5G	SA2	SP-170383
760043	Rel-16	Study on architecture enhancements for 3GPP support of advanced Vehicle-to-Everything (V2X) services	SA2	SP-180733
770039	Rel-16	Study on Enhancing Topology of Session Management Function (SMF) and User Plane Function (UPF) in 5G Networks	SA2	SP-180731
780037	Rel-16	Network Resource Model (NRM) for 5G networks and network slicing	SA5	SP-170956
780038	Rel-15	Performance Assurance for 5G networks including network slicing	SA5	SP-180814
750067	Rel-15	New Radio Access Technology	RAN2/3	RP-190213
750167	Rel-15	New Radio Access Technology: Core part	RAN3	RP-190213
820070	Rel-16	Integrated access and backhaul for NR	RAN3	RP-190712
800096	Rel-16	Study on New Radio (NR) V2X	RAN3	RP-190224
801000	Rel-16	Study on RAN-centric data collection and utilisation for LTE and NR	RAN3	RP-181456

European Telecommunications Standards Institute (ETSI)

A new ISG that was recently created in ETSI on Artificial Intelligence-based network management and orchestration called Experiential Network Intelligence (ENI) has also been the focus of 5G-MoNArch standardisation impact. 5G-MoNArch's approach partly overlaps with the goal of a new ETSI ENI, which proposes an engine that adds closed-loop AI mechanisms based on context-aware, metadata-driven policies to more quickly recognise and incorporate new and changed knowledge, and hence, make actionable decisions. As explained in [5GM-D4.2], a number of contributions have been provided and accepted by ENI in two different work items: use cases and proof of concept. On the first one, five contributions have been submitted starting from a new use case proposed by 5G-MoNArch on elastic resource management orchestration, hence establishing the basis of the architectural principles of elasticity on AI-based networks. The use case has been updated with subsequent contributions that refined and fine-tuned it to the simultaneously ongoing work on the architecture work item. Furthermore, a proof of concept framework demonstrating the basic principles of the above use case on elasticity was also proposed by 5G-MoNArch based on the Turin testbed. The proof of concept proposal was accepted, and 5G-MoNArch has been contributing to the work items with several developments on both the technologies and implementation of the testbed.

International Telecommunication Union – Radiocommunications (ITU-R)

5G-MoNArch contributed to the simulation-based evaluation of the IMT-2020 5G New Radio concepts as member of the 5G-PPP IMT-2020 evaluation working group, which executes the corresponding European efforts on behalf of the 5G-IA. Further details on this work are provided in Section 3.4, and an overview about the technical results of this work is provided in Chapter 9 in Part 2 of this report.

2.1.2 Industry fora

Global System for Mobile communications Association (GSMA)

The GSMA represents mobile network operators worldwide with around 800 operators and also includes further 300 companies from the broader mobile ecosystem, such as smartphone makers and internet companies. GSMA organises premium events in the ecosystem, namely the Mobile World Congress in Barcelona (formerly Cannes) (MWC), MWC Shanghai, MWC Americas, and the Mobile 360 Series [GSM-360] of conferences. Considering the importance of network slicing, GSMA has established a working group titled "Network Slicing Taskforce (NEST)" [GSM-N18]. The NEST analyses, for example, the vertical requirements on the network slicing and 5G networks in general and how these requirements can be fulfilled by the design of the 5G architecture. GSMA can also communicate with SDOs, e.g., 3GPP, to highlight the outcomes of different working groups. On this basis, 5G-MoNArch has identified the NEST as one of the key fora to coordinate with respect to 5G-MoNArch innovations, analyses, and findings. Throughout the project runtime, various bilateral meetings have been organised with GSMA NEST toward the Generic Slice Template (GST) [GSM-G19] design as well as the implementation of a slice via the slice blueprint. For instance, in one of the online meetings vertical requirements have been analysed with the participation of 5G-MoNArch partner HPA. In that meeting, vertical use cases are highlighted, and the associated requirements are detailed. The use cases include mMTC use case, e.g., measuring emissions from ships and eMBB use case, e.g., for video surveillance. This analysis has contributed to the white paper published by GSMA titled "Network Slicing Use Cases Requirements" [GSM-S18]. 5G-MoNArch has further demonstrated the slice implementation and slice blueprint design during the bilateral meetings and have provided feedback to GSMA GST design. This collaboration has been acknowledged by GSMA as the 5G-MoNArch testbeds showcase the realisation of the network slicing and on this basis the 5G-MoNArch slice blueprint design presents how the GSMA GST can be utilised for the slicing implementation.

NGMN Alliance

The Next Generation Mobile Networks (NGMN) Alliance [NGMN] is an industry organisation of leading world-wide telecom operators, equipment vendors and research institutes. Its objective is to ensure that the functionality and performance of next generation mobile network infrastructure, service platforms and devices will meet the requirements of operators and, ultimately, will satisfy end user demand and expectations. The NGMN Network Management and Orchestration (NWMO) work stream defines and works out uses case and requirement for 5G network and service management including orchestration, thereby covering all potential parts of the network including fixed and mobile access, cloud infrastructure and virtualised technologies, which are provided with the deliverable "5G Network and Service Management including Orchestration" [NGM-W19]. 5G-MoNArch has identified this deliverable to disseminate some of the developed concepts and requirement on (inter-)slice management and orchestration (e.g. related to resource elasticity) through the partner organisations involved in NGMN.

2.2 Patents

The partners in the project have worked to transfer the innovative aspects of the activities performed in the project into patent applications. In total 17 patent applications have been filed, of which 12 of these applications have been prepared directly from the research and innovation work conducted within the project by four different partners in the project. The topics these applications are related to are multi-connectivity, network slicing, network slicing management, and proactive fault management, all aligned with the most relevant technical project's objectives on resilience, reliability and elasticity in E2E Network Slicing. For these patent applications, the involved partners have shared within the consortium details such as filing date and brief content description. The additional five patent applications are characterised by a clear technical interrelation to the project work, and the involved partners have declared that these have been developed during the project lifetime and that they were prepared by people working within the project (e.g., Samsung UK, that declared three of them, and Nokia two). However, due to timing restrictions and confidentiality rules within the partner organisations no further details could be disclosed on these applications.

2.3 Impact summary

The results achieved in the activities for the dissemination towards standardisation bodies, industrial fora and 5G-PPP as presented in this chapter are summarised in Table 2-2 in terms of quantitative measures.

Table 2-2: Overall results for the dissemination towards future products and services

Contribution to SDOs (noted, approved or only submitted)	3GPP Radio Access Networks	• 11 RAN3 • 2 RAN2
	3GPP System Architecture	• 55 SA2 • 10 SA5
	ETSI Industrial Specification Groups	• 5 ENI (incl. one CR) • 18 ZSM
	ITU-R IMT-2020	• 3 scenarios
Contribution to industry fora	GSMA	• 1 presentation
	NGMN	• 2 presentations
Patent applications		17 applications in total • 12 applications directly from the 5G-MoNArch research work • 5 additional applications technically initiated through the research work within the project

3 Cooperation with other projects and 5G-PPP

5G-MoNArch has paid special attention to the collaboration with other projects, with special emphasis to those under the 5G-PPP framework. The main objective of the collaboration with 5G-PPP has been to jointly address with the other project the development the different aspects of the 5G technology and thus contribute to position Europe as the world leader in the development of this critical technology.

In the following, we explain the different activities undertaken by 5G-MoNArch in the collaboration with other 5G-PPP projects. In Section 3.1 we explain the general cooperation with 5G-PPP, comprising the project participation in the Steering and Technical Boards of 5G-PPP. These activities have proven very useful to align the use cases and requirements to be addressed by 5G-PPP as well as to understand the contribution of 5G-MoNArch to those objectives as compared to other projects; in particular, results of the different projects in terms of KPIs achievements and testbed deployments have been brought together in these boards. Section 3.2 explains the contribution of 5G-MoNArch as the leading project of the Architecture WG. As a matter of fact, 5G-MoNArch is the flagship 5G-PPP project and architecture and hence the natural leader of such as WG. In addition to the Architecture WG, 5G-MoNArch has also been an active participant to some other WGs, with a key role in some of them; Section 3.3 summarises the contributions and role played by 5G-MoNArch in such WGs. Section 3.4 further describes the contributions to IMT-2020, which is a very important initiative pushed by the European Commission to evaluate the performance of the 5G technology, to which 5G-MoNArch has been a key contributor. Section 3.5 describes the one-to-one collaborations with other projects, and Section 3.6 closes the chapter with a summary of the impact achieved on this front.

3.1 General cooperation with 5G-PPP

5G-MoNArch has been always very actively involved in the cross-project 5G-PPP activities, ensuring participation and input to all the working group that have been created under the umbrella of 5G-PPP. The outcome of this participation is twofold: i) cross-disseminate the scientific research performed within the project with others researching in similar areas and ii) seeking for opportunities of dissemination together with other projects. Furthermore, the 5G-MoNArch consortium is well-aware of the contractual commitment of the 5G PPP as well as its organisational structure and the requirement to work with peer 5G-PPP projects, as described in the 5G PPP contract and its technical annex. In the following, a detailed description of 5G-MoNArch's cooperation with the different 5G-PPP entities follows.

Steering Board (SB)

5G-MoNArch has been a very active member in the SB activities through the project coordinator, who regularly joined virtual and physical meetings. In general, 5G-MoNArch contributed to the following main activities: i) 5G-PPP Working Group reporting, coordination and planning, ii) planning and contributions of 5G-PPP projects to events (e.g., Mobile World Congress, EuCNC etc.) and further joint dissemination activities (such as the 5G annual journal), and iii) the interworking / coordination between Phase 1, Phase 2 and Phase 3 projects as well as with activities related to cross-continental research collaboration projects (EU-India, EU-Korea etc.). In particular, the main SB topics relevant for 5G-MoNArch during throughout the project execution were the event planning and contribution to MWC, and the planning and setup of the contributions of the project to the IMT-2020 evaluation.

Technical Board (TB)

5G-MoNArch has been a particularly active member in the TB activities. Besides the regular participation to virtual and physical meetings through the technical manager and his deputy, 5G-MoNArch also contributed to several ad-hoc initiatives promoted by the TB Chair. More specifically, the representatives of the project in this working group contributed to: i) the definition of the Phase II project cartography, including the definition of the scope of the project with respect to the other projects, ii) the description of the 5G trials, with the Turin and Hamburg testbeds and iii) the participation in the KPIs discussion. The latter point was of paramount important for the 5G TB, and the input provided by 5G-MoNArch (developed in WP6) was very appreciated as one of the fundamental inputs for the KPI ad-hoc team discussion. In particular, 5G-MoNArch contributed also with the KPI discussion obtained

by the testbeds developed in the project, which are among the ones in Phase-II that are both open to the general public (i.e., the touristic city) and providing a pre-commercial solution (the smart sea port).

The discussions held during the TB meeting, both remote and physical (there have been a total of 3 during the project lifetime), allowed 5G-MoNArch to both contribute with the project experience and get useful feedback from other projects in different areas. For instance, besides the aforementioned WP6 work promoted to the KPI ad-hoc team, 5G-MoNArch contributed to the definition of a common way of presenting the testbed results. In particular the way 5G-MoNArch involved verticals (i.e., Fondazione Torino Musei, the Municipality of Turin and the Hamburg Port Authority) was perceived as very appropriate from the TB, which used a similar template to the one defined by the project in his dissemination material to get feedback from other projects. This allowed 5G-MoNArch to assess the innovation of the project developed technologies with respect to other Phase-II projects. Also, the participation to the TB allowed the 5G-MoNArch representatives to assess the ambition and the extent of the testbeds produced by the projects, placing them in the high-end of the 5G-PPP Phase II projects.

3.2 Leading role in the 5G-PPP Architecture Working Group

Being one of the main goals of the project, namely, the consolidation of a 5G overall architecture capable of instantiating the envisioned novel services, the contributions to the 5G-PPP Architecture WG have been very important. The Architecture WG has been formed by the start of 5G-PPP Phase 1 projects and has been highlighting the consolidated European vision on the 5G architecture. To this end, the WG has published two white papers on the architecture view, which has been supported by most of the 5G-PPP projects and has been acknowledged by other global industry fora. 5G-MoNArch has actively participated in the Architecture WG including online and face-to-face meetings, shared the project results with other 5G-PPP projects and joined the architecture consolidation work. Through the four nominated delegates to the Working Group, 5G-MoNArch has substantially contributed to the latest release of the Architecture WG White Paper [5GP-W19], with contributions to all the chapters. Most importantly, 5G-MoNArch has been the main editor of Chapter 2 on the overall architecture and 5G-MoNArch has served as the vice-chairman of the Architecture WG as well as the editor of the whole white paper. In addition, the white paper has been released for public consultation at EuCNC 2019 during the workshop titled "International Workshops on 5G Architecture", where 5G-MoNArch has co-organised the workshop and has presented parts of the white paper, i.e., whole white paper, overall architecture, and RAN.

3.3 Cooperation with other 5G-PPP Working Groups

In addition to the 5G Architecture WG, 5G-MoNArch has also been an active contributor to a number of other WGs focusing on topics that were relevant for 5G-MoNArch, being a key contributor to some of these WGs. In the following we summarise the scope of the different WGs where 5G-MoNArch has participated, outlining the key contributions of 5G-MoNArch for some of them.

5G Comms

The dissemination activities of the project have been echoed through the group "5G Comms", led by the CSA projects in 5G-PPP Phase 2. In the same group the activities related to the presence of the project in the main conferences, events and industrial fora have been coordinated, in order to ensure an alignment with the activities of the other Phase 2 and Phase 3 projects.

Pre-standards WG

5G-MoNArch has actively participated in Pre-standards WG calls, and as part of the activities in this WG, some 3GPP study items (SIs) have been identified which have the potential for contributions from the running 5G-PPP project towards the technical specification Groups (TSGs) RAN and SA, being in line with current technical activities. One relevant work has been performed within the Architecture WG, where 5G-MoNArch has provided the key technology areas (KTAs) that have impacted the ongoing 5G specifications. This work has been jointly performed between Architecture WG and Pre-standards WG.

Performance KPI WG

The target of the performance KPI WG is to consolidate the KPIs available from the various 5G-PPP work group activities and projects by providing commonly agreed KPI definitions and methods for their measurement. 5G-MoNArch has actively participated in the WG calls and has been contributing with KPI results and with inputs in a draft document concerning KPI results by Phase 2 programmes. So far, three documents that will include parts of these contributions are planned. The annual Progress Monitoring Report (PMR) which is due on July 2019 will be published on the 5G-PPP website [5GPPP] along with two white papers on the Service Creation and End-to-End Latency KPIs due in the second semester of 2019.

5G Trials WG

The aim of this working group is to generate a strategy for developing a Pan-European 5G trials roadmap and to accordingly prepare this roadmap. 5G-MoNArch contributed to this roadmap with the elaborate information about the two project testbeds in Turin and Hamburg. Furthermore, to acquire the information from all the running 5G-PPP projects, the form generated by 5G-MoNArch for the criteria description of the trials as well as the project short information (flyer) was taken by the Trials WG as template for all projects.

5G Automotive WG

The goal of the Automotive WG is to leverage concepts developed by 5G-PPP projects which are relevant for the automotive industry sector and its interrelation with 5G mobile communication systems. In particular, the WG launched a number of white papers (available from [5GPPP]) related to technical requirements as well as business considerations. The project contributed to the activities of the Automotive WG with topics related to network architecture and slicing, especially in the phase that lead to the preparation of the white paper on the business feasibility study for 5G Vehicle-to-Anything deployment [5GP-.

3.4 IMT-2020 evaluation

The goal of this working group is to perform the second stage evaluation of the 3GPP 5G New Radio Interface standards as an input to the standards development of the International Telecommunications Union – Radiocommunications Sector (ITU-R) for IMT-2020 (International Mobile Telecommunications standard). The 5G Infrastructure Association (5G-IA) is the responsible partner to coordinate this evaluation within Europe. The actual execution of the evaluation, i.e., the computational and simulation-based verification of the different technical approaches for the 5G New Radio interface specifications as provided, e.g., by 3GPP, has been conducted through running and upcoming 5G-PPP projects (Phase 2 / Phase 3) that have the necessary competence to perform this work. The IMT-2020 evaluation is within an overall European interest and is therefore supported by the European Commission.

Despite the fact that this activity has not been within the core scope of 5G-MoNArch – according to the Description of Work provided in the project's Grant Agreement – the project contributed to this working group, and hence to the evaluation, through the project partner NOMOR Research (cf. Section 6.2.13). NOMOR brings a strong background in research and simulator development in particular for radio interface and radio network simulations. After an initial analysis of the tasks to be conducted within the 5G-PPP IMT-2020 evaluation WG, a work split between the projects and accordingly between the involved partners has been agreed. Based on this work split, the radio simulation environment has been adapted to the requirements issued by ITU-R, the simulator has been calibrated, and the simulations were conducted.

It is to be noted that the work of the IMT-2020 evaluation WG is not finished after the end of the 5G-MoNArch project – the necessary computational and simulation-based evaluation will likely continue at least until the first quarter of 2020. Only at that time the final results will be ready and can be provided towards ITU-R in form of a report.

A summary of the main technical results achieved under the auspices of 5G-MoNArch are available in Part 2 (Chapter 9) of this document, including a description of the simulation environment, calibration

results, and first results of the actual simulation work for indoor hotspot, dense urban, and rural scenarios.

3.5 Specific collaborations with other projects

The groups and initiatives described above offer the most suitable frameworks to collaborate with other projects. Indeed, such frameworks bring together a large number of projects and hence provide a very efficient means to understand how the project results complement and compared to those provided by other projects. Nevertheless, in some specific occasions where there was a common interest with a specific project, bilateral collaborations were the most suitable means to work together. In particular, 5G-MoNArch had such type of collaborations with the following projects:

- **5G TANGO**: 5G-MoNArch has made a bilateral collaboration with the 5G TANGO project in the field of experiment driven optimisation and inter-slice control and management. 5G TANGO is a 5G-PPP project that is working on the provisioning of an SDK and an Orchestration platform for development, validation and deployment of virtualised network services. 5G-MoNArch enabler on Inter-slice RRM using the SDN framework has been validated by the 5G-TANGO platform thanks to the joint efforts. Further, a joint paper has been submitted highlighting this joint work
- **ONE-5G**: 5G-MoNArch has prepared a special session together with ONE-5G EuCNC 2018. The special session provided the latest analyses from both projects and understand how they complement each other. As a matter of fact, ONE-5G focuses on lower layers than 5G-MoNArch, and hence such collaboration is very useful to jointly build a comprehensive view of 5G networks.
- **SPEED-5G**: 5G-MoNArch participated in the SPEED-5G workshop in London5G with a focus on spectrum management. Similar to the above, SPEED-5G focus on technical aspects around spectrum that complement 5G-MoNArch, making the collaboration with this project very useful to jointly provide a full 5G protocol stack.
- **NGPaaS**: Due to the overlap of some project partners that participated in both projects, a clear interaction and mutual exchange of concepts took place, in particular with respect to the definition of the overall architecture. Here, requirements on the virtualisation of the Management & Orchestration layer were provided to NGPaaS, while in return the requirements to integrate the container infrastructure (e.g., Container Infrastructure Management Function CIMF) into the functional design were provided. Corresponding impact was provided to WP3 function design. The results of this cooperation are documented in particular in [5GM-D23].
- **SliceNet**: Due to the joint work on Artificial Intelligence topics – within 5G-MoNArch focusing on resource elasticity, within SliceNet on cognitive network management – both projects jointly organised a workshop on "Artificial Intelligence for 5G Networks", which took place as part of the 2019 edition of the EuCNC conference.

3.6 Impact summary

Table 3-1 presents in the form of a summary the most important achievements for the scientific dissemination of the project.

Table 3-1: Overall results for the dissemination towards future products and services

General cooperation with 5G-PPP	• Continuous presence and interaction with • Steering Board (overall 5G-PPP coordination) • Technical Board (technical alignment among projects)
Activities in 5G-PPP Working Groups	Architecture WG • Co-leadership • Major contributions to 2 white papers
	IMT-2020 evaluation • Major contributions on target definition

	• Major contributions through simulation-based evaluation
	Active involvement in • 5G Comms • Pre-Standards • Performance KPI • Trials • Automotive
Collaboration with other 5G-PPP projects	• 5G-TANGO • ONE-5G • SPEED-5G • NGPaaS • SliceNet

4 Dissemination to the scientific community

In the previous chapters the dissemination activities towards the general public and towards the implementation of future products and services in Europe were reported. Another set of initiatives in the project is the one about the scientific impact of the research activities performed by the partners. This dissemination work is of great importance also as a way to promote the project results and as an opportunity to create possible standardisation input.

As already done in [5GM-D71], we distinguish between two major classes for scientific dissemination, namely i) publications and invited presentations to scientific journals and conferences, and ii) workshops and special issues organised and carried out from 5G-MoNArch. These dissemination activities are presented in detail in Sections 4.1 and 4.2.

Section 4.3 shortly describes the activities conducted together with the 5G-MoNArch Advisory Board, and in Section 4.5 the impact on the scientific community is summarised.

4.1 Conference and journal publications

Specific guidelines have been implemented for any publication that has been produced within the work of the project. Among these guidelines there is a certain timeline for project-internal approval before any scientific work is allowed to be submitted for publication in journals or conferences. This procedure (defined through the Consortium Agreement) leaves a sufficient amount of time for all consortium members to review the content of the publication and object, where applicable, to any publication that poses a conflict of interest to the project member.

In the following we provide a list of the 5G-MoNArch publications for each category: publications at conferences (Table 4-1); scientific magazines and journals (Table 4-2); and invited talks and presentations (Table 4-3).

Publications at conferences, workshops and special sessions

The list of conference or workshop papers provided in Table 4-1 is continuous, i.e., all such publications are listed from the beginning until the end of the project. Note that this list includes publications which were still in the status of "submitted" during the preparation of this deliverable.

Table 4-1: List of publications at conferences, workshops and special sessions

Main author	Title	Event	Date, Place	Status
Lars C. Schmelz et.al.	Mobile Network Architecture: End-to-End Network Slicing for 5G and Beyond	Wireless World Research Forum (WWRF) Meeting #39	October 18-20, 2017, Castelldefels, Spain	Presented
Diomidis S. Michalopoulos et al.	Network Resilience in Virtualised Architectures	International Conference on Interactive Mobile Communication, Technologies, and Learning, Special session on 5G Wireless and Optical Technologies for Mobile Communication Systems (IEEE)	December 1, 2017, Thessaloniki, Greece	Presented
David M. Gutierrez Estevez et.al.	The Path Towards Resource Elasticity for 5G Network Architecture	IEEE Wireless Communications and Networking Conference (WCNC) 2018 FlexNets workshop	April 15-18, 2018, Barcelona, Spain	Presented
S. Papadopoulos, A. Drosou, I. Kalamaras, D. Tzovaras	Behavioural Network Traffic Analytics for Securing 5G Networks	IEEE International Conference on Communications (ICC) 2018	May 20-24, 2018, Kansas City, MO, USA	Presented

		5th International Workshop on 5G Architecture (5GARCH)		
Gines Garcia-Aviles et.al.	SEMPER: A Stateless Traffic Engineering Solution for WAN based on MP-TCP	IEEE ICC 2018	May 20-24, 2018, Kansas City, MO, USA	Presented
Emmanouil Pateromichelakis, Konstantinos Samdanis	Graph Colouring based Inter-Slice Resource Management for 5G Dynamic TDD RANs	IEEE ICC 2018	May 20-24, 2018, Kansas City, MO, USA	Presented
Sina Khatibi, Kunjan Shah, Mustafa Roshdi	Modelling of Computational Resources for 5G RAN	EuCNC 2018 (IEEE)	June 18-21, 2018, Ljubljana, Slovenia	Presented
Borislava Gajic, Christian Mannweiler, Diomidis S. Michalopoulos	Cognitive Network Fault Management Approach for Improving Resilience in 5G Networks	EuCNC 2018 (IEEE) Special Session SPS4b: 5G Mobile Network Architecture and New Radio Advances	June 18-21, 2018, Ljubljana, Slovenia	Presented
Bin Han, Marcos Rates Crippa and Hans Schotten	5G Island for Network Resilience and Autonomous Failsafe Operations	EuCNC 2018 (IEEE) Special Session SPS4b: 5G Mobile Network Architecture and New Radio Advances	June 18-21, 2018, Ljubljana, Slovenia	Presented
Anastasios Zafeiropoulos et al	Enabling Vertical Industries Adoption of 5G Technologies: a Cartography of Evolving Solutions	EuCNC 2018 (IEEE)	June 18-21, 2018, Ljubljana, Slovenia	Presented
David Gutierrez Estevez et.al.	Overall 5G-MoNArch Architecture and Implications for Resource Elasticity	EuCNC 2018 (IEEE) Special Session SPS4a: Resource elasticity for 5G network architecture	June 18-21, 2018, Ljubljana, Slovenia	Presented
Pablo Serrano et.al.	On the Benefits of Bringing Cloud-Awareness to Network Virtual Functions	EuCNC 2018 (IEEE) Special Session SPS4a: Resource elasticity for 5G network architecture	June 18-21, 2018, Ljubljana, Slovenia	Presented
Antonio De Domenico, Nicola di Pietro, Ghina Dandachi, and Emilio Calvanese Strinati	Dynamic Deployment of Virtual Network Functions in Heterogeneous Telco Clouds	EuCNC 2018 (IEEE) Special Session SPS4a: Resource elasticity for 5G network architecture	June 18-21, 2018, Ljubljana, Slovenia	Presented
Sina Khatibi, Irina Balan, Dimitris Tsolkas	Slice-Aware Elastic Resource Management	EuCNC 2018 (IEEE) Special Session SPS4a: Resource elasticity for 5G network architecture	June 18-21, 2018, Ljubljana, Slovenia	Presented
Julie Bradford, Simon Fletcher	The Economic drivers for network elasticity	EuCNC 2018 (IEEE) Special Session SPS4a: Resource elasticity for 5G network architecture	June 18-21, 2018, Ljubljana, Slovenia	Presented

Dinh Thai Hoang et.al.	Optimal Cross Slice Orchestration for 5G Mobile Services	IEEE Vehicular Technology Conference (VTC) 2018 Fall	August 27-30, 2018, Chicago, USA	Presented
Michael Einhaus, Mohamad Buchr Charaf, Igor Kim, Paul Arnold	Bandwidth Part Adaptation and Processing Time Evaluation with OpenAirInterface	IEEE VTC 2018 Fall	August 27-30, 2018, Chicago, USA	Presented
Ömer Bulakci et.al.	Identifying 5G System Enhancements: Enabling technologies for multi-service networks	IEEE Conference on Standards for Communications and Networking (CSCN) 2018	October 29-31, 2018, Paris, France	Presented
David Gutierrez Estevez et.al.	5G-MoNArch Use Case for ETSI ENI: Elastic Resource Management and Orchestration	IEEE CSCN 2018	October 29-31, 2018, Paris, France	Presented
Bin Han et.al.	Admission and Congestion Control for 5G Network Slicing	IEEE CSCN 2018 Special Session on 5G-PPP Pre-Standardisation	October 29-31, 2018, Paris, France	Presented
Cristina Marquez, Marco Gramaglia, Marco Fiore, Albert Banchs, Xavier Costa-Perez	How should I slice my network? A multi-service empirical evaluation of resource sharing efficiency Enabling technologies for multi-service networks	ACM Mobicom 2018	October 29 - Nov 2, 2018, New Delhi, India	Presented
Marco Gramaglia, Ignacio Labrador Pavón, Francesco Gringoli, Gines Garcia-Aviles, Pablo Serrano	Design and Validation of a Multi-service 5G Network with QoE-aware Orchestration	ACM WiiNTECH 2018	November 02, 2018, New Delhi, India	Presented
Diomidis S. Michalopoulos, Andreas Maeder, Niko Kolehmainen	5G Multi-Connectivity with Non-Ideal Backhaul: Distributed vs Cloud-Based Architecture	IEEE Globecom WS on Cloudified Architectures for 5G and Beyond	December 9-13, 2018, Abu Dhabi, United Arab Emirates, United Arab Emirates	Presented
David M. Gutierrez Estevez	An Intelligent and Elastic Framework for 5G Architecture	Italian Networking Workshop	January 16-18, 2019, Bormio, Italy	Presented
Marco Gramaglia	Elastic 5G Network Function design and Orchestration: a primer	Italian Networking Workshop	January 16-18, 2019, Bormio, Italy	Presented
Ömer Bulakci, Emmanouil Pateromichelakis	Slice-aware 5G Dynamic Small Cells	IEEE Wireless Communications and Networking Conference (WCNC) 2019	April 15-18, 2019, Marrakech, Morocco	Presented
D. Schinianakis, R. Trapero, D. S. Michalopoulos, B. Gallego-Nicasio Crespo	Security Considerations in 5G Networks: A Slice-Aware Trust Zone Approach	IEEE WCNC 2019	April 15-18, 2019, Marrakech, Morocco	Presented
Bin Han, Vincenzo Sciancalepore, Di Feng, Xavier Costa-Perez, Hans D. Schotten	A Utility-driven Multi-Queue Admission Control Solution for Network Slicing	IEEE International Conference on Computer Communications (INFOCOM) 2019	April 29 - May 2, 2019, Paris, France	Presented

D. Bega, M. Gramaglia, M. Fiore, A. Banchs, X. Costa-Perez	DeepCog: Cognitive Network Managementin Sliced 5G Networks with Deep Learning	IEEE INFOCOM 2019	April 29 - May 2, 2019, Paris, France	Presented
D. Bega, M. Gramaglia, M. Fiore, A. Banchs, X. Costa-Perez	α-OMC: Cost-Aware Deep Learning for Mobile Network Resource Orchestration	IEEE INFOCOM 2019 (Workshop)	April 29 - May 2, 2019, Paris, France	Presented
Michael Einhaus, Igor Kim, Mohamad Buchr Charaf, Jens Klinger	A Framework for RAN Performance Evaluations based on Software Defined Radio	ITG Fachtagung Mobilkommunikation (VDE)	May 15-16, 2019, Osnabrück, Germany	Presented
Diomidis S. Michalopoulos, Volker Pauli	Data Duplication for High Reliability: A Protocol Level Simulation Assessment	IEEE International Conference on Communications (ICC) 2019	May 20-24, 2019, Shanghai, China	Presented
Antonio De Domenico, Ya-Feng Liu, Wei Yu	Optimal Computational Resource Allocation and Network Slicing Deployment in 5G Hybrid C-RAN	IEEE ICC 2019	May 20-24, 2019, Shanghai, China	Presented
Jakob Belschner, Diomidis S. Michalopoulos	A Hybrid Approach for Data Duplication and Network Coding	EuCNC 2019 (IEEE)	June 18 – 21, 2019, Valencia, Spain	Presented
Borislava Gajic, Ruben Trapero Burgos, Diomidis S. Michalopoulos	Telco Cloud Resilience: Synergies between Fault and Security Management	EuCNC 2019 (IEEE)	June 18 – 21, 2019, Valencia, Spain	Presented
Sina Khatibi, Alba Jano	Elastic Slice-Aware Radio Resource Management with AI-Traffic Prediction	EuCNC 2019 (IEEE)	June 18 – 21, 2019, Valencia, Spain	Presented
Mpatziakas A., Papadopoulos S., Khatibi S., Drosou A., Tzovaras D.	Slice-aware resource orchestration of an elastic 5G network via evolutionary algorithms	EuCNC 2019 – Workshop Artificial Intelligence for 5G Networks (IEEE)	June 18 – 21, 2019, Valencia, Spain	Presented
Kunjan Shah, Sina Khatibi, Borislava Gajic	An Analysis of Redundancy Schemes on Cloud Radio Access Network Reliability	EuCNC 2019 – Conference Poster	June 18 – 21, 2019, Valencia, Spain	Presented
Jose A. Ayala-Romero et.al.	vrAIn: A Deep Learning Approach Tailoring Computing and Radio Resources in Virtualised RANs	ACM Mobicom 2019	October 21-25, 2019, Los Cabos, Mexico	Accepted
Michael Einhaus, Mohamad Buchr Charaf, Igor Kim, Paul Arnold	Processing Time Aware Resource Allocation in Software Defined RANs	IEEE International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD) 2019	September 11-13, 2019, Limassol, Cyprus	Submitted
E. Ketzaki, A. Drosou, S. Papadopoulos, D. Tzovaras	vrAIn: A Deep Learning Approach Tailoring Computing and Radio Resources in Virtualized RANs	IEEE International Conference on Networks of the Future (NoF) 2019	October 1-3, 2019, Rome, Italy	Submitted

Scientific magazine or journal articles

The list of scientific magazine or journal articles provided in Table 4-2 is continuous, i.e., all such publications are listed from the beginning until the end of the project. Note that this list includes publications which were still in the status of "submitted" during the preparation of this deliverable.

Table 4-2: Scientific magazine or journal articles

Main author	Title	Title of the periodical or the series	Publisher	Status
Emmanouil Pateromichelakis, Ömer Bulakci, Chenghui Peng, Jiayin Zhang and Yuan Xia	LAA as a Key Enabler in Slice-aware 5G RAN: Challenges and Opportunities	IEEE Communication Standards Magazine, special issue on "Enabling 5G Verticals & Services through Network Softwarisation and Slicing" (invited), Volume 2, Issue 1, March 2018	IEEE	Published
P. Serrano, M. Gramaglia, D. Bega, D. Gutierrez-Estevez, G. Garcia-Aviles and Albert Banchs	The path towards a cloud-aware mobile network protocol stack	Transactions on Emerging Telecommunications Technologies, Volume 25, Issue 5, May 2018	Wiley	Published
L.C. Schmelz, A. Banchs, D. Michalopoulos, O. Bulakci, M. Gramaglia, D. Gutierrez Estevez	5G-MoNArch	The European 5G Annual Journal, June 2018	5G-PPP	Published
Bin Han, Lianghai Ji, Hans D. Schotten	Slice as an Evolutionary Service: Genetic Optimisation for Inter-Slice Resource Management in 5G Networks	IEEE Access, June 2018	IEEE	Published
Paul Arnold and Dirk v. Hugo	Future integrated communication network architectures enabling heterogeneous service provision	Advances in Radio Science Kleinheubacher Berichte, September 2018	URSI	Published
Francesco Gringoli, Paul Patas, Carlos Donato, Pablo Serrano, Yan Grunenberger	Performance Assessment of Open Software Platforms for 5G Prototyping	IEEE Wireless Communication Magazine, Volume 25, Issue 5, October 2018	IEEE	Published
P. Rost, M. Breitbach. H. Roreger, B. Erman, C. Mannweiler, R. Miller, I. Viering	Customised Industrial Networks – Network Slicing Trial at Hamburg Sea Port	IEEE Wireless Communications Magazine, Volume 25, Issue 5, October 2018 Special Issue on 5G Testing and Field Trials	IEEE	Published
Gines Garcia, Marco Gramaglia, Pablo Serrano, Albert Banchs	POSENS: a practical open-source solution for end-to-end network slicing	IEEE Wireless Communication Magazine, Volume 25, Issue 5, October 2018	IEEE	Published
Bin Han, Di Feng, Hans D. Schotten	A Markov Model for 5G Slice Admission Control	IEEE Networking Letters, Volume 1, Issue 1, October 2018	IEEE	Published

V. Sciancalepore, I. Filippini, V. Mancuso, A. Capone and A. Banchs	A Multi-traffic Inter-cell Interference Coordination Scheme in Dense Cellular Networks	IEEE/ACM Transactions on Networking, Volume 26, Issue 5, October 2018	IEEE	Published
Pablo Caballero, Albert Banchs, Gustavo de Veciana, Xavier Costa-Perez, Arturo Azcora	Network Slicing for Guaranteed Rate Services: Admission Control and Resource Allocation Games	IEEE Transactions on Wireless Communications, Volume 17, Issue 10, October 2018	IEEE	Published
Pablo Caballero, Albert Banchs, Gustavo de Veciana, Xavier Costa-Perez	Network Slicing Games: Enabling Customisation in Multi-Tenant Mobile Networks	IEEE/ACM Transactions on Networking, Volume 17, Issue 10, October 2018	IEEE	Published
Dario Bega, Albert Banchs, Marco Gramaglia, Xavier Costa-Perez, Peter Rost	CARES: Computation-aware Scheduling in Virtualised Radio Access Networks	IEEE Transactions on Wireless Communications, Volume 25, Issue 5, October 2018	IEEE	Published
Dario Bega, Marco Gramaglia, Albert Banchs, Xavier Costa-Perez and Vincenzo Sciancalepore	A Machine Learning approach to 5G Infrastructure Market optimisation	IEEE Transactions on Mobile Computing, February 2019	IEEE	Published
Mehrdad Shariat et.al.	A Flexible Network Architecture for 5G Systems	Wiley Transactions on Wireless Communications and Mobile Computing, Volume 2019, February 2019	Wiley-Hindawi	Published
Emmanouil Pateromichelakis et.al.	End-to-End Data Analytics Framework for 5G Architecture	IEEE Access, Volume 7, March 2019	IEEE	Published
Juan Rendon Schneir et.al.	A business case for 5G mobile broadband in a dense urban area	Telecommunications Policy - The International Journal of ICT Economy, Governance and Society, April 2019	Elsevier	Published
Gourab Ghatak , Antonio De Domenico, and Marceau Coupechoux	Small Cell Deployment Along Roads: Coverage Analysis and Slice-Aware RAT Selection	IEEE Transaction on Communications, May 2019	IEEE	Published
Mohammad Asif Habibi, Meysam Nasimi, Bin Han, and Hans D. Schotten	A Comprehensive Survey of RAN Architectures towards 5G Mobile Communication System	IEEE Access, Volume 7, May 2019	IEEE	Published
L.C. Schmelz, A. Banchs, D. Michalopoulos, O. Bulakci, M. Gramaglia, D. Gutierrez Estevez	5G-MoNArch	The 5G Annual Journal, May 2019	5G-PPP	Published
Vincenzo Sciancalepore et.al.	A Future-proof Management and Orchestration	IEEE Access, Volume 7, June 2019	IEEE	Published

	Architecture for 5G Multi-Domain Networking			
C. Marquez, M. Gramaglia, M. Fiore, A. Banchs, X. Costa-Perez	Resource Sharing Efficiency in Network Slicing	IEEE Transactions on Network and Service Management, June 2019	IEEE	Published
David M. Gutierrez Estevez et.al.	Artificial Intelligence for Elastic Management and Orchestration of 5G Networks	IEEE Wireless Communications Magazine, 2019	IEEE	Accepted
Joan S. Pujol Roig, David M. Gutierrez-Estevez, and Deniz Gunduz	Management and Orchestration of Virtual Network Functions via Deep Reinforcement Learning	IEEE Journal on Selected Areas in Communications (Special Issue)	IEEE	Submitted

According to the above tables, the number of conference and journal papers published by 5G-MoNArch during the course of the project amounts to 39 (+ two submitted) and 23 (+ one submitted), respectively. This is a very remarkable achievement that not only meets the initial target established (51 publications as stated in the Grant Agreement) by the project but substantially exceeds such target. However, beyond the number of publications, the aim of 5G-MoNArch has rather been quality and impact, publishing in the top venues in the area and impacting the work of the other researchers.

In terms of the **quality** achieved by 5G-MoNArch publications, we would like to highlight the publications of the project in the following conferences:

- 5G-MoNArch published two papers at ACM MOBICOM. This conference is the very top conference in the area of mobile communications. It is ranked as A* by the CORE conference rankings; this ranking corresponds to excellent conferences and is reserved to a very reduced number of very high-quality conferences. It is worth highlighting that 5G-MoNArch is the only European projects with 2 research paper publications at ACM MOBICOM over this period.
- 5G-MoNArch published 3 papers at IEEE INFOCOM 2019, which is the top conference in networking according to Google Scholar, ranked as A* in the CORE conference rankings.
- 5G-MoNArch published 2 papers at IEEE ICC 2018 and 2 papers at IEEE ICC 2019, which is one of the two flagship conferences of the IEEE Communications Society (jointly with IEEE GLOBECOM).
- 5G-MoNArch also published in other top conferences in wireless communications such as IEEE WCNC, IEEE VTC and CSCN, among others.
- Finally, it is also worth highlighting in terms of conference publications the project contributions at EuCNC at various fronts, including papers, workshops, booths and demo. This provides an excellent venue to share the project scientific results with other EU projects and more broadly with the European research community.

Besides publishing at the very top conferences in the area, 5G-MoNArch has also published a substantial number of articles in the most prestigious journals and magazines in the area. Among others, we can highlight the following ones:

- 5G-MoNArch published two papers at IEEE Transactions on Wireless Communications, which is considered as the best journal in the area of wireless communications. The impact factor of this journal according to the Journal Citation Report (JCR) is of 5.888, being one of the journals with highest impact in the whole area of telecommunications (position 7 out of with the 87 journals).
- 5G-MoNArch published one paper at IEEE Transactions on Mobile Computing. This is a very high-quality journal, regarded as the top journal in the area of mobile computing, with an impact factor of 4.098 at JCR (position 13/87).

- 5G-MoNArch published two papers at IEEE/ACM Transactions on Networking, also a very high-quality journal. This is regarded as the top journal on networking in general (impact factor of 3.110 and position 23/87).
- 5G-MoNArch published four papers at IEEE Wireless Communications, which is the flagship magazine of the IEEE Communications Society. This magazine has a very wide reach, with a very large audience and high impact. Its impact factor in the JCR is of 9.202 and its position is 3/87.

In terms of **impact**, we would like to highlight that some of our papers have reached a substantial number of citations in spite of being very recent papers. Among others, the paper 'Network Slicing Games: Enabling Customisation in Multi-Tenant Mobile Networks', published at the IEEE/ACM Transactions on Networking in April 2019, has already received 36 citations according to Google Scholar, which is a very remarkable achievement in such a short time period. Other papers, such as 'Slice as an Evolutionary Service: Genetic Optimisation for Inter-Slice Resource Management in 5G Networks' and 'How should I slice my network? A multi-service empirical evaluation of resource sharing efficiency Enabling technologies for multi-service networks' have received 14 and 11 citations, respectively, which is a very valuable number given their publication date. Based on their current citation count, we would expect that these papers will end up being highly cited papers in the future, becoming reference papers in the area.

Invited talks and presentations

With the high visibility of the project in the research community and the strong commitment of the involved partners, 5G-MoNArch participants got invited to multiple events (panel discussions, keynotes, talks, presentations) during the runtime of the project, also reflecting the impact achieved by the scientific work and the testbed implementations. These are summarised in Table 4-3. This list is continuous, i.e., all such invited talks, tutorials and presentations are listed that have occurred from the beginning until the end of the project runtime.

Table 4-3: List of invited talks, tutorials and presentations

Main author	Type	Title	Event	Date	Place	Type of audience
CEA-LETI	Keynote presentation	Cloudification of 5G	IEEE International Conference on Cloud Networking - http://cloudnet2017.ieee-cloudnet.org/program/keynotes	September 25, 2017	Prague, Czech Republic	Participants of the conference
Samsung UK	Talk within Seminar	5G Architecture: Key Concepts & View from the 5G-MoNArch Project	Seminar at University of Pavia	February 02, 2018	Pavia, Italy	Graduate and undergraduate students
Nokia DE	Presentation	5G-MoNArch: Turning 5G mobile network architecture concepts into practice	MWC 2018	February 28, 2018	Barcelona, Spain	Participants of MWC 2018
Real Wireless	Talk within workshop	5G-MoNArch project intro	SPEED-5G: Advanced spectrum management in 5G+ networks	March 7, 2018	BT, London, UK	Participants of SPEED 5G workshop

HPA	Talk	Höhere Geschwindig-keit, bessere Konnektivität von Maschinen und Geräten – Einblick in das 5G Projekt der Hamburg Port Authority AöR	VOICE e.V. Regionalgruppe Nord - CIO Organisation in Germany / HPA	March 21, 2018	Hamburg, Germany	CIOs from different Companies in northern Germany
Samsung UK	Talk within workshop	A Flexible 5G Mobile Network Architecture: The 5G-Monarch Approach	H2020 SONNET workshop	March 23, 2018	London, UK	Participants of H2020 SONNET workshop
TIM	Talk within conference call	5G-MoNArch project intro	NWMO periodic conference call	March 28, 2018		NWMO members
HPA	Talk	5G-MoNArch in the Port of Hamburg	Event at DIHK - https://www.dihk.de/en	April 19, 2018	Berlin, Germany	Stakeholder from German Industry
Samsung UK	Talk within workshop	5G-MoNArch project intro	IEEE ICC - 5GArch workshop	May 24, 2018	Kansas City, MO, USA	Participants of the workshop
Real Wireless	Participation in panel session on business case for virtualised networks	Providing insights on the business drivers for flexible 5G virtualised networks (part of panel session)	Cambridge Wireless, "UK5G: Show me the money: Understanding the business case for NFV", https://www.cambridgewireless.co.uk/events/show-me-money-nfv/	May 24, 2018	London, UK	Operators, vendors, UK government groups, infrastructure providers, industry analysts and consultants
Real Wireless	Presentation & panel participation in conference / special sessions	Economic drivers for more engagement between verticals and mobile	EuCNC 2018	June 21, 2018	Ljubljana, Slovenia	Mobile network operators, vendors and academics and other EC 5G-PPP project participants at EuCNC
HPA and DT	Invited talk: Overview of 5G, network slicing, 5G-MoNArch, and Sea Port testbed (joint presentation, split into 2 parts)	Project 5G-MoNArch - Network Slicing Testbed at Hamburg Sea Port	Workshop of Innovation Network Future Car - Phase V on Development Processes, at the Fraunhofer Institute for Industrial Engineering IAO	July 13, 2018	Hamburg, Germany	Vertical industries (e.g., Daimler, Ferrari, Continental, ZF, ThyssenKrupp, Lufthansa) and research institutes
Huawei	Invited Talk	1, 2, 3, 4, ... Counting to Sustainable 5G	5G and what's next?	September 19, 2018	Huawei Brussels	Journalists, Policy

		Networks (includes WP6 results)	Challenges and opportunities			Makers, Open to Public
CERTH	Talk in conference	5G-MoNArch project presentation	IEEE 5G and IoT Thessaloniki Summit 2018, http://www.5gsummit.org/Thessaloniki/	October 25, 2018	Thessaloniki, Greece	Participants of the conference
UC3M	Talk in conference	5G-MoNArch Use Case for ETSI ENI: Elastic Resource Management and Orchestration	IEEE CSCN 2018	October 30, 2018	Paris, France	Attendees to CSCN 2018
Nokia DE	Talk in conference (auditorium)	Pilotprojekt Hamburger Hafen: 5G Network Slices für passgenaue Netze	Smart City Convention	November 22, 2018	Berlin, Germany	Participants of the conference and trade fair
UC3M	Talk in workshop	Elastic 5G Network Function design and Orchestration: a primer	Italian Networking Workshop 2019, https://www.inw2019.polimi.it/program	January 16, 2019	Bormio, Italy	Participants of the conference
UC3M	Talk in Workshop	5G Architecture and Slicing for Customised Networks: the 5G-MoNArch Vision	India EU Stakeholders' Workshop on 5G Technology Landscape https://5g-ppp.eu/india-eu-stakeholders-workshop-on-5g-technology-landscape/	February 5, 2019	New Delhi, India	Participants of the conference
Real Wireless	Presentation at seminar of Dutch Association of Business and Mission critical users	Evolving 5G for industrial applications – Hamburg Port	KMBG (Dutch Association of Business and Mission critical users) seminar, https://www.btg.org/verslag-expertsessie-kritisch-mobiel-in-essentiele-bedrijfsprocessen-13-februari-2019/	February 13, 2019	Nijkerk, The Netherlands	KMBG (Dutch Association of Business and Mission critical users)
UC3M	Talk in PhD school	Elastic Network Operation: Rationale, Challenges and Solutions	5G AURA PhD School	April 2, 2019	York, UK	PhD students from the 5G AURA project

4.2 Panels, workshops and special sessions

One of the goals of 5G-MoNArch is to disseminate the advantages of the developed technologies and innovations into the research community, to analyse such advantages within the research community and accordingly to attain technical feedback. Table 4-4 lists the panels, workshops and special sessions that have been organised on behalf of the project during its runtime, i.e., between July 2017 and June 2019. All related events taking place outside the project runtime are not provided. Note that the contributions to the 5G-PPP Architecture WG, which included a number of workshops (e.g., at EuCNC 2019) are not listed here.

Note that those events that already took place during the first project year, i.e., between July 2017 and June 2018, have already been described in detail in [5GM-D71]. Only for those events that took place during the second project year, i.e., between July 2018 and June 2019, a dedicated description is provided.

Table 4-4: List of panels, workshops and special sessions

Organiser	Type	Title	Event	Date / Place	Publisher
DT, Huawei, TIM	Panel moderation and presentations	Network Slicing for 5G Systems	IEEE / EURASIP International Symposium on Wireless Communication Systems (ISWCS) 2017	August 29, 2017, Bologna, Italy	N/A
Samsung UK, Huawei, Nokia DE	Panel moderation and presentations	5G/NR network architecture: Is it revolutionary or evolutionary?	IEEE Conference on Standards for Communications and Networking (CSCN) 2017	September 20, 2017, Helsinki, Finland	N/A
David M. Gutierrez Estevez, Diomidis S. Michalopoulos, Vincent Wong	Workshop	5G Architecture (5GArch)	IEEE International Conference on Communications (ICC) 2018	May 24, 2018, Kansas City, MO, USA	IEEE
5G-MoNArch WP4	Special Session	Resource Elasticity for 5G Network Architecture	EuCNC 2018	June 21, 2018, Ljubljana, Slovenia	IEEE
5G-MoNArch, ONE-5G project	Special Session	5G Mobile Network Architecture and New Radio Advances (5GMoNANeRA)	EuCNC 2018	June 21, 2018, Ljubljana, Slovenia	IEEE
D. M. Gutierrez Estevez, Y. Wang, A. Gavras, J. M. Alcaraz Calero	Workshop	Artificial Intelligence for 5G Networks	EuCNC 2019	June 20th, 2019, Valencia, Spain	IEEE

Workshop on Artificial Intelligence for 5G Networks

The use of AI for network operation and management is known to have great potential to enhance the network performance and efficiency, therefore has received significant interest in both research and industry standardisation groups. As this standardisation is still in an early stage, and 5G-MoNArch has conducted several efforts – in particular within Work Package 4 – on providing input towards ETSI and 3GPP, the purpose of this workshop was to bring together experts from this area, and to showcase recent 5G-MoNArch research results on the employment of AI to achieve resource elasticity, i.e., an efficient and autonomous utilisation of computational resources in the network, by enhancing the design of VNFs and their scaling mechanisms. This workshop was organised in cooperation with the SliceNet project,

where AI is investigated to achieve cognitive network management to improve both operation experience for network operators and quality of experience for vertical users, especially in the context of network slicing.

Being very well visited, this joint workshop was a full success and achieved its goal to bring together experts from research and standardisation bodies, and to drive the topic forward – even towards further research activities beyond the two projects.

4.3 5G-MoNArch contributions to EuCNC 2018 and 2019

Being the core project within 5G-PPP Phase II on mobile network architecture, 5G-MoNArch has been present at both occurrences of the European Conference on Networks and Communications during the runtime of the project – 2018 in Ljubljana, Slovenia, and 2019 in Valencia, Spain. In the following a short summary of the project's contributions to these two events is provided.

EuCNC 2018

Taking place at the mid-term of the project, the main contribution of 5G-MoNArch to EuCNC 2018 was on disseminating the intermediate research and development results of the technical work packages on the one side, but also to provide a first glance of the ongoing implementation of the two testbeds in Hamburg and Turin as well as the status of the simulation work conducted as part of the verification and validation tasks of Work Package 6. In particular, 5G-MoNArch contributed to, or organised the following sessions:

- 2nd Workshop on business models and techno-economic analysis for 5G networks (project presentation by Real Wireless)
- Special Session 4a on Resource Elasticity for 5G Network Architecture (session chair: Samsung UK) – organised by 5G-MoNArch
- Special Session 4b on 5G Mobile Network Architecture and New Radio Advances (5GMoNANeRA), organised together with the EU project ONE5G (5G-MoNArch session chairs: Nokia, UC3M, Telecom Italia)
- Special Session 5 on 5G Architecture towards Verticals (session chairs: Nokia and Huawei), organised by the 5G-PPP Architecture WG and with core contributions from 5G-MoNArch

5G-MoNArch was furthermore represented with an exhibition booth, which provided a demonstrator from 5G-MoNArch partner NOMOR on network slicing and resource elasticity, together with an updated project video and a number of posters on the scientific work within the project.

In total there were six papers prepared by 5G-MoNArch (cf. Table 4-1) at EuCNC 2018, including papers presented at workshops and special sessions.

EuCNC 2019

This conference – co-located with the 7th 5G Global Event – took place from June 17-21, 2019 in Valencia, Spain, and was the last event with strong 5G-MoNArch contributions and participation during the runtime of the project. The core part hereby was a large booth (see some pictures in Figure 4-1)where a live demonstration of the Turin Touristic City testbed could be presented to the visitors, together with several rollup posters providing background information on the Touristic City testbed setup and installation, on the Hamburg Smart Sea Port testbed, and on results from Work Packages 2 (Architecture), 3 (Resilience and Security) and 4 (Resource Elasticity). These posters are available from the 5G-MoNArch website [5GM-EP]. The booth was very well visited during the two events, with numerous visitors trying out the experience of the Virtual Reality application of the Touristic City testbed, and the distinct impact of migrating this application from the central to the edge cloud during its runtime, showcasing the advances of resource elasticity on the perceived performance (cf. [5GM-D52] on details regarding the implementation).

Besides the booth, 5G-MoNArch participants presented five papers during the conference (cf. Table 4-1), and 5G-MoNArch contributed to, or organised the following sessions:

- Workshop 7: Artificial Intelligence (AI) for 5G Networks, jointly organised by 5G-MoNArch WP4 and the SliceNet project, see https://www.eucnc.eu/workshops/workshop-7/; in two sessions, the core findings on AI-based resource orchestration and the impact on standardisation

were presented and discussed. This workshop was very well received by the visitors, in particular due to the fact that AI currently gains a strong momentum in mobile networks, and the contributions by the two projects could bring the topic clearly forward.

- Workshop 8: International Workshops on 5G Architectures, organised by the 5G-PPP Architecture Working Group and with major contributions from 5G-MoNArch WP2 (also co-chaired by the WP2 lead), see https://www.eucnc.eu/workshops/workshop-8/. The focus of this workshop was on providing an overview about the novelties on the 5G mobile network architecture as brought together in the version 3 of the 5G Architecture Whitepaper [5GP-W19], which was issued for public consultation during the workshop. Main contributions to this workshop from 5G-MoNArch came on the overall architecture and the radio & edge architecture.

Figure 4-1: Pictures from the 5G-MoNArch presence at EuCNC 2019

4.4 Project Advisory Board

The 5G-MoNArch Advisory Board had been set up as a voluntary project external group, which had, according to the description in the Grant Agreement, the role to provide advices on technical directions and potential challenges within the project, to expand and complement the expertise within the project consortium, and to further promote the project's results. The members of the External Advisory Board were chosen to maximise the geographic and topic diversity of the project beyond the addressed use cases and include representatives of vertical industries, operators, technology consulting and organisations that furthermore cover regulatory issues.

More specifically, during the initial phase of 5G-MoNArch, the Advisory Board has ensured that a broader spectrum of opinions regarding the requirements for the mobile network architecture (WP2), and the use cases and functional innovations for resilience & security (WP3) and resource elasticity (WP4) was considered. During the further course of the project, The Advisory Board has ensured that feedback on the project's conceptual work is provided besides the regular exploitation and dissemination activities. For this purpose, the progress of the conceptual work, but in particular results on the verification and validation of the concepts, and the implementation and results of the testbeds have been presented to the Advisory Board members during several phone conferences, to allow for feedback and further advices regarding the applicability of the concept and implementation work to the use cases and applications of the Advisory Board members' organisations.

Confirmed members of the 5G-MoNArch Advisory Board were Continental (Germany), Robert Bosch GmbH (Germany), China Mobile IoT Research Institute (China), ERTICO-ITS Europe (Belgium), Office of Communications (Ofcom, UK), Rysavy Research (USA), and the European tourism association (ETOA, UK). Besides the project external members, representatives of the two mobile network operators (Deutsche Telekom and Telecom Italia) participating in the project contributed to the Advisory Board.

A first teleconference meeting with the 5G-MoNArch Advisory Board took place in March 2018. The purpose of this meeting was mainly to present the requirements and KPIs together with initial conceptual results and findings – in particular the baseline concepts – to the Advisory Board members. More specifically, this included a short wrap-up on the overall project setup and goals, the current status of the 5G-MoNArch initial mobile network architecture concept (WP2) together with the related enabling innovations, the concepts and functional innovations for network resilience and security (WP3), the concepts and functional innovations developed for resource elasticity (WP4), and the scope, planned use cases, and current implementation status of the two project testbeds in Hamburg and Turin (WP5). A number of comments and feedback were given by the Advisory Board members, in particular with respect to the applicability of the 5G-MoNArch network slicing concept to automotive use cases, and with respect to standardisation and regulatory aspects of the initial mobile network architecture and the functional innovations.

A second teleconference meeting with the 5G-MoNArch Advisory Board took place in January 2019. The purpose of this second official meeting was to present the almost finalised results of the conceptual and development phase of 5G-MoNArch (covering WP2, 3 and 4) to the advisory board members. A particular focus, however, was on the presentation of the current status of the implementation of the two testbeds in Turin and Hamburg, and first insights – including a live demonstration – on the operation of the Hamburg testbed. Furthermore, the concepts for the techno-economic validation of the 5G-MoNArch concepts were presented, including the intermediate results on this work. Of particular interest for the consortium was thereby to gather further feedback on the implemented methodology as well as on the relevance of the results from the perspective of the Advisory Board members. In so far, the selected date for the presentation was important as the WP6 work entered its final phase.

Besides the teleconferences, the Advisory Board members were invited to the 5G-MoNArch presences at EuCNC, the ICT 2018 conference, the MWC presence in particular in 2019, and the two dissemination events in Turin (May 2019) and Hamburg (June 2019). Further discussions with some of the Advisory Board members took place at these events.

4.5 Impact summary

The following Table 4-5 presents a summary of the most important achievements for the dissemination of the project to the scientific community in terms of quantitative measures.

Table 4-5: Overall results for the scientific dissemination.

Conference papers	39
Journal and magazine articles (incl. special editions)	23
Invited talks, presentations and keynotes	20
Workshops, special sessions and panels (co-) organised by the project	6

5 5G-MoNArch dissemination events

Within the two years of the project runtime, 5G-MoNArch has been present at multiple events in order to present the project's scope, goals, approach, research and (testbed) implementation results, but also to exchange with stakeholders from industry and research in order to get further feedback and input on the project's work.

Being very successful with this approach, it is to be mentioned in particular that 5G-MoNArch has been selected among all the 5G-PPP projects to be present at the Mobile World Congress both in 2018 (in the Mobile World Capital booth) and in 2019 (in the 5G IA booth), see Section 1.5. Moreover, a project presence has been organised also in other large exhibitions, like the EuCNC in 2018 and in 2019 (cf. Section 4.3), and at the European ICT conference 2018 in Vienna, see Section 1.6.

The above-mentioned events, organised by the scientific or industrial community, had some limitations in live presenting the implementation and functioning of the two project testbeds, which represent a major outcome of the project. For this reason, the project organised two specific events dedicated to the public, both having a clear scope on the testbeds, taking place in Turin on May 22 to 24th, 2019, and in Hamburg, on June 5th, 2019.

5.1 Turin Touristic City event

The first public event organised by 5G-MoNArch to showcase the results of the two years activity on elasticity in Network Slicing implementation took place in Turin, in Palazzo Madama premises, on May 22 to 24, 2019. The full details of the testbed, from a technical point of view, are available in [5GM-D52].

The first two days of the event, May 22 and 23, were dedicated to the general public, in an effort to strengthen the Public Relation framework of the project to show to the tourists the outcome of the project research in an easily understandable approach. The tourists that experienced the Virtual Reality demo were asked to answer some questions prepared by the Innovation Management of the project and by the WP6 (details are available in [5GM-D62] and [5GM-D63]).

The last day, May 24, was an invitation-only event with a dedicated session in the Congress Room of Palazzo Madama, with the attendance of around 70 delegates coming from TIM, City of Turin municipality, Fondazione Torino Musei, members of the project, members of ICT-19 projects such as 5G-Tours and 5G-Solutions, other companies like Ericsson, RAI Radio Televisione Italiana, and other interested players in the arena of 5G. Four presentations were given: after the one of the Project Manager of 5G-MoNArch, the Head of Technology and Innovation of TIM presented the plans of the company for 5G in the next years. Afterwards, the General Director of the Fondazione Torino Musei, owner of the Palazzo Madama premises, explained the importance of Virtual Reality applications in the museums experience all over the world. Finally, the Deputy Mayor of the City of Turin illustrated the importance of 5G innovations for the City of Turin, with a central role for the European Projects. In this context, 5G-MoNArch was a first opportunity for the city to interact with local partners in the context of the H2020 program of the European Commission.

After the session a visit of the demo in Palazzo Madama bookshop followed still on May 24th. More than 50 people had the opportunity of using the Virtual Reality application where a latency issue was added artificially to illustrate the benefits of the orchestration functionalities in the Network Slicing based set-up of the network.

Figure 5-1 shows some pictures of the event on May 24th.

Figure 5-1: Pictures from 5G-MoNArch event in Turin on May 24th, 2019

5.2 Hamburg Smart Sea Port event

The focus of the second public event, organised by 5G-MoNArch on June 5th in the premises of Dialoghaus Hamburg, was twofold: (i) public presentation of all use cases and features of the Hamburg Smart Sea Port testbed, and (ii) the public presentation of the main results of the research and innovation work of the technical work packages. The event was organised in form of an exhibition, with a dedicated booth for each Smart Sea Port testbed demonstration / use case and for the technical work packages, including also the Turin Touristic City testbed. Two introductory talks were given to the visitors: the first one providing an overview about the 5G-MoNArch project and the exhibition, and the second one on the challenges and solutions for the future sea port, providing the perspective of HPA on the outcome of the Smart Sea Port testbed implementation. The event targeted the research community as well as stakeholders of industrial 5G use cases and sea ports. The around 40 participants of the workshop came from almost 20 companies and institutions external to the project consortium, indicating the high relevance of the presented topics and the testbed showcases given. In particular, several port operators (besides HPA, the ports of Le Havre, France, and Montreal, Canada were present), IT service providers (e.g., a representative of the IT integrator of the port of Rotterdam) and other companies active in the area of sea ports and related businesses were present. The feedback by the participants was very good, directly provided to the presenters as well as through the feedback forms provided through WP6 which will be integrated in deliverable D6.3 [5GM-D63]. Figure 5-2 shows some pictures from the event.

Booths for the Smart Sea Port testbed:

- Network slice creation and management – fast and scalable service-specific networking: real-time design, creation, deployment and deletion of network slices in the live testbed through the testbed's GUI
- Network slice isolation – highly reliable traffic light control: impact of slice isolation on the performance of the traffic light control, in particular with respect to latency; since the actual traffic light of the testbed is installed at a road far away from the event location, for the purpose of the event, a mobile traffic light has been installed in front of the building, such that the isolation impact could directly be seen
- Multi-connectivity – IoT sensors on mobile barges for environmental measurements: the live measurements from the three barges roaming in the port could be monitored live
- New services – eMBB improved port operations using connected AR headsets: two dedicated demonstrations of the Augmented Reality (AR) applications were given to the visitors in particular to visualise the importance of the digital technologies within the smart sea port scenarios

Booths for the technical work packages and the Turin Touristic City testbed:

- Touristic City testbed demonstration – implementing E2E 5G network slicing and resource elasticity for a new experience in a virtual museum visit at Palazzo Madama, Turin (posters and video recording from the event in Turin on May 22-24, 2019)
- 5G flexible and adaptive architecture (WP2) – functions supporting and enabling a diverse range of use cases and services (poster and slides) and their interconnection with different representations (reference point and service-based); including the highlights of the novel concepts introduced by 5G-MoNArch
- Resilience, reliability and security (WP3) – functions for enabling industrial use cases (poster) through dual connectivity, data duplication and network coding as implemented in the Smart Sea Port testbed
- Resource elasticity (WP4) – functions for enabling multimedia & entertainment use cases (poster and slides) with different approaches for elasticity, the architectural implications and the concepts for the use of Artificial Intelligence for elastic management & orchestration
- Verification of technical results (WP6) – setup of verification methodology and the evaluation framework, and results for relevant KPIs (poster and slides)
- Techno-economic verification (WP6) – what benefits do the solutions developed by 5G-MoNArch provide to ports and industry (poster and slides), including an introduction of the evaluation scenarios used for the analysis

Figure 5-2: Pictures from 5G-MoNArch event in Hamburg on June 5th, 2019

5.3 Impact summary

The following Table 5-1 summarises the impact to stakeholders through the two public events organised by 5G-MoNArch in terms of quantitative measures.

Table 5-1: Impact of 5G-MoNArch events

Number of attendees in Turin general public days	Around 100 visitors
Number of attendants to Turin event	Around 70 people (City of Turin, Fondazione Musei di Torino, TIM and others)
Number of attendants to Hamburg event	Around 40 people from 16 different companies external to the project consortium, including port operators, information technology service providers, city representatives and others

6 Exploitable Results

As already stated in [5GM-D71] the project has given the greatest relevance to the exploitation process, starting from the statements of the partners in the Declaration of Work of the project, and having the first check already after one year in the above-mentioned deliverable. The summarised information about the exploitation topics of the whole consortium is provided in Table 6-1. This information with its structure has been confirmed and updated in the course of project Year 2.

To specifically provide more detailed information about the 5G-MoNArch partners' exploitation results after Year 2, and their plans beyond the runtime of the project, the overall list of exploitable results as provided in Table 6-1 is complemented by providing the partners' exploitation achievements and plans in Section 6.2. In Section 6.2, each partner provides a brief summary on the internal exploitation activities and provides a detailed explanation on each of the relevant exploitation items from Table 6-1.

A summary of the exploitation achievements – per type of project partner – is provided finally in Section 6.3.

6.1 Exploitation plan

The following Table 6-1 provides an overview about the plan for exploitable results for all project partners, with

- a description of the result, the product or measure for which the result is planned to be used within the partner companies,
- the sectors of application within the different partner organisation types,
- the expected time plan / schedule for use of the result (or its implementation),
- the related 5G-MoNArch deliverables where these results are described,
- the owners of the result, i.e., the project partners which regard the result as relevant to be exploited by and within their organisation.

Table 6-1: Exploitation plan - overview of exploitable results

Description of exploitable result / knowledge	**Exploitable product(s) or measure(s) in which the result / knowledge will be used**	**Sector(s) of application**	**Time-plan for use**	**Deliverable(s) to which 5G-MoNArch deliverables / results does the topic relate to**	**Owner and other beneficiaries involved**
Extension of existing simulation tools	Research studies; verification of concepts and products; consultancy; participation in research projects; PhD theses;	Vendors; operators; research SMEs; simulation tool vendors; education; government and regulatory groups; wireless users and site and infrastructure providers.	2017-2020	D6.1 [5GM-D61]; D6.2 [5GM-D62]; D6.3 [5GM-D63]; D2.2 [5GM-D22]; D2.3 [5GM-D23]; D3.2 [5GM-D32]; D4.2 [5GM-D42]	NOK NOMOR CEA LETI HWDU SRUK RW
Open source software solution for e2e slicing to support intra-slice orchestration	Scientific papers, PhD theses, teaching, verification of concepts, development of NFV program	Prototypes, research proof of concepts	2018-2020	https://github.com/wnlUc3m	UC3M ATOS

Novel Master Courses	UC3M: "Specialist in 5G Networks" (5 courses updated) TIM: novel 5G courses for TIM and its subsidiaries UKL: exploration of 5G-MoNarch topics in Seminar courses	Education, Industry	2018-2019	https://www.uc3m.es/ss/Satellite/Postgrado/en/Detalle/Estudio_C/1371232764892/1371219633369/Master_in_NFV_and_SDN_for_5G_networks#program	UC3M TIM UKL
Knowledge on 5G mobile network architecture	Product development; competence building, service development for future 5G scenarios	Vendors; operators; research SMEs; simulation tool vendors; education	2017-2020 and beyond	D2.1 [5GM-D21]; D2.2 [5GM-D22]; D2.3 [5GM-D23]	TIM NOK ATOS HWDU SRUK DT CEA LETI
Knowledge on 5G network slicing	Product development; competence building, service development for future 5G scenarios, adaptation of portfolio, service development, open new lines of investigation, enable new business opportunities; Scientific papers; Patents; consultancy on 5G network slicing opportunities to deliver new services and network implications.	Vendors; operators; research SMEs; simulation tool vendors; education; government and regulatory groups; wireless users and site and infrastructure providers.	2017-2020 and beyond	D2.1 [5GM-D21]; D2.2 [5GM-D22]; D2.3 [5GM-D23]; D6.3 [5GM-D63]	TIM NOK ATOS HWDU SRUK DT UKL MBCS CEA LETI RW CERTH
Knowledge on orchestration in 5G mobile networks	Product development; competence building, service development for future 5G scenarios	Vendors; operators; research SMEs; simulation tool vendors; education	2017-2020 and beyond	D2.1 [5GM-D21]; D2.2 [5GM-D22]; D2.3 [5GM-D23]; D4.1 [5GM-D41]; D4.2 [5GM-D42]	TIM NOK ATOS HWDU SRUK DT CEA LETI
Knowledge on data analytics in 5G mobile networks	Product development; competence building, service development for future 5G scenarios	Vendors; operators; research SMEs; simulation tool vendors; education	2017-2020 and beyond	D2.1 [5GM-D21]; D2.2 [5GM-D22]; D2.3 [5GM-D23];	HWDU SRUK
Knowledge on requirements and concepts to achieve resilience in 5G mobile networks	Scientific papers, product development, competence building, service development for future 5G scenarios, consultancy on ability of 5G to deliver new services and network dimensioning implications	Vendors; operators; research SMEs; simulation tool vendors; education; industrial wireless user groups; infrastructure providers	2017-2020 and beyond	D3.1 [5GM-D31]; D3.2 [5GM-D32]; D6.3 [5GM-D63]	TIM NOK ATOS HWDU DT UKL RW

Knowledge on requirements and concepts to achieve security in 5G mobile networks	Scientific papers, product development, competence building, service development for future 5G scenarios	Vendors; operators; research SMEs; simulation tool vendors; education	2017-2020 and beyond	D3.1 [5GM-D31]; D3.2 [5GM-D32]; D6.3 [5GM-D63]	TIM NOK ATOS DT CERTH
Knowledge on requirements and concepts to achieve resource elasticity in 5G mobile networks	Service development for future 5G scenarios, service development for future 5G scenarios, consultancy on ability of 5G to deliver new services and network dimensioning implications	Vendors, operators; wireless users; infrastructure providers	2017-2020 and beyond	D4.1 [5GM-D41]; D4.2 [5GM-D42]; D6.3 [5GM-D63]	TIM ATOS SRUK DT CEA LETI RW
Knowledge on operators' view on importance and timeline for SON functions and on operators' view on SON management	Product development; competence building, service development for future 5G scenarios	Vendors; operators	2017-2020 and beyond	D2.2 [5GM-D22]; D2.3 [5GM-D23]	TIM NOK ATOS HWDU
Knowledge on SDN / NFV in 5G mobile networks	Product development; competence building, service development for future 5G scenarios	Vendors; operators; education	2017-2020 and beyond	D2.1 [5GM-D21]; D2.2 [5GM-D22]; D2.3 [5GM-D23]; D3.1 [5GM-D31]; D3.2 [5GM-D32]	NOK
Knowledge of AI/data analytics-based network mechanisms	Patents, Scientific papers, PhD theses, teaching material	Education and Research	2017-2020 and beyond	D4.1 [5GM-D41]; D4.2 [5GM-D42]	SRUK UC3M CEA LETI NOMOR CERTH MBCS DT
Knowledge on Proof of Concept development	Scientific papers, product development, competence building	Education and Research, Prototypes, research proof of concepts	2018-2020 and beyond	D5.1 [5GM-D51]; D5.2 [5GM-D52]	UC3M CEA LETI HWDU
Knowledge and practical experience on network slice integration into IT-processes	Three operational prototypes in port of Hamburg	verticals; wireless users;	2018-2020	D5.1 [5GM-D51]; D5.2 [5GM-D52]	HPA
Knowledge and industry insights on the business drivers for and wider socio-economic value of 5G networks and 5G-MoNArch innovations	Industry validated inputs and assumptions and 5G business case analysis framework that can be applied in future consultancy and research projects.	Vendors; operators; government and regulatory groups; wireless users and site and infrastructure providers.	2017-2020 and beyond	D6.1 [5GM-D61]; D6.2 [5GM-D62]; D6.3 [5GM-D63]; D2.3 [5GM-D23]; D4.2 [5GM-D42]	RW SRUK NOK

Knowledge, expertise and experience in developing multi-slice high bandwidth and concurrently low latency mobile applications such as those in VR and AR	VR application in Turin Testbed	verticals; wireless users;	2018-2020	D5.1 [5GM-D51]; D5.2 [5GM-D52]	CERTH
Experience on the planning and implementation of a distributed testbed platform	Product development; competence building; verification of concepts and products, service development for future 5G scenarios	Vendors; operators	2018-2020 and beyond	D5.1 [5GM-D51]; D5.2 [5GM-D52]	TIM NOK ATOS HWDU
Experience on the implementation of network slicing in a testbed	Product development; competence building; verification of concepts and products, service development for future 5G scenarios	Vendors; operators	2018-2020 and beyond	D5.1 [5GM-D51]; D5.2 [5GM-D52]	TIM NOK ATOS HWDU SRUK DT
Experience on the implementation of an orchestrator in a testbed	Product development; competence building; verification of concepts and products, service development for future 5G scenarios	Vendors; operators	2018-2020 and beyond	D5.1 [5GM-D51]; D5.2 [5GM-D52]	TIM NOK ATOS HWDU DT
Experience with the implementation of multiple applications in a testbed	Product development; competence building; verification of concepts and products, service development for future 5G scenarios	Vendors; operators	2018-2020 and beyond	D5.1 [5GM-D51]; D5.2 [5GM-D52]	TIM NOK ATOS HWDU MBCS DT
Standardising on value creation and capture analysis frameworks for Socio-economic contexts	Methodology and standard process for assessment of value creation in new industrial sectors	Vendors; operators; government and regulatory groups; wireless users and site and infrastructure providers.	2018-2020 and beyond	D6.1 [5GM-D61]; D6.2 [5GM-D62]; D6.3 [5GM-D63]	RW
KPI improvement, techno-economics of 5G-MoNArch innovations	Methodology for verification & validation of 5G systems	Vendors; operators; research SMEs; simulation tool vendors; government and regulatory groups; wireless users and site and infrastructure providers.	2018-2020 and beyond	D6.1 [5GM-D61]; D6.2 [5GM-D62]; D6.3 [5GM-D63]	DT RW CERTH UC3M UKL TIM NOK NOMOR MBCS CEA LETI

6.2 Exploitation results per partner

6.2.1 Nokia Germany and France (NOK-DE and NOK-FR)

Powered by the research and innovation of Bell Labs Research, Nokia serves communications service providers, governments, enterprises and consumers, with the industry's most complete, end-to-end portfolio of products, services and licensing. Nokia invests significant efforts in research & development activities on 5G, and with the innovations initiated by the 5G-MoNArch results the features of several Nokia products will be enhanced. For example, results on softwarisation will be brought to the cloud technologies integrated in many Nokia products, and the features developed for network reliability (multi-connectivity), resilience and security (fault detection) play an important role for enhancing the AirScale radio base station product line, the cloud platforms for the core network (including the AirFrame server products), and the IoT portfolio with features particularly targeting services and applications for industrial use cases and customers. The architectural extensions developed in 5G-MoNArch contribute to the further development of features for network slicing, such as the implementation of the full network slice lifecycle feature set into the networking as well as software products. Selected innovations developed as part of the project work have been filed as patent applications, with the goal to strengthen Nokia's patent portfolio that form the basis for product developments.

The implementation of the Hamburg Smart Sea Port testbed has played a central role on the exploitation activities for Nokia. This testbed addressed a number of use cases with strong commercial interest within the ecosystem of sea ports, but also industry and smart city stakeholders. The setup of the testbed has been a cooperative effort of a vertical (HPA), an operator (Deutsche Telekom) and Nokia as a vendor, has been implemented using Nokia pre-commercial products that have been extended with 5G-MoNArch functionality and has deployed into a production environment of Deutsche Telekom. The gained experience already impacted the development of improved solutions and products (hardware and software) in Nokia's mobile networks and IoT portfolio. The 5G-MoNArch project thereby supported Nokia to maintain and extend its technical and market position in the mobile networks market for 5G.

The involvement in 5G-MoNArch and the collaboration with the project partners has clearly contributed to deepening Nokia's knowledge in 5G mobile network architecture, network management, orchestration, slicing and softwarisation. It helped Nokia to further strengthen its involvement in the relevant standards bodies, through the strong relationship the Nokia Bell Labs staff contributing to the project has with Nokia's business groups. This can be seen from the corresponding standards contributions – to be mentioned are particularly 3GPP SA2 (Architecture) and SA5 (Network Management). The involvement in 5G-MonArch also paved the way for Nokia to learn and experiment various open source tools and emulators. This acquired expertise will be reinvested during future research activities and projects, the development of products and solutions, and consultancy activities.

Description of exploitable result / knowledge	**Detailed description**
Extension of existing simulation tools	As part of the work conducted by Nokia within the 5G-MoNArch project several simulations on various topics have been conducted. This included, for example, the SDN-C framework, Kubernetes orchestrator, the srsLTE protocol stack, and analytics simulators for network optimisation. The corresponding simulation environments – partially open-source-based – could be improved, or new features could be added. Thereby, future simulations in particular within research can be improved and lead to more realistic results.

Knowledge on 5G mobile network architecture	In the context of the work conducted in WP2 and WP3, the knowledge on requirements and capabilities of 5G mobile network architecture could be enhanced. This knowledge was particularly built up with the development of the additional enablers for the overall architecture, the features for resilience and security, and with their integration in the overall architecture. The gained knowledge will play an important role in the research and development of further use case and service-/application-specific features, and their integration into the overall 5G mobile network architecture together with the development of future 5G scenarios. The gained knowledge has furthermore been exploited within the Nokia standardisation activities and towards the business units for product development of 5G features and solutions.
Knowledge on 5G network slicing	The knowledge gained in the work in particular in WP2 and WP3 has been exploited within Nokia for the definition of further research topics going beyond the 5G-MoNArch scope, in particular with respect to the interworking between network slicing and network management. The competence building will positively impact further research activities, including the definition of new research areas, and has already led to the definition of new Ph.D. thesis works in this area. The development of future products and solutions as well as of services and applications for future 5G scenarios has been leveraged by the acquired knowledge on network slicing and opened new business opportunities for Nokia in particular for industrial networks. The gained knowledge has furthermore been exploited within the Nokia standardisation activities.
Knowledge on orchestration in 5G mobile networks	Within WP2 and WP5, Nokia has been among the major contributors of a multi-domain orchestration solution for 5G mobile networks. On the conceptual side (WP2 results), this has been exploited for White Papers on Network Slicing Orchestration for internal training and dissemination as well as the definition of new research topics in Bell Labs. Regarding work for the Hamburg Sea Port testbed (WP5 results), the implementation has been done in cooperation with product development teams. Hence, the major findings and identified gaps could immediately be exploited for improvements of products in the network and service orchestration domain.
Knowledge on requirements and concepts to achieve resilience in 5G mobile networks	In the context of the WP3 work, a deep understanding on resiliency requirements across different use cases has been developed. Furthermore, through the development of enablers for achieving such resiliency requirements additional knowledge has been built, especially with respect to challenges and trade-offs in terms of e.g. economic costs, complexity and performance. The acquired knowledge has been used in further research and standardisation activities from Nokia regarding the industrial networks.
Knowledge on requirements and concepts to achieve security in 5G mobile networks	Within the WP3 work significant improvements in the security competence as well as the knowledge on the relationship between security and resilience issues has been achieved. In particular, through the detailed analysis of interrelations between the security, fault and resource management, a more comprehensive insight on use-case specific network deployment has been gained. Such insights have been further used within Nokia for improvement of 5G features and solutions.
Knowledge on operators' view on importance and timeline for SON functions and on operators' view on SON management	With the work on the overall network architecture, but also the work on the resilience and security features and the implementation of these into the Hamburg testbed some further insight could be gained on the requirements for an automated operation on a network slicing-enabled mobile network. These insights were used e.g. to define further research activities in the area of network automation and cognitive management for 5G.
Knowledge on SDN / NFV in 5G mobile networks	With the work conducted in WP2 and WP3, the knowledge on the implementation of SDN and NFV concepts and principles in 5G mobile networks (architecture) could be enhanced. This had an impact on the development of further research work with the definition of project topics beyond 5G-MoNArch and the further development of simulation tools. Furthermore, with the gained knowledge the development of patent-related concepts and the input to standardisation could be strengthened.

Knowledge and industry insights on the business drivers for and wider socio-economic value of 5G networks and 5G-MoNArch innovations	In particular with the implementation of the Smart Sea Port testbed, where a close cooperation with DT and HPA took place, but also the work conducted within WP6 on the techno-economic analysis helped Nokia on the definition of research topics related to 5G industrial communication. Furthermore, the gained insights have been discussed and handed over to the business units, in particular to the solutions business where these insights helped to improve the solutions for industrial customers.
Experience on the planning and implementation of a distributed testbed platform	The planning and implementation of the Hamburg testbed was a core task for Nokia within the 5G-MoNArch project. In particular with the cooperation between HPA (as "customer"), DT (as "operator") and Nokia (as "vendor") some experience on the requirements and processes associated with such a testbed implementation could be gained. These will be used to improve the implementation of future (cooperative) testbeds and trials.
Experience on the implementation of network slicing in a testbed	Several findings from the implementation of network slicing into the Hamburg testbed were of relevance for Nokia in the planning and implementation of other testbeds and trials. This included the preparation of Android-based terminals that support Access Point Name (APN)-based network slicing as well as the implementation of the corresponding protocol stack into Nokia base stations. These findings were handed over from the research departments involved in 5G-MoNArch to the supporting business units.
Experience on the implementation of an orchestrator in a testbed	The experience gained with the implementation of the orchestrator for the Smart Sea Port testbed contributed to the definition of research topics and concepts going beyond the scope of 5G-MoNArch. The experience furthermore contributed to the improvement of corresponding network functions within the commercial 5G product prototypes within Nokia.
Experience with the implementation of multiple applications in a testbed	Implementing multiple applications with clearly different requirements, capabilities and characteristics into the Smart Sea Port testbed strongly contributed to strengthening the competence in particular of the Nokia research departments on the development of such environments. This experience could be used e.g. for the implementation of other testbeds and demonstrators within projects beyond 5G-MoNArch, including demonstrators shown e.g. at trade fairs such as MWC or the Hannover Messe.
KPI improvement, techno- economics of 5G-MoNArch innovations	The findings from 5G-MoNArch enablers evaluation has improved the competence on the enablers' performance. For example, the evaluation with respect to WP3 enablers in terms of wide-network simulations and techno-economic evaluation conducted in WP6 has shown the performance of resilience enablers. Such knowledge has been further used within Nokia for improving the 5G features and solutions.

6.2.2 Universidad Carlos III de Madrid (UC3M)

The target of the University Carlos III of Madrid (UC3M) within 5G-MoNArch has been to create knowledge in different subjects, disseminate them to the scientific community and provide advanced training courses for the students enrolled in the university degrees.

The participation in the 5G-MoNArch project has provided the University Carlos III of Madrid with a very deep understanding of 5G Network Communications Standard, with a particular focus on the architectural and implementation aspects. This knowledge has been leveraged in the following courses, which were created by UC3M during the course of the project: (i) Master in NFV and SDN for 5G networks, (ii) Specialist in NFV/SDN, (iii) UC3M Specialist in 5G Networks, (iv) Master on 5G, (v) Bachelor on Big Data, and (vi) Master on Connected Industry. These courses provide very advanced content on 5G networks which is closely related to the knowledge created by 5G-MoNArch. This represents a very useful contribution to society, as these courses will help to create better engineers in a critical area with very high economic impact.

-The close collaboration with very important operators, vendors and manufacturers enabled by the project allowed University Carlos III of Madrid to improve the skills of the Ph.D. and M.Sc. students and engineers involved in the project. In particular, the UC3M involved four Ph.D. students, three

engineers and a number of M.Sc. students in the project. As a result of their participation, these professionals have become better qualified, being a potentially strong asset for European industry.

One of the goals of UC3M in the project has been to produce high quality scientific research in the field of 5G virtualised networks. Within 5G-MoNArch, UC3M has published its research findings in the top journals and conferences in the field and has also contributed to the organisation of leading conferences in the area and the edition of top journals and special issue. These results have contributed to position the research group of UC3M involved in the project at the forefront of a highly relevant scientific area, gathering the recognition of the international research community.

Finally, the involvement of the University Carlos III of Madrid in the advanced testbeds developed by the project allowed to strengthen the skills on the 5G networks standards implementations, which have also been partially contributed to the open source. This provides a strong basis for transferring the technology developed by the project to the economic sector, either through contracts with industry or the creation of spin-offs. UC3M has a proven record of creating successful spin-offs, and the research group involved in 5G-MoNArch has executed a large number of industry contracts.

Description of exploitable result / knowledge	**Detailed description**
Open source software solution for e2e slicing to support intra-slice orchestration	With the work conducted in WP4 (for the theoretical design) and WP5 (for the implementation) of novel elastic network orchestration software in a network slicing aware network, several research papers (see Section 4) and Open Source code have been produced. Moreover, as the work done in WP5 has also been selected as PoC for the ETSI ENI ISG, it also allowed to increase the future standardisation impact opportunities.
Novel Master Courses	Five master courses (M.Sc.) at the university on the degree "Specialist in 5G Networks" have been updated based on the knowledge and experience gained within the course of the project, in particular based on the results on the overall network architecture (WP2) and on resource elasticity (WP4). The project results have also been fed to courses in the following degrees: (i) Master in NFV and SDN for 5G networks, (ii) Specialist in NFV/SDN, (iii) Master on 5G, (iv) Bachelor on Big Data, and (v) Master on Connected Industry
KPI improvement, techno- economics of 5G-MoNArch innovations	The involvement in WP6 was helpful to improve the skills in the field of the methodology for verification and validation of 5G systems. In particular, this allowed to extend the knowledge towards the usage of new Big Data tools in this context. In particular one MsC thesis has been finalised in this topic.
Knowledge of AI/data analytics-based network mechanisms	Big Data and Artificial Intelligence techniques are nowadays very hot topics in the networking research. The work in WP4 was leveraged for being among the first to propose AI-Based solutions for problem such as Network Slice admission Control and Resource Allocation (see Section 4). Currently, two PhD thesis are being pursued on these topics.
Knowledge on Proof of Concept development	The work done in WP5 in the context of the touristic city testbed has been leveraged to improve the skills on two concrete topics (i) the creation of scientific demonstrators tailored also to the general public (as the Turin testbed) and (ii) its dissemination into the standardisation efforts promoted by the ETSI ENI ISG. This will also allow to further strengthen the possible future impact of UC3M in this area, which is expected to be key in the next years.

6.2.3 Deutsche Telekom (DT)

Deutsche Telekom is investing significant resources on the deployment of 5G networks. On March 26, 2019, the first commercial European 5G network has been taken into operation by its Austrian subsidiary T-Mobile Austria. In particular, professional mobile radio applications in vertical industries (e.g. automotive, e-health etc.) are expected to benefit from the novel features of 5G. Network Slicing is a key feature in 5G and seen as enabler allowing to provide application-specific networks for applications with fundamentally different requirements in a cost-efficient manner.

Deutsche Telekom has already been involved in FP7 project METIS and later on in 5G-PPP Phase 1 projects 5G NORMA and METIS-II. With its engagement in 5G-MoNArch, DT has continued these activities to further evolve 5G network technologies and trial them in a real-life environment.

The design of network slices, their orchestration and management during runtime are key research activities for network operators like Deutsche Telekom. The experience obtained as part of the work within Work Package 2 on network architecture have been brought to standardisation bodies like 3GPP and GSMA's NEtwork Slicing Task force (NEST), and they are exploited in DT's internal work on 5G network design. The validation of 5G KPIs and the techno-economic analysis performed in 5G-MoNArch will provide valuable guidance for DT's network design.

Reliability and availability of the communication network are critical requirements for many industries, like automotive, manufacturing or e-health. The expertise on data duplication and network coding, gained within 5G-MoNArch WP3 will be beneficial in network design as well as in joint design activities with suppliers for the respective network components.

The RAN system level simulator as well as the lab tests based on enhancements of open source radio protocol stacks developed by the 'Hochschule für Telekommunikation Leipzig' (HfTL) and DT within 5G-MoNArch WP4 contributed to a deeper understanding of the potential and the challenges of RAN virtualisation.

The 5G-MoNArch testbed in Hamburg has been highly beneficial to demonstrate the capabilities and potential benefits of 5G networks and network slicing for industrial applications to users. The gathered data and hands-on experiences made in testbed setup and operation will influence the design of DT's future 5G networks.

A more specific description of the most important exploitation items for DT is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Knowledge on 5G mobile network architecture	In the context of WP2, WP3 and WP4, DT has enhanced its knowledge on 5G network architecture, reliability aspects and radio resource management. The gained knowledge plays an important role in the setup of DT's future 5G networks. It is instrumental for the development of new products and services addressing the needs of vertical industries. The knowledge is beneficial for defining the requirements on 5G network equipment for discussions with equipment manufacturers as well as in network design and planning.
Knowledge on 5G network slicing	Requirements of future network services, in particular those addressing vertical industries, are likely to become more heterogeneous in the future. Thus, network slicing will play a major role in the design of DT's networks. The knowledge gained in WP2 and WP5 will be exploited in the development of network slicing concepts for DT's 5G networks and the development of new services for users from vertical industries.
Knowledge on orchestration in 5G mobile networks	DT's engagement in WP2 has been used for competence building on lifecycle management procedures for sliced networks. The gained experiences contribute to investigations on DT's OSS / BSS tools and operational procedures for its future 5G networks. Furthermore, the gained knowledge has been exploited by contributions to GSMA's Network Slicing Task Force, which has been chaired by DT.
Knowledge on requirements and concepts to achieve resilience and reliability in 5G mobile networks	Ultra-reliable networks are foreseen to be an important enabler for industrial usage of mobile networks. For DT as a network operator it is of importance to study and compare different concepts and algorithms to prepare corresponding future service offerings. In this regard, the work within WP3 of 5G-MoNArch provided important insights on the characteristics of the RAN reliability schemes Data Duplication and Network Coding as well as on resilient Telco Cloud operation. The results developed by DT with respect to RAN reliability were also published in a paper at EuCNC 2019.

Knowledge on requirements and concepts to achieve security in 5G mobile networks	The testbed in Hamburg has illustrated the high importance of security aspects in industrial environments. The concept of security trust zones investigated in WP5 is seen as a valuable tool for improving the security of 5G networks in the future and will be studied further in DT.
Knowledge on requirements and concepts to achieve resource elasticity in 5G mobile networks	The lab tests on enhancements of available open source radio protocol stacks and the extended notion of resource management (radio and computational resources) brought a deep understanding on possible enhancements of resource handling in a virtualised RAN. Different aspects such as the required processing time for the virtualisation of different functionalities within the RAN protocol stack has been investigated and unveiled limitations of virtualisation techniques. Furthermore, an extension of the radio resource scheduler has been investigated based on large scale simulations. It shows the influence on the performance in a virtualised higher order MIMO mobile network when computational resources are limited, and the number of spatial transmission layers is high.
Experience on the implementation of network slicing in a testbed	DT's engagement in the setup of the testbed in Hamburg allowed building competence in the preparation of data centres and transport networks for network slicing. These experiences have been shared with engineering and operational departments in DT. They are furthermore used in the setup of other 5G pilot networks. DT has gained significant experience regarding overarching connected industries' networks, including future requirements on automation. These learnings will be considered in future network implementations and further detailed studies will be conducted.
Experience on the implementation of an orchestrator in a testbed	The lifecycle management tool developed by Nokia in WP5 has demonstrated the capabilities of a network orchestrator for a sliced network. The experiences gained from this lifecycle management tool will influence DT's expectations and requirements to future OSS solutions for its networks and contribute to respective development activities.
Experience with the implementation of multiple applications in a testbed	Requirements of future network services are expected to become more heterogeneous in the future. The use cases implemented in the testbed in Hamburg show clearly diverse requirements and contributed to a deeper understanding on the requirements of industrial applications and use cases. The testbed has been presented in a workshop to potential users in order to illustrate the capabilities of network slicing; furthermore, the testbed has been visited by DT's board member for Technology & Innovation to get a first-hand impression of the potential of this technology.
KPI improvement, techno- economics of 5G-MoNArch innovations	The findings from 5G-MoNArch' validation and verification activities in WP6 have improved DT's understanding on the cost structure of 5G networks and the market potential of novel services and applications. This knowledge will be used as valuable guidance for a cost-effective design of DT's 5G networks.
Knowledge of AI/data analytics-based network mechanisms	The work on architectural concepts for OSS and network control has stimulated a joint activity with a network supplier on the use of AI/ML tools. This activity contributes to DT's internal investigations on AI/ML, and it is planned to continue this joint activity after 5G-MoNArch.

6.2.4 Huawei (HWDU)

The 5G-MoNArch scope has been very relevant for HWDU with a strong focus being put on the topics of overall architecture design, service-based architecture, integrated data analytics, core network, RAN, network slicing, RAN reliability enhancements, and touristic city testbed. The work performed within the project has had strong relevance with the ongoing standardisation efforts in 3GPP and ETSI, namely, 3GPP SA2, SA5, RAN3 and ETSI ENI, ZSM. On this basis, HWDU has made numerous technical contributions, among which various contributions have been made together with the 5G-MoNArch partners. With these contributions a strong impact on the 5G specifications could be attained. As the work has also long-term implications on the 5G, the solid basis built inside the project can be further exploited for the next 3GPP releases as of Release 17, e.g., enablers for network automation (eNA) Phase 2. One of the main targets in the project was the consensus building in particular between the vendors and mobile operators, and hence HWDU has closely collaborated with other partners on topics of common interest, which was expressed by various jointly written conference papers and journal

papers as well as co-signed 3GPP contributions. One of the key platforms of the cross-project actions is the 5G PPP working groups (WGs). The project results have been thus also exploited in a wider coverage, particularly, in the Architecture WG, where HWDU has served as the Vice-chairman. The Architecture White Paper v3.0 together with other 5G PPP projects has reflected the EU vision on the 5G architecture. The timeline of 5G-MoNArch has nicely matched with the increasing efforts toward the end-to-end (E2E) slicing realisation. On this basis, the joint efforts inside the project and research into 5G architecture realisation has enabled HWDU to build further competence building, to pinpoint 5G system (5GS) gaps and the associated enhancements, and to bring these enhancements to the 5G specifications. Besides the standardisation contributions, with 5G-MoNArch partners, HWDU has collaborated with GSMA toward the designs of generic slide template (GST) and slice blueprint. Moreover, HWDU has filed three patents within the framework of the project. Further, HWDU has provided the 5G NR compliant radio interface for the touristic city testbed, where low-latency communications and multi-slice/multi-flow design paradigms have been explored. The enablers developed by HWDU in WP2 and WP3 and the testbed analysis in WP5 have contributed to the 5G KPI analysis in WP6.

A more specific description of the most important exploitation items for HWDU is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Knowledge on 5G mobile network architecture	Within the framework of WP2 and WP3, the knowledge on requirements and capabilities of 5G mobile network architecture could be attained. This has been in part possible thanks to the developed enablers in both WPs, where the functional extensions and protocol implications have been analysed and the associated novel components have been integrated into the overall architecture. The inter-relations of these novel components with the others developed by the project partners enabled HWDU to gain further knowledge on the E2E network slicing realisation. The gained knowledge has played an important role for the ongoing standardisation activities where individual and joint technical contributions have been made. The gained knowledge will play an important role in the research and development of further use cases, in particular, related to 3GPP Release 17 and beyond.
Knowledge on 5G network slicing	The work in WP2 has focussed on the E2E network slicing realisation from conceptual point of view spanning multiple network domains and layers. This has provided HWDU further knowledge and competence on the cross-SDO aspects that are needed. Accordingly, HWDU has actively contributed to 3GPP SA2, SA5, RAN3 as well as ETSI ENI and ZSM. HWDU could also exploit new use cases on multi-slice applications as well as slice-aware dynamic radio topologies. These use cases are expected to have long-term product relevant enhancements. Moreover, the work in WP5 has helped HWDU build competence on the multi-slice support on the radio interface.
Knowledge on orchestration in 5G mobile networks	Within WP2, HWDU has worked together with partners on multi-domain management & orchestration including ETSI NFV interactions. This provided knowledge particularly on cross-slice and intra-slice management & orchestration solutions. This has been exploited for joint papers. Within WP5, the testbed implementation has involved orchestration solutions, where realistic analyses could be obtained.
Knowledge on data analytics in 5G mobile networks	Within WP2, HWDU has been among the major contributors of the integrated data analytics framework. The original framework of data analytics being only in the 5G core could be extended to management & orchestration layer. The interactions among the data analytics functions have been utilised to develop the integrated data analytics framework. Thanks to the joint work with the partners, a new data analytics function could be accepted in the 3GPP SA5. The work has been further exploited with various 3GPP SA2 technical contributions. It is expected that the work has long-term implications for 3GPP Release 17 and beyond. The work has been also exploited for a joint journal paper and further knowledge has been gained on the role of a possible data analytics function in RAN.

Knowledge on requirements and concepts to achieve resilience in 5G mobile networks	Within WP3, HWDU has worked on the network coding solutions to improve resilience in RAN. Although the network coding schemes originally intended for the physical layer, the work could be exploited to extend the solutions to the higher layers. With the joint work in WP2, knowledge on architectural implications could be attained.
Knowledge on operators' view on importance and timeline for SON functions and on operators' view on SON management	With the work on the overall network architecture as well as the Turin testbed further insights could be gained on the operator views on the slice-enabled 5G network. This knowledge has been used for the technical contributions made to the SON-related study item in 3GPP RAN3, i.e., RAN-centric data collection and utilisation. The solutions included critical service continuity for network slicing.
Knowledge and industry insights on the business drivers for and wider socio-economic value of 5G networks and 5G-MoNArch innovations	The slice blueprint work performed in WP2 and the associated collaboration with GSMA has provided HWDU various industry insights with regard to vertical requirements on the network slicing and how the network slicing can be deployed starting from a generic slice template. The work conducted within WP6 on the techno-economic analysis helped HWDU on the definition of research topics related to 5G industrial communication. Moreover, the Turin testbed analyses provided insights on new multi-slice applications that can be observed in the future 5G deployments.
Knowledge on Proof of Concept development	The work conducted in WP5 Turin testbed has required the integration of solutions from multiple partners and included conceptual solutions developed in WP2. Accordingly, this work has helped HWDU gain more insights into multi-partner proof of concept development.
Experience on the planning and implementation of a distributed testbed platform	The Turin testbed has included multiple partners including vendor (HWDU), operator (TIM), customer (Turin municipality), and research institutes (UC3M, MBCS, and CERTH). This provided HWDU experience on multi-partner testbed implementation.
Experience on the implementation of network slicing in a testbed	HWDU has implemented multi-slice radio interface to support new multi-slice/multi-flow 5G services. The radio interface has been integrated with the higher-layer concepts. The wort has thus provided valuable experience on multi-slice implementations.
KPI improvement, techno- economics of 5G-MoNArch innovations	The enablers developed in WP2 and WP3 and the associated evaluations have improved the state-of-the art solutions. These evaluations have been fed to WP6 techno-economic evaluations and knowledge on system-level analyses has been gained.

6.2.5 Telecom Italia (TIM)

The exploitation of 5G-MoNArch for an industrial partner like TIM has been wide especially for the competence building ensured by the participation in a consortium where many important players in the 5G definition have been active, and this competence has been widely used internally for the service development of new 5G services, being these of essential importance in this phase of the 5G deployment in Italy. In particular, TIM has been involved in the resource elasticity-based testbed hosted in Turin in Palazzo Madama, which has cast some light on this specific feature of the network slicing application, never experienced before in the company. Moreover, TIM has contributed in a very committed way to the definition of the new E2E architecture in 5G-MoNArch, also with the presence in standardisation bodies like 3GPP or the newly created and fully supported ETSI ISG ENI. Finally, TIM has also contributed to the business and 5G KPI analysis using and exploiting the results of the touristic city testbed in Turin.

A more specific description of the most important exploitation items for TIM is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Knowledge on 5G mobile network architecture	The participation of TIM Technology and Innovation department in the 5G-MoNArch project has been very fruitful for the gained knowledge on the E2E architecture for the 5G development, in particular for the impacts on the various "options" in the New Radio defined in 3GPP. Especially the Network Slicing "blueprint" defined in the project is a clear advancement in the definition of the Core functionalities for 5G.
Knowledge on 5G network slicing	As stated already in the previous topic, Network Slicing has been the focus of the innovative presence of TIM in the project, with contributions and scientific papers produced in that framework. This has been of absolute relevance also in terms of awareness of the potential impacts of 5G in the future network deployment as an operator.
Knowledge on orchestration in 5G mobile networks	The orchestrator is a fundamental technology component for a network based on Network Slicing concepts and in 5G-MoNArch TIM gained experience on the adoption of an orchestrator, especially in the Touristic City testbed in Palazzo Madama in Turin, where a first version of orchestration functionalities has been applied to the experimental layout of the performed test.
Knowledge on requirements and concepts to achieve resilience in 5G mobile networks	In this area TIM has gained knowledge through the participation of delegates into the WP2 dedicated to the overall architecture, where the concepts of resiliency have been taken into account for the overall layout.
Knowledge on requirements and concepts to achieve security in 5G mobile networks	Also, in terms of security the same applies as in the previous topic.
Knowledge on requirements and concepts to achieve resource elasticity in 5G mobile networks	Elasticity has been the key issue managed in the project for the Network Slicing orchestration in the Turin testbed, and as such it has been the most important topic shown and appreciated during the Turin Touristic City testbed, where TIM organised the complete set-up.
Knowledge on operators' view on importance and timeline for SON functions and on operators' view on SON management	SON and SON management were already and even before the 5G-MoNArch start a clear topic of research for TIM in the Innovation and Technology departments, but the step forward registered in 5G-MoNArch on these specific topics have been a clear exploitation gain for TIM in terms of improved knowledge and awareness of the relevance of the topic for its future business.
Experience on the planning and implementation of a distributed testbed platform	The platform implemented by 5G-MoNArch has been limited in scope, as it was clear for a Phase 2 5G-PPP project, but on the other hand it has been much wider in scope than expected, giving TIM the opportunity of implementing a successful testbed in Turin and at the same time the access to the results of another relevant testbed in Hamburg, for topics, like smart cities, that are as well very important for the success of the 5G future evolutions.
Experience on the implementation of network slicing in a testbed	As already stated beforehand in this table, the Network Slicing concept has been the focus of the project participation for TIM, resulting also as a clear future implementation opportunity as an operator. The knowledge gained in the project on the topic helped also to start checking the possible threats that a bad implementation of NS could imply for an operator, in case the regulation on the topic won't be fair for the needs of the operators.
Experience on the implementation of an orchestrator in a testbed	The orchestrator used in the Turin Touristic City testbed has been limited in scope, being centred on the needs of the testbed specifically. Nevertheless, it has been one of the very first applications of an orchestrator and the results achieved cast a very positive light for the future deployments in the commercial networks.

Experience with the implementation of multiple applications in a testbed	The concept of the Turin testbed was really the one of having multiple slices together, and the demonstration helped to assess the fact that 5G is absolutely capable of managing multiple network implementations in the same time. This is an important result for the future.
KPI improvement, techno- economics of 5G-MoNArch innovations	The involvement of TIM in the project, as already stated, has been limited to the Innovation and Technology department, but the results of WP6 on the analysis of the KPIs have been considered internally and represent a valuable source for the future decisions on the evolution of the 5G market.

6.2.6 Samsung UK (SRUK)

Samsung is the world's highest-selling mobile phone company and number one in global and European smart phone sales. The 5G-MoNArch project is providing an important opportunity for Samsung to enhance the global R&D in future 5G systems by cooperation with key vendors and operators, leading research centres and universities across Europe. SRUK is utilising 5G-MoNArch output and results for future development of Samsung devices and networking products. So far, key innovative ideas have been developed within the project in the emerging fields of AI for resource and network elasticity and terminal-based data analytics aspects, as well as knowledge on 5G mobile network architecture, End-to-End network slicing and orchestration in 5G mobile networks that have expanded our competence towards mobile product developments in near future. These innovations will be protected through international patents whenever applicable.

Furthermore, through collaborative research in 5G-MoNArch, SRUK managed to build industry consensus, leading to the proposal of new use cases and solutions to incorporate network intelligence and enabling network automation in ISG ETSI ENI (Experiential Networked Intelligence) as well as 3GPP SA2 studies on terminal-driven analytics which will be exploited to maintain Samsung competitiveness of future products. In particular, SRUK had an instrumental role in liaison with ISG ENI through Samsung delegate (Rapporteur of Use Cases Working Item).

Moreover, Samsung plays an active role in project representation in the 5G PPP Pre-standards WGs and has also been committed to spreading the results of 5G-MoNArch to other international 5G fora and research collaborations where Samsung is a key member, including Korea 5G forum, Giga Korea projects, ARIB (Japan), 5G Innovation Centre (UK) and NYU Wireless Centre (USA), as well as operator stakeholder groups such as GSMA and NGMN.

A more specific description of the most important exploitation items for Samsung is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Knowledge on 5G mobile network architecture	The participation of Samsung in 5G-MoNArch has been crucial for the acquisition and development of knowledge of its European R&D site on this highly relevant field for Samsung's strategy within 5G, which has allowed the global company to exploit the expertise acquired and disseminated through this EU-funded effort. This applies to dissemination, standardisation strategy as well as product roadmaps. In particular, Samsung's participation on WP2 topics on overall architecture and WP4 leadership on resource elasticity have made this possible.
Knowledge on 5G network slicing	Similar to the above, knowledge of network slicing developed within 5G-MoNArch (mostly on WP2 but also on WP4) has translated into an exploitation impact best represented by contributions to SDOs by Samsung in both 3GPP SA2 and ETSI ENI during the lifetime of the project and beyond.

Knowledge on orchestration in 5G mobile networks	Samsung's leadership of WP4 and the overarching new knowledge on elastic orchestration developed therein has contributed to the company progressively increasing its commercial and standardisation interests in network management and orchestration. As a matter of fact, a new (and first) 3GPP SA5 delegate working on orchestration aspects has been recruited with the purpose of closely collaborating with the Samsung European site, whose 3GPP system members have been active participants of 5G-MoNArch.
Knowledge of AI/data analytics-based network mechanisms	Samsung has been instrumental in developing two project innovations in this category that have also had a high exploitation impact within Samsung, namely AI-based elasticity and terminal analytics. A major result of this exploitation impact has been the recent involvement of Samsung's European site in the global 3GPP SA2 delegation with a particular focus on enablers for network automation, with the task of leading two work streams that originated within 5G-MoNArch, namely the application of AI and analytics on control plane for elastic slicing optimisations and UE-based analytics for optimised network performance. These ideas have naturally become part of the global strategy of Samsung for analytics in its 5G system vision. Furthermore, Samsung has increased its high-impact dissemination footprint with leadership and participation in flagship project papers published at e.g., IEEE Wireless Communications Magazine and IEEE Access. Finally, Samsung's leadership of WP4 has allow to strengthen its footprint in ETSI ENI by leading or contributing to 5G-MoNArch use cases and PoC contributions in the above mentioned SDO.
Knowledge on requirements and concepts to achieve resource elasticity in 5G mobile networks	As in the case of knowledge on orchestration of 5G networks, which has been greatly influenced by Samsung's leadership role on WP4, concepts related to resource elastic have been exploited by Samsung on its standardisation impact (both 3GPP and ETSI ENI), high-profile dissemination impact (i.e., IEEE Wireless Communications Magazine), and product roadmaps.
Knowledge and industry insights on the business drivers for and wider socio-economic value of 5G networks and 5G-MoNArch innovations	Insights coming from research, demonstrators and testbeds, particularly those developed in WP6 with close collaboration with WP4 on the economic impacts of elasticity, have been handed in to Samsung's relevant business units as business drivers to pursue highly resource efficient optimisations based on analytics within on their product portfolio roadmap.

6.2.7 Atos

Atos is an international information technology company, leading the transformation of digital services and telecoms operators to generate more business value from their networks.

Atos has been deeply involved in FP7 and 5G-PPP Phase 1 projects and now with the work in 5G-MoNArch, we have continued these activities to further evolve and get expertise in 5G network technologies.

The involvement in the project has provided Atos with a deep knowledge in 5G mobile network architecture and in key fields for software networks like elasticity, network slicing and orchestration. Furthermore, Atos has also played a strategic role in the research activity performed in the security and resilience aspects for future 5G networks. As an industrial company, this expertise will play a vital role to enhance the current portfolio of products and technologies offered to our customers. ATOS will use the knowledge and the expertise acquired during the project to strategically position the telco portfolio in an environment in which Software Networks are transforming the telecom landscape. This project has provided ATOS with the opportunity to be prepared for new customer demands and enable new business offerings. Building on the expertise gained during the project, ATOS will analyse the return of investments of its customers that are willing to acquire 5G services.

The project has also widened ATOS' knowledge in other relevant vertical markets which also open the door to new business opportunities for the organisation.

Last but not least, this knowledge will be the baseline for future research projects.

A detailed description of the most important exploitation items for Atos is given in the following table:

Description of exploitable result / knowledge	**Detailed description**
Knowledge on 5G mobile network architecture	The work carried out by Atos in WP2, WP3 and WP4 has allowed Atos to gain expertise in 5G mobile network architecture and security and resilience features. This knowledge will be used for future research activities to explore new use cases and enhancements on the mobile networks. This knowledge has also spread internally in the company in order to get competence on the integration with the overall telecom architecture and to develop 5G solutions for our customers, not only in the telecom area but also for different types of vertical sectors.
Knowledge on 5G network slicing	Continuing the work carried out in different previous projects, the research activities performed in WP2 and WP4 have contributed to extend the knowledge in relation to the 5G network slicing. This new paradigm will allow different verticals to have tailor made networks adapted to their requirements, so it plays a key role in the Atos portfolio. We are providing consultancy services to different vertical industries in order to take advantage of this new concept. This has also led to new lines of research that will lead to the development of products and solutions in the near future.
Knowledge on orchestration in 5G mobile networks	Within WP2, we have gained knowledge in cross- and intra-domain E2E management and orchestration. The orchestrator is the main component of software networks, where Atos is focused and contributes to organisations like OSM.
Knowledge on requirements and concepts to achieve resilience in 5G mobile networks	Atos counts with an asset, called XL-SIEM, for the detection of security incidents within ICT infrastructures. Atos is currently moving towards its usage over 5G ones as part of the work carried out in 5GMoNArch. Atos is currently working on the incorporation of mitigation capabilities to the Atos XL-SIEM, which would allow to automatically decide and automatically apply the most suitable mitigation to react to a detected security incident. The suitability of a mitigation would depend on several factors, such as the criticality and, in the case of 5G infrastructures, the expected resilience of the network. The evaluation of the trade-off between security requirements of an infrastructure and resilience requirements as a factor that determine the suitability of a mitigation is a feature that has been conceived in 5GMoNArch and is currently in the roadmap of incorporating to the mitigation capabilities of the Atos XL-SIEM.
Knowledge on requirements and concepts to achieve security in 5G mobile networks	The Atos XL-SIEM, which allows to monitor ICT infrastructures and report about security incidents found, has been reworked from its deployment design to deal with the special requirements of a 5G infrastructure. One of the main features required in a Network Slice based infrastructure, which is based on the concept of virtualisation of resources is the dynamic instantiation of security detection enablers to fulfil with the specific requirements of a Network Slice. To this end the XL-SIEM has been modified to allow the dynamic allocation of resources and by virtualising its different components, moving from a monolithic solution to a modular solution flexible and adaptable to specific requirements. This new approach for the XL-SIEM derives from the Security Trust Zone approach created in WP3 and is becoming one of the main advancements of the Atos XL-SIEM which is currently studied for its application in additional domains beyond 5G infrastructure.
Knowledge on requirements and concepts to achieve resource elasticity in 5G mobile networks	Atos has got a big expertise through its involvement in WP4, where 3 dimensions of elasticity were defined, together with their implications in the architecture and network orchestration. Atos is adding this expertise in the solutions catalogue under development. We are also providing consultancy services to our customers that leverage on this knowledge.

Knowledge on operators' view on importance and timeline for SON functions and on operators' view on SON management	Software Networks and its management and orchestration are one of the main research topics for Atos. With the work on the overall network architecture as well as the Turin and Hamburg testbeds further insights could be gained on the operator views on the slice-enabled 5G mobile network. This knowledge will enable future research and development in this area to further strength Atos' competence.
Knowledge of AI/data analytics-based network mechanisms	The work performed in WP2 and WP4 has given us experience on the new trend of applying Artificial Intelligence to the management and orchestration of software networks. Based on this, we are opening new research lines to further investigate how AI can result to zero touch operation networks, a key area for network operators.
Experience on the planning and implementation of a distributed testbed platform	The involvement of Atos in the 2 testbeds developed within the project, a Sea Port testbed in Hamburg and Touristic City testbed in Turin as WP5 leaders, has provided a wide knowledge on the different requirements and processes associated with these multi-partner testbeds oriented to different vertical industries. Atos will use this expertise to improve the implementation of future testbeds and will have continuity in 5G Tours, an ICT-19 project under H2020 work program starting June 1st, 2019.
KPI improvement, techno- economics of 5G-MoNArch innovations	The results from WP6 have a great importance for Atos to understand the cost structure of the different 5G enablers. With this knowledge we plan to perform specific business plans and adapt the portfolio offering accordingly to the market trends and figures.

6.2.8 Hamburg Port Authority (HPA)

The Hamburg Port Authority AöR (HPA) has been providing future-oriented port management services offering one face to the customer since 2005. To ensure safe and efficient processes in the Port of Hamburg and meet the demands of a growing port, the HPA relies on intelligent and innovative solutions. The HPA is responsible for resource-efficient, sustainable planning and the implementation of infrastructure projects in the port. It is the contact point for all kinds of questions concerning the waterside and landside infrastructure, the safety of navigation for vessels, port railway facilities, port property management and business conditions in the port. The HPA ensures the provision of land as required, carries out all statutory duties placed on it and provides port industry services. It markets port-specific technical knowledge and represents the interests of the Port of Hamburg at a national and international level.

Coming from these manifold business areas, HPA gained great insights in 5G-technology by joining 5G-MoNArch. HPA's business requires different kinds of connectivity: Legacy copper cables (even analogue), fibre channel, Wi-Fi, directional radio and proprietary radio technology for maritime navigation are in production in Port of Hamburg, today. Therefore, HPA exploited 5G network slicing for two reasons. Firstly, with the broad range of communication technologies in production, HPA always evaluates ways to operate the port-infrastructure more economic. Secondly, HPA is looking for technologies, which allow HPA to connect assets which cannot be sufficiently connected with today's technology.

For both areas HPA's involvement in 5G-MoNArch gave a great insight of future capabilities of 5G network slicing in the applications in Port of Hamburg. 5G is seen as a key technology for future use-cases in Port of Hamburg. A detailed description of the most important exploitation items for HPA is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Knowledge and practical experience on network slice integration into IT-processes	The three prototypes in Port of Hamburg required a deep integration into HPA's IT-infrastructure. Overall 5G-MoNArch did help HPA to understand the requirements on integration of network slicing. Network Slicing itself is now well understood - from a business point of view and from a technical point of view.

Experience with the implementation of multiple applications in a testbed	5G-MoNArch build up the competence inside HPA to develop new applications. Verification of concepts for products and service development for future 5G scenarios has been highly improved. Each aspect of 5G-service-triangle and slice isolation has been incorporated in HPA's knowledge.
Identification of network slicing as technology supporting emergency management	Port of Hamburg is a critical public infrastructure with high demands on safety and security. Emergency management is one of the duties of HPA for the Port of Hamburg. The Smart Sea Port Trial results have shown, that network slicing can become a relevant technology for our emergence management teams. The vision is to instantiate a slice with highest available privileges in case of an emergency for the member of the team.
Ideation of future 5G-Use-Cases	5G-MoNArch caused a great interest inside HPA and in the City of Hamburg in 5G technologies. In different internal presentations and workshops 5G-MoNArch's use cases were presented. Employees from many divisions afterwards created ideas for new use cases for 5G applications in the Port of Hamburg.

6.2.9 CEA-LETI

Through 5G-MoNArch, CEA-LETI has developed new competences and improved its knowledge on several technological and theoretical aspects of 5G communications and future networks, like 5G network's management, orchestration, slicing, and architecture design. A particular interest has been devoted to AI-enabled network management algorithms for elasticity. This acquired expertise will be reinvested during future research projects, consultancy activities, and academic collaborations. It has also allowed CEA-LETI to actively participate in ETSI's ISG ENI standardisation group, focused on experiential network intelligence. All these aspects have helped and will help CEA in fulfilling its mission of transfer of technological knowledge to industries in France.

A detailed description of the most important exploitation items for CEA-LETI is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Extension of existing simulation tools	To validate the studies carried out in the context of WP2 and WP4, CEA-LETI extended its existing simulation solutions integrating network slicing and cross-slice and intra-slice orchestration and management functions. These simulations have been used for publications and patenting innovative ideas.
Knowledge on 5G mobile network architecture	In the context of WP2, CEA-LETI has extended its background related to 5G mobile architecture and participated to multiple publications related to these topics. We have specifically participated to the design of slice–aware functionalities in the RAN layer.
Knowledge on 5G network slicing	CEA-LETI did not have specific background on networks slicing before 5G-MoNArch. During the project, our group has learnt the specific challenges and benefits of this technology. This has led to open new lines of investigation, and the opportunity for new collaborative and industrial project; Finally, it has resulted in producing scientific papers and patents.
Knowledge on orchestration in 5G mobile networks	Due to the work carried out in WP2 and WP4, CEA-LETI has extended its background related to orchestration in 5G mobile networks; Specifically, in WP2, we have worked in the context of cross-slice resource orchestration. In WP4, we have studied how to achieve elasticity through slice orchestration. This has led to open new lines of investigation; producing scientific papers and patents.
Knowledge on requirements and concepts to achieve resource elasticity in 5G mobile networks	In WP4, CEA-LETI has extended its background related to concepts to achieve resource elasticity in 5G mobile networks; this has results in publications, patents, and contribution to ETSI ENI ISG.

Knowledge of AI/data analytics-based network mechanisms	In WP2, CEA-LETI has extended its background related to AI/data analytics-based network mechanisms; This has led to open new lines of investigation; producing scientific papers and patents.
Knowledge on Proof of Concept development	In WP5, CEA-LETI has extended its background related to Proof of Concept development by working on the touristic city testbed.
KPI improvement, techno- economics of 5G-MoNArch innovations	In WP6, CEA-LETI has extended its background related methodology for verification & validation of 5G systems. This background has been exploited for publications, extension of the proprietary simulator, and patenting.

6.2.10 CERTH

The Centre for Research and Technology-Hellas (CERTH) is one of the largest research centres in Greece and CERTH - Information Technologies Institute (ITI) is one of the leading Greek institutions in the fields of Informatics, Telematics and Telecommunications, with long experience in numerous European and national R&D projects. Taking part in the 5G-MoNArch project has allowed CERTH to raise its knowledge on both on the conceptual and the technological aspects that will lead to the commercial actualisation of the 5G communication systems.

By cooperating with numerous partners that are on the forefront of advancing 5G related technology, we gained valuable knowledge concerning various technical parts of the 5G network such as network slicing, security and the realisation of new multi-slice services.

New concepts were realised, such as a method for handling the slice resource workload through AI enhanced management and a security related module that detects network anomalies based on traffic analysis.

Additionally, valuable expertise was gained through the development of a virtual reality (VR) application that uses high bandwidth and concurrently low latency slices to provide a novel guided tour experience. This service was demonstrated in one of the two projects' testbed situated in the Palazzo Madama museum in Turin, Italy.

Finally, as leaders of task T6.3, among other undertakings we were heavily involved in the verification of the projects' technical results, the validation of these results by various stakeholders along with the communication of these results to other related projects through a working group organised by 5G Infrastructure for Public – Private Partnership (5G-PPP). This enables us to have a solid understanding of the current progress and requirements of the 5G systems, which will be reused in future collaborations of both academic and commercial nature.

A more specific description of the most important exploitation items for CERTH is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Knowledge on requirements and concepts to achieve security in 5G mobile networks	CERTH has a long experience on the subject of network security either on the web or in existing wireless communication systems such as LTE. Participation in WP3, allowed us to update our approaches so that they help achieve the unobstructed operation of the 5G infrastructure which is threatened by more security incidents and malicious attackers compared to legacy networks. In tandem with NOKIA-DE, the effects of attacks to the network performance where examined. CERTH created approaches based on artificial intelligence that can be easily be incorporated in any 5G security tools suite. The results of our work where published in high quality venues.

Knowledge of AI/data analytics-based network mechanisms	Work performed in the context of WP2 and WP4 allowed us to investigate the fairly new and hot topic of network slicing in the context of softwarised networks and virtualised network functions. CERTH modelled the cloud and radio resources of a 5G network and developed an inter-slice resource allocation and slice admission mechanism based on an artificial intelligence technique called Multi-objective Optimisation. In cooperation with NOMOR, who provided realistic data in a network level we further developed and evaluated our results. These results are captured in scientific publications.
Knowledge on 5G network slicing	CERTHs' work in numerous work packages involved slices: slice admission mechanism (WP2), slice resource allocation (WP4), VR application using eMBB and URLCC slices (WP5) and verification of the gains all technical results including elasticity i.e. slices (WP6). This has allowed us to gain substantial knowledge on the subject which will be further used in additional research projects, developing products/apps that will be deployed in 5G networks or consulting on these subjects.
Knowledge, expertise and experience in developing multi-slice high bandwidth and concurrently low latency mobile applications such as those in VR and AR	CERTH developed a VR application for the Turin Touristic City testbed (WP5), which incorporated two slices: the first for video streaming served over an eMBB slice, and the second for an URLLC slice used to transmit object's position and haptic interactions among VR avatars. This service combined a number of technologies such as Unity, 360º video, realistic physics engine, photogrammetry combined with 3D modelling to create a guided tour in the Palazzo Madama Museum. Such an application can be adapted to other places of touristic interest and commercially used. Finally, this knowledge is directly transferable to VR educational of recreational gaming which is expected to flourish after the commercial deployment of 5G networks.
Experience with the implementation of multiple applications in a testbed	CERTH developed a VR application that was hosted as a service over a 5G network in the Turin testbed (WP5). During the implementation of the application in the testbed, interworking with numerous partners was required to achieve the seamless integration of the various parts that comprise the final setup tested. This has augmented the competence of the members of CERTHs VR/AR development team that participated in the project. Often problems not be foreseen in the design/ early development phase of a VR application, but the experience gained will help avoiding such risks leading to more efficient completion of similar products in the future.
KPI improvement, techno- economics of 5G-MoNArch innovations	Through leading the evaluation and assessment of the technical parts of the project (task 6.3) in WP6 and the participation in the relevant 5G-PPP technical board, CERTH knowledge concerning the measurement and evaluation of 5G mobile network capabilities has been greatly enhanced. Publication of a least one scientific publication in high quality venue/magazine, after WP6 finishes has been agreed and this task will be led by CERTH. This knowledge is expected to be applicable to the evaluation of other complex communication systems that leverage Artificial Intelligence and Machine learning techniques. This enables us to have a solid understanding of the current progress and requirements of the 5G systems, which will be reused in future collaborations of both academic and commercial nature.

6.2.11 Mobics

Mobics is a Greek SME that specialises in the design, development and provision of innovative applications and value-added services for mobile, Web and pervasive environments. The Mobics R&D team is led by internationally well-known researchers with a long record of research contributions in the areas of mobile and pervasive networking services and applications, and participation in many international, national and regional R&D projects. The participation of Mobics in the 5G-MoNArch project was beneficial from many perspectives. First, deep knowledge and hands on experience has been acquired in the research area of 5G networks. Its close collaboration with key stakeholders in the EU 5G domain (i.e., industrial partners in the 5G-MonArch consortium) was very important due to the know-how transfer and also to the links established with them. The R&D staff of the company, that was actively involved in the project, transferred their knowledge and expertise to other members of the Mobics R&D team, setting the opportunity the company to undertake bigger research and development tasks in future 5G projects. The joint research publications achieved are also important towards this

direction. Clearly, the involvement in the 5G-MoNArch managed to set the company as a competitive SME in the 5G ecosystem in Greece. Additionally, through the central role that the company undertook for the development and integration of the Touristic City 5G testbed, know-how in commercial solutions has been acquired, creating the potential to enrich the company's product portfolio. Another positive aspect for the company was the interaction with thriving SMEs of other 5G-PPP projects in the context of the NetWorld2020 European Technology Platform. Moreover, the strong bonds established with other partners in the consortium set the field for future bilateral collaborations. Overall, Mobics enhanced its capability to become a competitive SME partner in future 5G projects (research or industrial) with multiple roles: core research, service development/integration and consultation.

A more specific description of the most important exploitation items for Mobics is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Knowledge on 5G network slicing	Mobics built strong competence on key 5G concepts, such as networks slicing. Its extensive participation in one of the testbeds will help Mobics to participate in future 5G service development or provisioning activities in Greece or abroad. Moreover, its research work, published through in scientific venues, is important as it showcases its research capability. Mobics, given its size and competencies will pursue R&D outsourcing from bigger 5G stakeholders.
Knowledge of AI/data analytics-based network mechanisms	Mobics researchers made several research contributions, related to the AI and data analytics, including the devise of an elastic resource allocation mechanism and the development of network function for the RAN domain These are surely state-of-the-art in telecom research and thus it helps Mobics to assume a role in this domain from its very beginning.
Experience with the implementation of multiple applications in a testbed	Participation in the testbed implementation and integration gave Mobics the ability to understand at a pragmatic level how all the 5G concepts and techniques are applied and performed. Hence, it will help build strong consultancy skills for participation in future research or industrial projects.
KPI improvement, techno- economics of 5G-MoNArch innovations	Participation of Mobics to such activities, is fully aligned with its business orientation, since a key role that it can assume in the 5G domain is consultation for end to end 5G service development and deployment.

6.2.12 Real Wireless (RW)

Real Wireless is a UK based independent wireless advisory firm. Real Wireless brings technical and strategic expertise to clients in the wireless industry and to users of wireless technology. Our services help clients navigate the wireless options available against their requirements, and, to understand network deployment strategies, business case opportunities, wider socio-economic benefits and regulatory trade-offs. We have already been assisting clients in understanding the opportunities and implications of 5G across a range of projects and the techno-economics of 5G is a particularly growing area for us.

Participation in the 5G-MoNArch program has been extremely valuable to us as it has given us the opportunity to interact with a range of partners who are leaders in 5G technology and thinking. The insights from these interactions enhance our 5G consultancy services and have also been translated into improvements in our 5G business case analysis toolset (initially developed under 5G NORMA and enhanced under 5G-MoNArch). In particular, through participation in 5G-MoNArch we have been exposed to the technical detail of network slicing, network elasticity and the ability to deliver secure and resilient services over 5G networks and the network dimensioning and hence cost implications of these.

Through our leadership of Task 6.4 in Work Package 6, we have established a framework for evaluating 5G business cases in a range of scenarios including those with an industrial or hotspot related focus. This includes not only understanding network dimensioning under evolving 5G spectrum, air interface, topology and service requirements conditions but also understanding the value of 5G services to end

users and how these might be translated into revenues. This allows us to articulate and evaluate a comprehensive 5G business case that considers cost and revenue implications.

Finally, the stakeholder validation work on 5G-MoNArch has given us the opportunity to interact with end users of 5G services and hear first-hand their challenges and the value of wireless and anticipated value of 5G to them. This is valuable not only for validating the assumptions applied in our business case analysis toolset and consultancy services but has also started discussions which may evolve into future client relationships.

A more specific description of the most important exploitation items for Real Wireless is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Extension of existing simulation tools	Real Wireless has led the techno-economic verification analysis of 5G-MoNArch within WP6. This has required the further development of our 5G business case analysis toolset (initially developed under 5G NORMA and enhanced under 5G-MoNArch). Through participation in 5G-MoNArch we have been exposed to the technical detail of network slicing, network elasticity and the ability to deliver secure and resilient services over 5G networks and the network dimensioning and hence cost implications of these. This enhanced 5G business case analysis toolset will be directly applicable in future Real Wireless 5G business case consultancy projects for a range of other clients.
Knowledge on 5G network slicing	Participation in WP2 of 5G-MoNArch has given Real Wireless exposure to the architectural enablement and technical detail of implementing network slicing in real networks. These insights will be applied on further consultancy projects on the business case for 5G and opportunities offered by network slicing.
Knowledge on requirements and concepts to achieve resilience in 5G mobile networks	Assessment of the cost implications of delivering secure and resilient industrial wireless services under evaluation case 1 within WP6 has given Real Wireless first-hand experience of understanding the implications of increased RAN and telco cloud reliability on network and equipment dimensioning and hence cost. These insights and enhancements to the 5G business case analysis toolset can be utilised in future consultancy projects particularly for vertical industry related clients looking to understand if 5G can assist with their operations.
Knowledge on requirements and concepts to achieve resource elasticity in 5G mobile networks	Assessment of the cost implications of delivering improved wireless services to demand hotspots in a more cost-efficient way under evaluation case 2 within WP6 has given Real Wireless first-hand experience of how elasticity in virtualised networks can be used to make the business case in challenging high demand locations more feasible. It has also given Real Wireless the opportunity to explore new infrastructure sharing and ownership models that are assisted by elasticity and encourage new entrant neutral host vendors to the ecosystem. These insights and enhancements to the 5G business case analysis toolset can be utilised in future consultancy projects for regulatory bodies, venues and vendors looking to understand the business case around localised demand hotspots and how best to serve these.
Knowledge and industry insights on the business drivers for and wider socio-economic value of 5G networks and 5G-MoNArch innovations	Participation in 5G-MoNArch has given Real Wireless the opportunity to interact with a range of partners and stakeholders who are leaders in 5G thinking or who have first-hand experience of the operational challenges facing vertical industries. This has meant that, as well as enhancing our business case analysis toolset, the assumptions, inputs to and conclusions from this toolset for the evaluation cases assessed under 5G-MoNArch have also undergone thorough industry validation. This validation brings quality assurance to our analysis tool enabled approach to 5G consultancy projects.
Standardising on value creation and capture analysis frameworks for Socio-economic contexts	The specific context of smart cities, ports and touristic venues has enabled Real Wireless to develop and standardise an analysis process and procedures that enables the more rapid acquisition of value driven analysis projects in the future within similar business contexts. These processes also define a capability that informs the Real Wireless analysis approach to new industrial sectors and vertical contexts for future clients.

KPI improvement, techno- economics of 5G-MoNArch innovations	Participation in WP6 and helping to shape the verification and validation methodology applied there, has given Real Wireless first-hand experience of developing realistic evaluation cases for 5G. This has included service definitions, starting network assumptions, network evolution assumptions to apply over time and a benefits assessment framework. This methodology can be re-applied on future 5G consultancy projects.

6.2.13 NOMOR

NOMOR Research is a leading SME providing services in the area of the future wireless communication system. Through participation in 5G-MoNArch project, NOMOR has improved its strength in the field of simulation, standardisation and product commercialisation. Being core competencies of NOMOR since a decade, NOMOR's simulators (i) network level simulator and (ii) system level simulator are calibrated and extended with several features. Besides, NOMOR has established End-to-End mobile network testbed using open source software. NOMOR foresees the testbed as a critical asset for future projects related to standard compliant patent verification. Experience gained within 5G-MoNArch has enhanced capabilities of NOMOR in system design, simulation and rapid prototyping which are going to be an essential factor of NOMOR's future projects. An important task within the 5G-PPP framework was NOMOR's contribution to the IMT-2020 evaluation with its strong experience in radio simulations. The corresponding competence and NOMOR's international visibility with its experience could clearly be enhanced and improved.

A detailed summary of exploitation results for NOMOR is presented in the following table:

Description of exploitable result / knowledge	**Detailed description**
Extension of existing network level simulation tool	Within the framework of WP6, NOMOR has modelled enablers from WP3 and WP4 in their network-level simulator-MxART and verify their impact within the Hamburg study area. This activity provided NOMOR with an exposure to work with operator and configure a replica of Hamburg's network deployment in MxART. Besides of real-world network deployment, through this activity NOMOR has extended MxART with features implemented such as Network Slicing, Data Duplication, Telco cloud resilience and algorithms exploring capabilities of Orchestration driven elasticity, computational elasticity and slice aware elasticity. Thereby, in future topics such as radio resource management, mobility management and SON (Self Organising Network) algorithms can be studied in more realistic and large-scale environment.
Calibration and extension of existing system level simulation tool	Under the umbrella of 5G-IA (5G Infrastructure Association, an independent evaluation group), NOMOR is conducting the major share of the system level simulations required for IMT-2020 evaluation. We choose 5G Real-time Network Simulator (RealNeS) which is capable of simulating 3GPP Rel. 15 for this evaluation work. RealNeS has been calibrated against 3GPP's system level calibration results. Carefully selected KPIs (Key Performance Indicators) are simulated for 5G NR in RealNeS and evaluated against IMT-2020 requirements as per ITU-R guidelines. Calibration and validation of 5G NR is expected to bring more projects related to standard compliant simulation activities.
Establishment of End-to-End mobile network testbed	NOMOR's commitment within WP4 regarding understanding of computational resource requirement of RAN, led to establish in house End-to-End mobile network (consists of open source 3GPP UE, Radio Access Network and Core Network). NOMOR gained understanding of open source solutions for complete protocol stack and their first-hand experience. In future, we expect to get more patent validation and/or consultancy-oriented projects focussed on protocol stack solutions.
Knowledge of AI/data analytics-based network mechanisms	Within WP4, NOMOR has collaborated with other partners and developed a proof of concept AI algorithms applying on the mobile network. Exposure to ETSI ENI working group enhanced our understanding of AI from standardisation point of view. NOMOR acquires further projects from academic partners in the area of AI for the mobile network.

Knowledge on RAN reliability improvement and corresponding proof of concept implementation	Within WP3, partners have proposed several enablers to improve RAN reliability. NOMOR have gathered an understanding of operators and OEM (Original Equipment Manufacturer) s point of view, modelled data-duplication and four resilience schemes within WP6 as a part of verification activity.
Knowledge of sensitivity analysis	Sensitivity analysis has been carried out on NOMOR's MxART to understand a) how network configuration affects the KPI b) how KPIs correlate to each other. Results and knowledge of sensitivity analysis provided us knowledge on interdependencies between KPIs and it is expected to fasten project life cycle development for the future.
KPI improvement, techno-economics of 5G-MoNArch innovations	After choosing enablers from WP2, WP3 and WP4; NOMOR modelled them within a single Hamburg scenario and performed KPI analysis. It provided us a better understanding of quantitative KPI improvements and their correlation. This knowledge can be further exploited for large scale and multi enabler scenarios.

6.2.14 University of Kaiserslautern (UKL)

As an academic partner, 5G-MoNArch helped UKL to expand its research and educational competences in the area of 5G, network resilience, network slicing, and machine learning for network management. The project was an opportunity for UKL to expand network resilience concepts created in previous projects, as well as start quality research in the area of machine learning for better network slice and network resource management. UKL was able to use all the new topics covered in 5G-MoNArch to improve its master courses in the area of wireless communications, allowing the students to be exposed to state-of-the-art research. This project allows UKL to remain in the edge of 5G research among all universities in Germany.

A more specific description of the most important exploitation items for UKL is given in the following table.

Description of exploitable result / knowledge	**Detailed description**
Novel Master Courses	UKL was able to use the knowledge acquire in 5G-MoNArch to enrich our seminar master's courses with topics such as "An Architectural and Functional Framework on Network Slicing in 5G Networks" and "The Life-cycle Management of a Network Slice Instance". Two Master students that attended the seminar went on to start working on master's theses on the area of network slicing.
Knowledge on 5G network slicing	UKL work in 5G-MoNArch on progressing the new generation network mobile architecture has led to many interesting research opportunities, including inter-slice resource management and slice admission control. Two high-quality journal (IEEE Access and IEEE Networking Letters) papers on those topics are worthy of mentioned here. Further details can be found in section 4.
Knowledge on requirements and concepts to achieve resilience in 5G mobile networks	The work UKL did for Work Package 3, focusing on how to improve resilience in 5G networks, has led to great advancement on our knowledge, especially on the area of 5G islands and autonomous failsafe network operation. As a highlight for this advancement, our paper for the EuCNC 2018 must be mentioned here.
KPI improvement, techno- economics of 5G-MoNArch innovations	As part of Work Package 6, UKL work on defining a baseline deployment architecture, to be used later as a benchmark for the verification of the 5G-MoNArch architecture. This specification led to two big exploitable results that will advance our knowledge on 5g architectures: • specification of a network slice definition (Network Slice Templates) focusing on relevant elements for the verification of a network sliced 5G network • specification of a functional and topological diagram format, useful for mapping network slices on cloudified networks

6.3 Summary of the exploitation achievements

The detailed exploitation planning and the results and plans of the partners in the consortium are thoroughly detailed in Section 6.1 and Section 6.2, respectively. For each partner's organisation, the tables in Section 6.2 provide a specific insight on the most relevant achievements and further planning in their respective organisation. An analysis of these tables, and of the general items reported in Section 6.1, are the basis to derive some overall remarks for the various types of partners in the consortium.

- *Telecom Operators*. It is still valid what reported already in [5GM-D71], even after the second year of the project. This second year has been important especially for the operators, because the activity of the project has been more dedicated to the implementation of the testbeds, rather than on the theoretical studies supporting them. The two large events in Turin and Hamburg represented an important milestone of the project and in both of them the operators supported the activities and succeeded in sharing the news internally and also to the local communities, receiving an echo that highlighted the importance of the topics of elasticity and resiliency for the network slicing in the future evolutions of NR-based standardisation waves.
- *Equipment providers*. The relevant exploitation items within the second year of 5G-MoNArch for equipment vendors remained valid from what has been reported in [5GM-D71] and have been manifold with respect to product development, generating standards impact, and the identification of further research topics. The efforts spent within the project on realising a deployable overall 5G system (architecture, slicing, management and orchestration) enabled further competence building and the identification of enhancements to be conceptually worked out, patented and brought to standards. The interworking with verticals from within and outside the project consortium, the implementation of the testbeds in Hamburg and Turin, and the feedback gained from stakeholders and the general public due to the increased visibility of network slicing as a cornerstone of 5G systems helped to better understand the requirements of real-world use cases, and to therefrom influence the directions of research, standardisation and product development strategies within the companies. Finally, the visibility of the research work and results achieved by the presence of 5G-MoNArch in public events can to some extent also be seen as a marketing success.
- *Research centres and universities*: 5G-MoNArch activities enabled to increase Research centres and universities knowledge with respect to 5G research topics such as network's management, orchestration, slicing, and architecture design. A particular interest has been devoted to AI-enabled network management algorithms. This acquired expertise will be reinvested during future research projects, consultancy activities, academic collaborations, and teaching, education.
- *SMEs*. The specific exploitation achievements in this case are directly reported by the SMEs in the project directly in their specific statements, due to the different kind of activities they have performed in the project. Generally spoken, all three SMEs participating in 5G-MoNArch could strengthen their competence and enhance their visibility in the scientific as well as the business communities related to 5G: Mobics for the Turin testbed, Real Wireless for the socio-economic analysis, NOMOR on the simulation-based evaluation of 5G-MoNArch technical results, performance KPIs, and on the IMT-2020 evaluation activity.

7 Summary and conclusions

The final deliverable of 5G-MoNArch Work Package 7 has reported in detail the complete set of activities performed to support the dissemination, standardisation and exploitation impact.

Regarding the dissemination aspects, the dissemination towards the general public has been considered first, outlining the effort to create a Public Relations framework for the project in the context of the 5G-PPP environment. While the project website has primarily been intended to serve as a portal for visitors to access information about, and results of the project, the regularly updated blog on the entry page of the website became a central means of communicating and announcing project results, achievements and event (contributions) to the public. This blog has been complemented by the Twitter and LinkedIn channels, with a good audience during the complete project runtime. In doing this, a constant coordination with the 5G-PPP channels has been ensured. Also, the individual project partners have echoed the achievements of the project through their respective dissemination channels, e.g., through press releases or websites.

An important milestone within the Public Relations framework were undoubtedly the participation at Mobile World Congress in 2018 and 2019, and in particular the two public events organised by the project in Turin and Hamburg. These events provided an excellent means to increase the visibility of the project results to a non-technical audience, and to highlight the importance of the two project testbeds for bringing the concept, advantages and capabilities of network slicing to the public.

The overall reception of this Public Relations framework through the general public was very good, also compared to other projects. This became visible through numerous expressions of interest – by e-mail or personally to project members – as well as through the large number of visitors to the website and at the booths, workshops and sessions where 5G-MoNArch was present.

In terms of the dissemination of project results towards the scientific community, continuing from the successful approach started in the first project year, all partners were committed to the preparation of high-quality papers, journal and magazine articles as well as to giving talks and presentations, organising workshops, or to participate in panels at conferences. The approach and the topics of the project – network slicing, reliability, resilience and security, and resource elasticity – received a strong interest within the various conferences and events where the project partners have been involved and invited also in the second year.

Finally, the dissemination of project results towards standardisation remained very strong also during the second project year. This becomes visible from a total number of more than one hundred submissions of topics emerging from the 5G-MoNArch work during the total project runtime, towards 3GPP working groups SA2, SA5, RAN 2 and RAN3, and to ETSI industry specification groups ZSM and ENI. Thereby, the concepts developed within the project on mobile network architecture will finally be visible in the standards.

When it comes to the exploitation of project results within the partner organisations, this deliverable provides a comprehensive view of all the topics identified as relevant for exploitation, and a detailed view of each partner's exploitation plans and already achieved results. As already stated in [5GM-D71], the areas of exploitation are very widespread, including research, development of new products or services, standards, education, and patents submission. As it can be seen from these exploitation plans, for several topics the plans have already started to be implemented, which shows the timeliness of the project with respect to the addressed work areas.

Summarising the above it can be stated that 5G-MoNArch has been very successful – in its technical solutions, in bringing these solutions to practice, but also in bringing these solutions to a large audience – the general public, the scientific community, but in particular to the future users and stakeholders of 5G.

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PART 2: RESULTS OF IMT-2020 EVALUATION

In this part of the document, those results of the evaluation of the 5G New Radio (NR) which were conducted by 5G-MoNArch partner NOMOR as contribution to the 5G-PPP IMT-2020 evaluation working group, are summarised.

Despite the fact that this work was not a core part of the research and development topics predominantly conducted within the project, the second-stage evaluation of the 5G New Radio as input to the upcoming International Mobile Telecommunications (IMT) 2020 standard, which takes place under the auspices of the International Telecommunication Union – Radiocommunications Sector (ITU-R) represents an important European contribution to establishing a worldwide standard for mobile communication networks. This European contribution is coordinated by the 5G Infrastructure Association (5G-IA), and the actual work is conducted by those European research projects where partners have the background and capabilities in particular to conduct the complex simulations required to evaluate the standards defined, e.g., by 3GPP.

List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
5G-IA	5G Infrastructure Association
AP	Access Point
AWGN	Additive White Gaussian Noise
BLER	Block Error Rate
BW	Bandwidth
CDF	Cumulative Distribution Function
CU	Central Unit
DFTS	Discrete Fourier Transform-spread
DL	Downlink
DU	Distribution Unit
eMBB	Enhanced Mobile Broadband
FEC	Forward Error Correction
FR	Frequency Range
gNB	Next generation Node B (5G base station)
GoB	Grid of Beams
HARQ	Hybrid Automatic Repeat Request
IMT-2000	International Mobile Telecommunications standard 2020
InH	Indoor Hotspot (test environment)
IP	Internet Protocol
KPI	Key Performance Indicator
LAN	Local Area Network
LDPC	Low Density Parity Check
LL	Link Layer
LTE(-A)	Long Term Evolution (-Advanced)
LOS	Line of Sight
MAC	Medium Access Control
MCS	Modulation and Coding Scheme
MCS	Modulation Coding Scheme
MIESM	Mutual Information Effective SINR Metric
MIMO	Multiple Input Multiple Output
mMTC	massive Machine Type Communication
MU-MIMO	Multi User MIMO
NB	NodeB (base station)
NR	New Radio
OFDM	Orthogonal Frequency-Division Multiplexing
PC	Personal Computer
QAM	Quadrature Amplitude Modulation
RAN	Radio Access Network
RMa	Rural (test environment)
Rx	Receiver
SDU	Service Data Unit
SE	Spectral Efficiency
SINR	Signal to Interference plus Noise Ratio
SISO	Single Input Single Output
SLS	System Level Simulator
SNR	Signal to Noise Ratio

SRS	Sounding Reference Signal
SU-MIMO	Single User MIMO
TCP	Transfer Control Protocol
TDD	Time Division Duplex
TRxP	Transmission Reception Point
Tx	Transmitter
TXRU	Transceiver Unit
UDP	User Datagram Protocol
UE	User Equipment
UL	Uplink
UMa	Dense Urban (test environment)
URLLC	Ultra-Reliable Low-Latency Communication

9 IMT-2020 evaluation of 5G New Radio

The chapter is structured as follows: Section 9.1 briefly introduces NOMOR's system level simulator that builds the basis for the simulation-based evaluations, including the necessary development activities that have been performed. Section 9.2 describes the calibration of the SLS in simplified reference scenarios including a short description of the reference scenarios and the results Section 9.3 introduces the evaluation methodology and parameter settings and provides the simulation results achieved, including an interpretation and conclusion. Finally, Section 9.4 provides the references.

9.1 NOMOR's system level simulator

NOMOR's system level simulator (SLS) "RealNeS" is used to perform the system-level simulations required for the evaluation of 3GPP's proposal for IMT-2020. Besides being used in development and analysis of Radio Access Network (RAN) methods and protocols, it can also be operated on high-performance but off-the-shelf PCs or laptops as a highly portable live demonstrator with a graphical user interface on top of it.

It is a packet / event-based simulator primarily focused on the user plane covering the various protocol layers from a large set of data traffic generators over User Datagram Protocol (UDP) / Transfer Control Protocol (TCP) and down to a detailed emulation of the physical layer. Accurate spatial channel models are used, where the latest model from [3GPP-38901] has been added in the course of this project. Its overall structure is illustrated schematically in Figure 9-1.

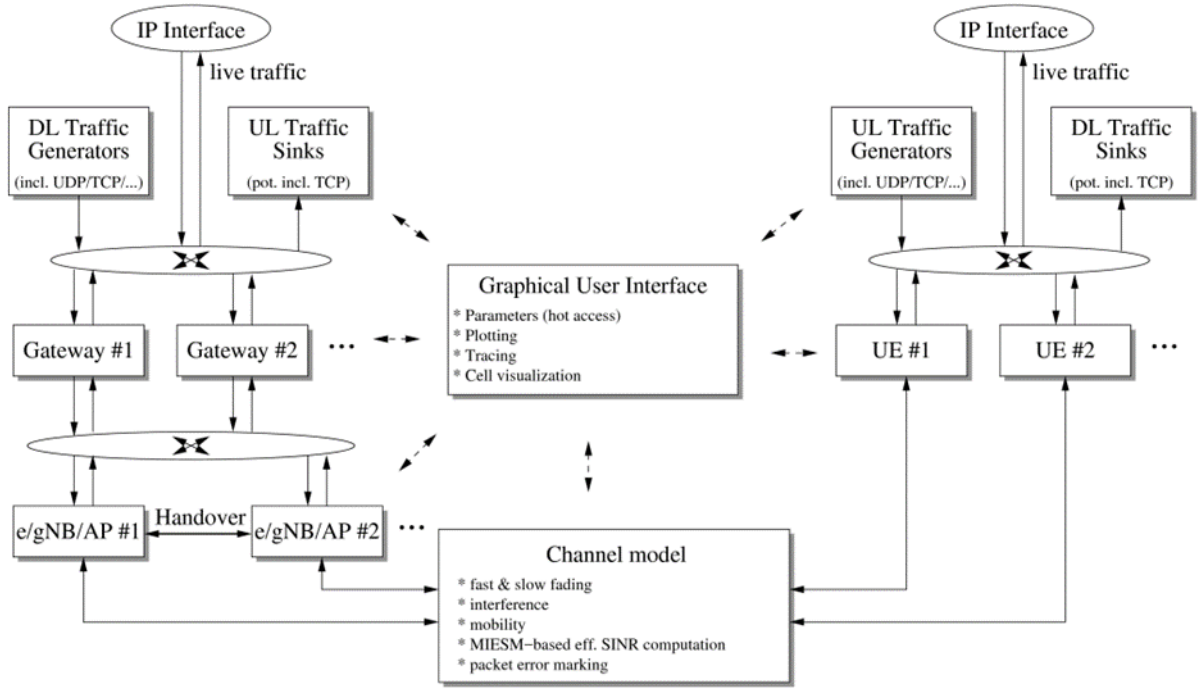

Figure 9-1: Structure of NOMOR's system level simulator RealNeS

In order to obtain meaningful simulation results for large systems, simulation accuracy must be sacrificed to some extent. A common approach that constitutes the next lower level of simulation accuracy compared to classical link-level simulations uses certain abstractions at layer-1. In particular, the complex operations of FEC en-/decoding, de-/modulation and convolution of the signal with a dispersive channel are omitted but replaced with appropriate models. The chain of functions to emulate the physical layer processing, that is also used in system-level simulations in this project is illustrated in Figure 9-2.

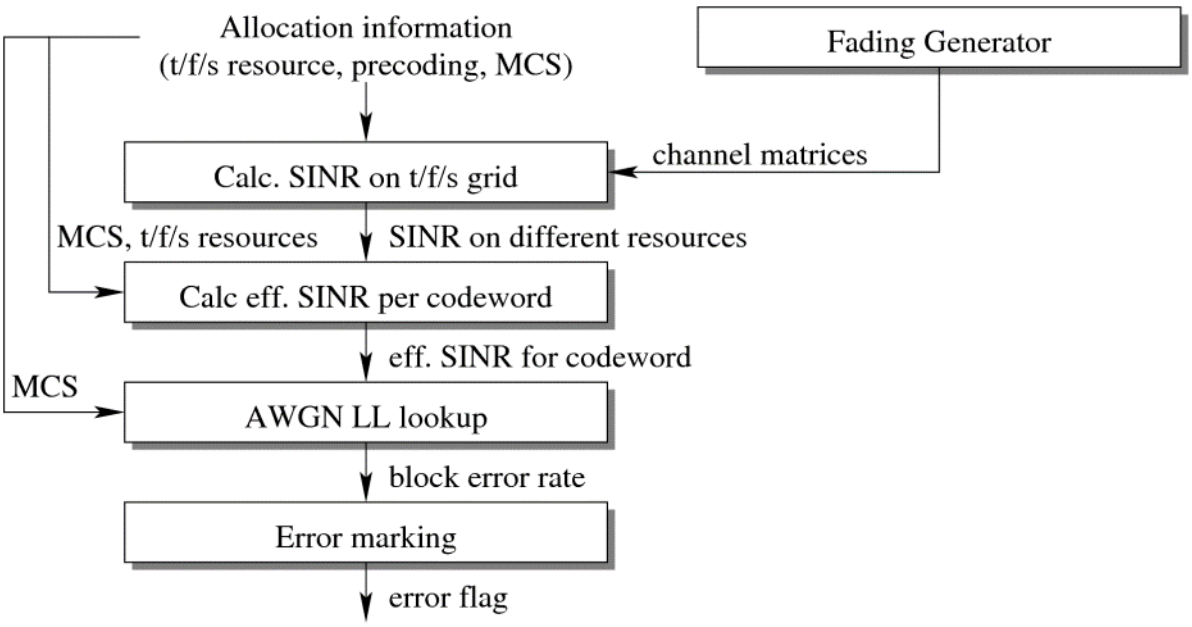

Figure 9-2: Layer 1 emulation of RealNeS

The individual steps are briefly described as follows:

- The system level simulator has—based on whatever criteria—allocated certain radio resources to a transmission, with a certain Modulation and Coding Scheme (MCS) and a precoding scheme and passes them to the physical-layer emulator.
- A fading generator generates channel matrices in the Equivalent Complex Baseband (ECB) for all relevant links (serving or interfering) based on positions, mobility, antenna parameters and many other parameters that affect the channel conditions.
- The first block "Calc. SINR on t/f/s grid" computes the effective Signal to Interference plus Noise Ratio (SINR) including Multiple Input Multiple Output (MIMO) precoding, Orthogonal Frequency-Division Multiplexing (OFDM) modulation, fading channel, receiver filtering and potentially realistic channel estimation on the time / frequency / spatial resources used for a particular transmission. Thereby, the block channel modelling includes the addition of noise and interference arriving from other entities transmitting on the same radio resources. For a simple example of SINR computation for Single User MIMO (SU-MIMO) without interference, cf. e.g. Eq. (6) in [VP-09]; extending this to include other interference terms or applying arbitrary receive filters is rather trivial. To limit computational complexity, this is not done for every single resource element (Quadrature Amplitude Modulation (QAM) symbol) used in the transmission, but with reasonable sampling in time and frequency depending on the coherence time and bandwidth of the fading channels.
- The block "Calc. eff SINR per codeword" averages these SINR samples into a single effective SINR that is applicable to the whole codeword; "effective" here means that the expected error rate for this transmission given the current state of the transmission channel is (approximately) the same as that of a transmission of this codeword over a flat Single Input Single Output (SISO) Additive White Gaussian Noise (AWGN) channel with the eff. SINR as actual and constant SINR. For this, various approaches have been proposed in [KB-05]. Of these models the one called "Mutual Information Effective SINR Metric" (MIESM), cf. Eq. (1) with Eq. (4) of [KB-05] for OFDM or [Mot-Sim05] for Discrete Fourier Transform-spread (DFTS)-OFDM, is highly accurate for powerful coding schemes such as Turbo and Low-Density Parity Check (LDPC) codes. What it does, is that it computes from each eff. SINR sample obtained above how much mutual information can be transmitted per symbol assuming this SINR and modulation scheme. This is then aggregated over the different eff. SINR samples to derive the total amount of mutual information that can be transmitted within the codeword for the current channel state. Via the same relation between SINR and mutual information for a given

modulation scheme the effective SINR over the entire transmission is obtained. This is highly accurate if it can be assumed that each data bit is uniformly represented by each of the code bits, which is reasonably true for powerful coding schemes such as Turbo or LDPC codes, but not so much e.g. for convolutional codes.

- The effective SINR for the codeword is then passed to the block "AGWN LL lookup". This block holds lookup tables of Block Error Rate (BLER) vs. Signal to Noise Ratio (SNR) for each Modulation Coding Scheme (MCS). These may be obtained e.g. via link-level simulation for the AWGN channel with noise being applied directly on BPSK-modulated code bits. Hence, all that this block does, is to report the BLER corresponding to the eff. SINR received from above from these tables using the MCS as an index.
- Finally, the block "Error marking" performs random error marking of the codeword with the probability reported by the above block. The thus marked codeword is then passed to the receiving protocol stack, where the physical layer only needs to check the error flag to determine how to further proceed with the packet, i.e. discard it and possibly ask for a retransmission, if it was received in error or pass it on to higher layers for further processing if received without error.

The simulator allows for simulation of both generic environments such as "dense urban", "rural" or "indoor" as defined in [3GPP-38901] or [ITU-5/57-E] and real-world scenarios, where actual geographical, building and mobility data can be imported for analysis in more realistic scenarios and catchy demonstrations.

RealNeS is actually not a single simulator for a particular radio access technology, but it covers various technologies, namely Long Term Evolution /-Advanced LTE(-A), Wireless LAN IEEE 802.11 and 5G NR, the latter obviously being under heavy development as 3GPP is in the process of standardising 5G NR.

Development of NOMOR's system level simulator

Within the scope of this project and the parallel project 5G-Xcast, that is also funded by the European Commission, and in which NOMOR is active, as well, the NR simulator has been enhanced to maintain 3GPP decisions being made in the standardisation of NR. In this context the simulator is being enhanced significantly to reflect the flexibility of the layer 1 / layer 2 schemes that is allowed by 5G and exploited in 3GPP calibration and evaluation for IMT-2020. This involves among other things:

- Update to have flexible Hybrid Automatic Repeat Request (HARQ) / Medium Access Control (MAC) layer timing
- Mixed single-user multi-user (massive) MIMO and scheduling schemes in uplink and downlink
- Various antenna configurations and support for hybrid beamforming
- SRS-based channel sounding mechanisms
- Central Unit (CU) – Distribution Unit (DU) network architecture
- New 3D channel models.

These activities are accompanied by careful code optimisation firstly to maintain the capability to simulate a meaningful portion of a cellular communication network in a single PC at decent speed and secondly to support simulation of very large scenarios for IMT-2020 evaluation, where memory consumption of the simulation process would otherwise be a problem.

9.2 Calibration of NOMOR's system level simulator

In the course of this project and in coordination with the parallel projects 5G-Xcast, One5G and 5G-Essence, which are also funded by the European Commission, the evaluation of 3GPP's proposals for IMT-2020 is performed. The first step in the evaluation process is to calibrate the SLS in simplified reference scenarios which are introduced in the following. 3GPP, as a proponent for IMT-2020, is required to perform self-evaluation based on scenarios and constraints defined by the ITU-R. Therefore, NOMOR calibrated its SLS against the various simulators used in 3GPP, cf. [Hua-Cal18].

The ITU-R defined three different usage scenarios in [ITU-M2412], namely Enhanced Mobile Broadband (eMBB), Massive Machine Type Communications (mMTC) and Ultra-Reliable Low

Latency Communications (URLLC) and combines each of them with one or several geographical environment(s) resulting in different test environments. In the scope of this project, we restrict ourselves to the eMBB usage scenario where three test environments are defined:

- Indoor Hotspot (InH),
- Dense Urban (UMa) and
- Rural (RMa).

9.2.1 Network layouts

For the network layout no specific topography is considered, instead base stations are placed in regular grids [ITU-M2412].

For the InH test environment, 12 sites are placed at a height of 3 meter (m) with an inter-site distance of 20m in a confined and isolated area of 120m x 50m, see Figure 9-3. The scenario represents one floor of a building which has a height of 3m with ceiling mounted base stations. Internal walls are modelled via the stochastic Line of Sight (LOS) probability model. In two variants of this scenario one site can be configured with one or three sectors or cells, respectively.

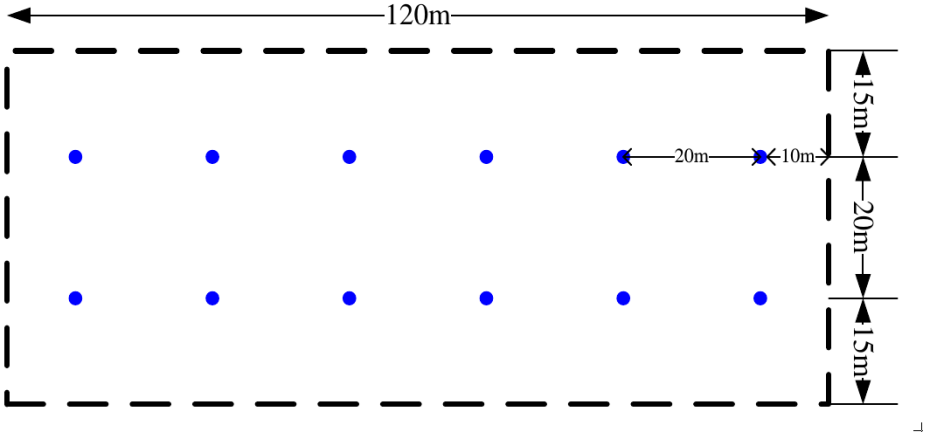

Figure 9-3: Layout for InH [ITU-M2412]

The UMa test environment for calibration is a regular hexagonal layout, where each site has three sectors, see Figure 9-4.

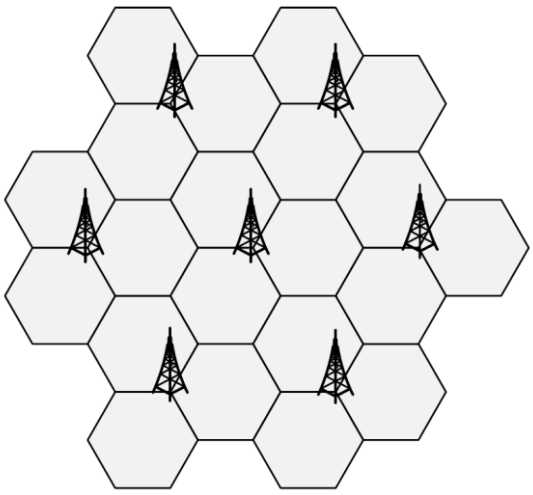

Figure 9-4: Hexagonal site layout for UMa and RMa [ITU-M2412]

For the RMa test environment the network deployment is the same as for the UMa test environment but differs in terms of inter-site distance and height of the base stations.

9.2.2 Parameter settings

In Table 5 of [ITU-M2412], the ITU-R defines evaluation configurations for each test environment. For several parameters such as the number of antenna elements or the bandwidth, a range is given. 3GPP specified these parameters for its calibration within the framework of the self-evaluation. An overview of all parameters used is given in e.g. [Hua-Cal18]. The 3GPP parameter settings are applied in NOMOR's SLS calibration.

For each test environment different configurations are available. The considered scenarios with the characterising configurations are summarised in Table 9-1.

Table 9-1: Scenario parameters with characterising configuration

Test environment	Configuration	Carrier frequency	Tx × Rx	GoB
InH	A	4GHz	32 × 4	–
	B	30GHz	64 × 32	✓
UMa	A	4GHz	128 × 4	✓
	B	30GHz	256 × 32	
RMa	A	700MHz	64 × 2	Fixed downtilt
	B	4GHz	128 × 4	

For InH and UMa, carrier frequencies of 4GHz and 30GHz are used, i.e. two different frequency ranges are investigated; namely frequency range 1 (FR1), frequencies below or equal 6GHz, and frequency range 2 (FR2), frequencies above 6GHz. For the RMa scenario, there are two configurations in FR1, one with 700MHz and one with 4GHz carrier frequency. In the scope of this project, uplink (UL) in FR1 and downlink (DL) and uplink in FR2 are considered, while downlink in FR1 is covered by the parallel project 5G-Xcast. For the sake of completeness, the parameters of both frequency ranges are discussed here.

In case of InH Config. A, 32 antenna elements are configured at the base station and 4 antenna elements at the UE. All antenna elements are controlled individually meaning there is a one-to-one mapping between transceiver units (TXRUs) and antenna elements.

The calibration of all InH scenarios is performed with one sector per site as well as with three sectors per site. As mentioned above the configuration can be selected by the proponent.

A Grid of Beams (GoB) with 8 or 12 different directions is applied at the gNB in the InH Config. B scenario or in the two (A and B) configurations of the UMa scenario, respectively, i.e., the antenna elements are grouped as disjoint sets into sub-array partitions served by different TXRUs. Within the TXRUs analogue beamforming is applied on the individual antenna elements, while for the combination of the different TXRUs digital precoding is used. In the InH Config. B scenario the 64 antenna elements are grouped into 8 partitions each connected to a TXRU. Each partition has 4 columns and 2 rows of antenna elements. The TXRUs of the two UMa scenarios each feed partitions of 32 antenna elements arranged in 8 columns and 4 rows. While for Config. A, 4 TXRUs are used, Config. B uses 8 TXRUs.

At the User Equipment (UE), 4 antenna elements with a one-to-one mapping are configured for Config A both of InH and UMa. Considering the appropriate configurations in FR 2, GoB with 8 different directions is applied at the UE. 32 antenna elements are grouped into 4 partitions. Each partition has 4 columns and 2 rows of antenna elements. While for the gNB, the TXRUs or antenna elements are positioned such that the beams or patterns look all into the same direction, the partitions of the latter configurations are as separate panels positioned back-to-back to allow a reception focused in various different directions.

For RMa, there is a fixed downtilt at the base station for all TXRUs. 8 antenna elements spaced in one column are fed by one TXRU. For Config. A (carrier frequency of 700MHz), there are 8 TXRUs; for Config. B (carrier frequency of 4GHz) 16 TXRUs, resulting in a total number of antenna elements of 64 or 128, respectively. On the UE side, 2 antenna elements are used for Config. A, whereas 4 antenna elements are used for Config. B.

At the gNB cross polarisation with an orientation of +45° and -45° is applied. The orientation of the antenna elements at the UE is 0° and +90°.

For all simulations, a bandwidth of 10MHz is applied and IMT channel model B [ITU-M2412] which corresponds to the 3GPP channel model for frequencies from 0.5GHz to 100GHz specified in [3GPP-38901]. Further parameter settings can be found in [Hua-Cal18].

9.2.3 Calibration results

3GPP's calibration process is based on two metrics, namely Downlink Coupling Gain and Downlink Geometry [Hua-Cal18].

The Downlink Coupling Gain includes the pathloss, the antenna gains and the average fast fading gains [Nom-Cal18]. Any processing gains at transmitter or receiver like beamforming or maximum ratio combining gain are excluded, except for analogue beamforming gains of the TXRUs where applicable.

The Downlink Geometry is the ratio of received signal power to the sum of interference and noise power where all signals are averaged individually over the used bandwidth. Like the Downlink Coupling Gain, it does not include any processing gain at transmitter or receiver except with analogue beamforming where applicable. As such the Downlink Geometry is a kind of wideband Signal to Interference plus Noise Ratio (SINR).

NOMOR's SLS is calibrated against various simulators used in 3GPP, cf. [Hua-Cal18]. The calibration results, regarding the metrics Downlink Coupling Gain and Downlink Geometry, are presented from Figure 9-5 up to Figure 9-20.

The results of the various 3GPP simulators are included in the figures tagged with legend entries '3GPP #i'', the index i being that specified in [Hua-Cal18].

The figures show a very good match of system level calibration results with the 3GPP results regarding Downlink Coupling Gain as well as Downlink Geometry. Only in RMa, Config. A (carrier frequency 700MHz) our results indicate a slightly increased probability of the Downlink Geometry in the range below -3dB, cf. Figure 9-19.

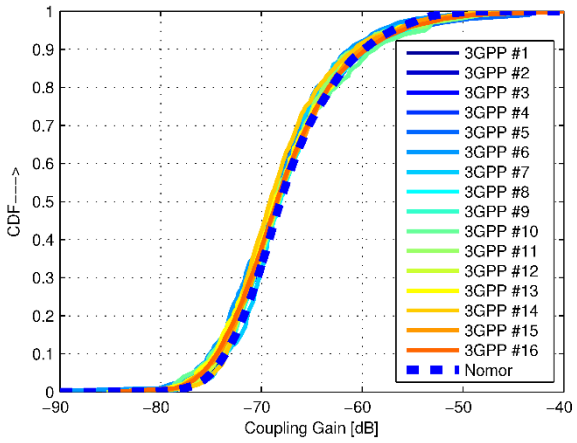

Figure 9-5: Coupling Gain, InH, Config. A, 1 sector

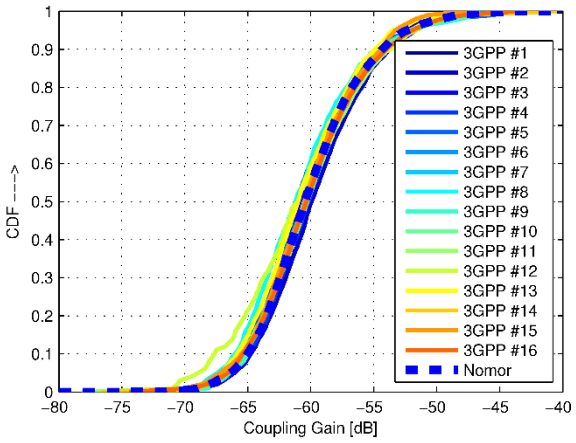

Figure 9-6: Coupling Gain, InH, Config. A, 3 sector

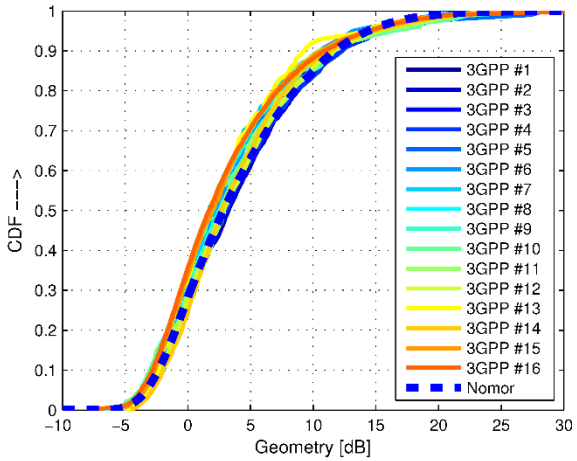

Figure 9-7: Geometry, InH, Config. A, 1 sector

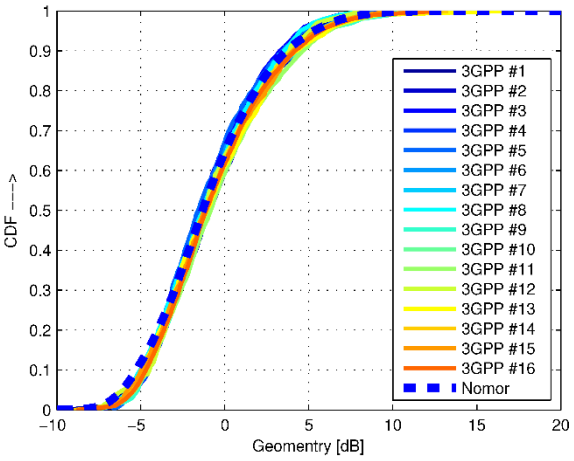

Figure 9-8: Geometry, InH, Config. A, 3 sector

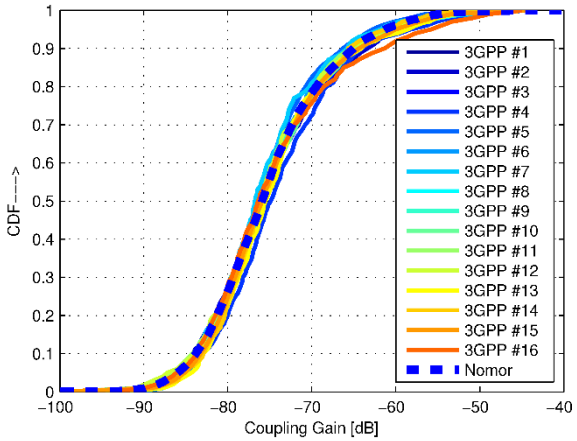

Figure 9-9: Coupling Gain, InH, Config. B, 1 sector

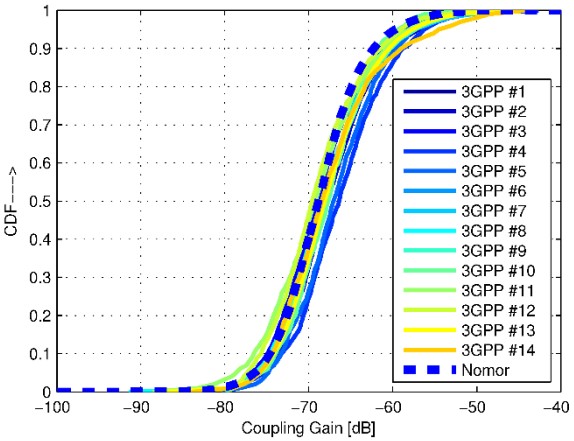

Figure 9-10: Coupling Gain, InH, Config. B, 3 sector

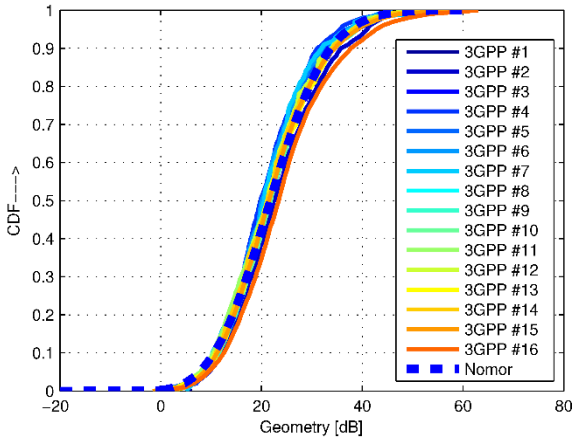

Figure 9-11: Geometry, InH, Config. B, 1 sector

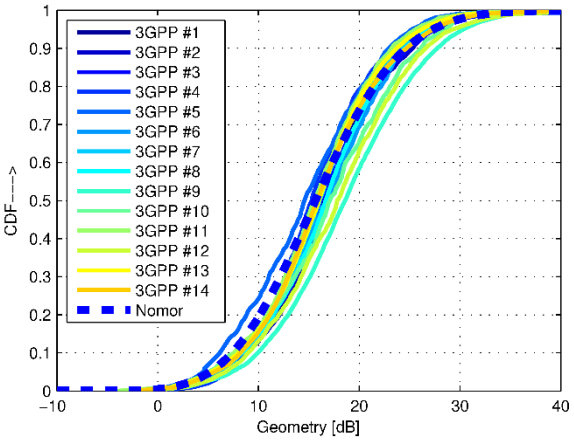

Figure 9-12: Geometry, InH, Config. B, 3 sector

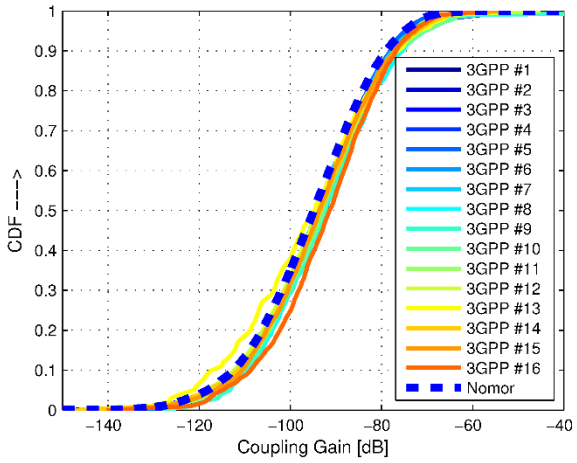

Figure 9-13: Coupling Gain, UMa, Config. A

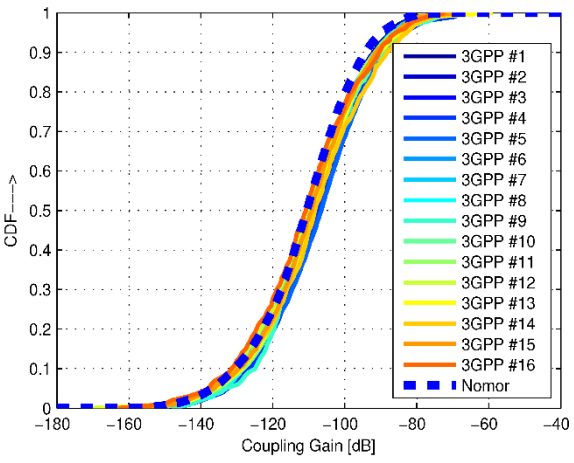

Figure 9-14: Coupling Gain, UMa, Config. B

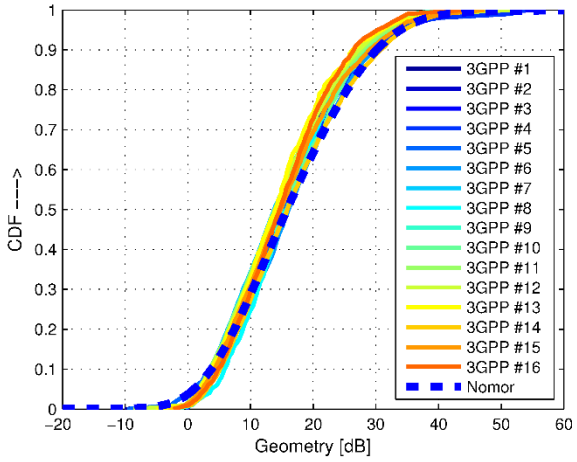

Figure 9-15: Geometry, UMa, Config. A

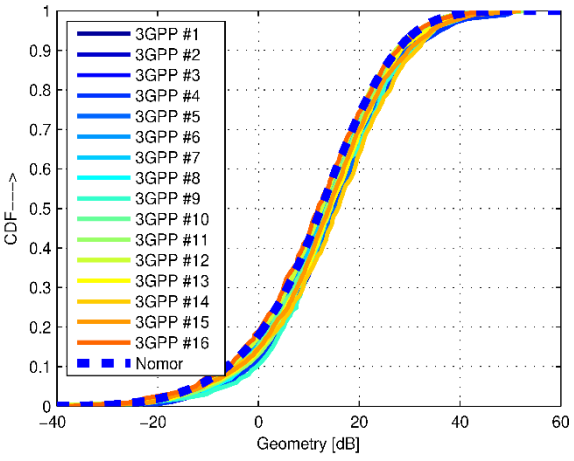

Figure 9-16: Geometry, UMa, Config. B

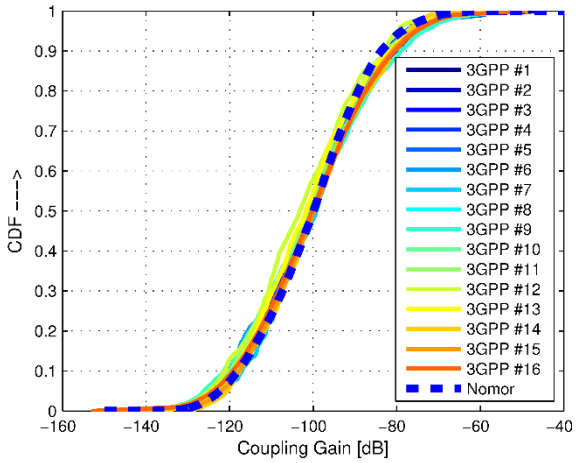

Figure 9-17: Coupling Gain, RMa, Config. A

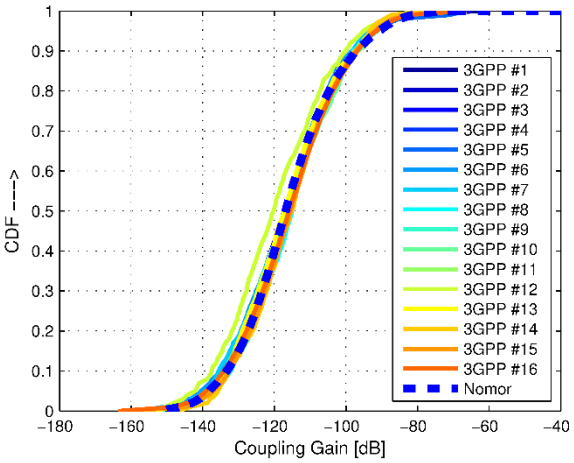

Figure 9-18: Coupling Gain, RMa, Config. B

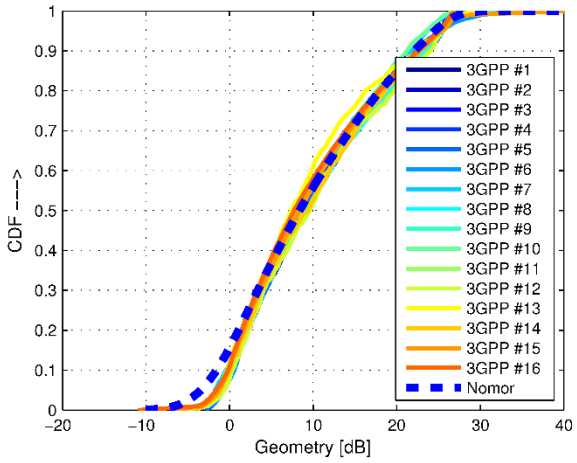

Figure 9-19: Geometry, RMa, Config. A

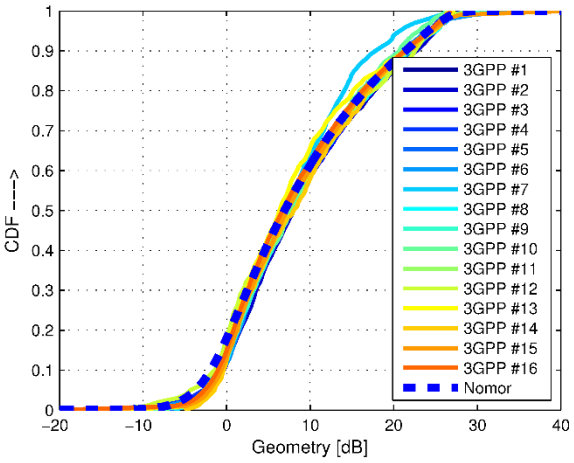

Figure 9-20: Geometry, RMa, Config. B

9.3 IMT-2020 system level simulations

After successful calibration of the SLS in simplified reference scenarios (see Section 9.2), system level simulations are performed for the IMT-2020 evaluation.

In the context of this project, system level simulations focus on uplink simulations in FR1, i.e. frequencies below or equal 6GHz and downlink and uplink simulations in FR2, i.e. frequencies above 6GHz. Downlink simulations in FR1 are performed in the parallel project 5G-Xcast, which is also funded by the European Commission. As mentioned in Section 9.2, the evaluation of 3GPP's proposal for IMT-2020 within the scope of 5G-Xcast and 5G-MoNArch is restricted to the usage scenario eMBB where three test environments are defined by ITU, namely Indoor Hotspot (InH), Dense Urban (UMa) and Rural (RMa), see [ITU-M2412].

9.3.1 Evaluation methodology

The three different test environments of eMBB are evaluated via system level simulations against four of the ITU-R key minimum technical performance requirements for IMT-2020 which are explained in the following.

Average spectral efficiency

The average spectral efficiency is obtained by summing up the throughput of all users and dividing it by the effective bandwidth and the number of transmission reception points (TRxPs). The throughput $R_i(T)$ of user i is defined as the number of bits contained in the Service Data Units (SDUs) delivered to Layer 3 over a certain period of time T. Furthermore, the effective bandwidth BW is the operating bandwidth normalised appropriately by the ratio between uplink and downlink.

Considering a scenario with N users and M TRxPs where each TRxP transmits with effective bandwidth BW, the average spectral efficiency SE_{avg} is calculated by

$$SE_{avg} = \frac{\sum_{i=1}^{N} R_i(T)}{T \cdot BW \cdot M}. \qquad \textbf{(1)}$$

The unity of metric average spectral efficiency is bit/s/Hz/TRxP [ITU-M2410].

5th percentile user spectral efficiency

For the normalised user throughput r_i of user i, the correctly received bits $R_i(T_i)$, meaning the bits contained in the SDUs delivered to Layer 3, are added up over a certain period of time T_i and divided by T_i as well as the effective channel bandwidth BW.

$$r_i = \frac{R_i(T_i)}{T_i \cdot BW} \qquad \textbf{(2)}$$

Using the normalised user throughput of all users in a scenario and simulating many times the determined period of time, a Cumulative Distribution Function (CDF) can be created. The 5% point of

this CDF is defined as the 5th percentile user spectral efficiency SE_{user} and is given in bit/s/Hz [ITU-M2410].

User experienced data rate

The user experienced data rate R_{user} is easily derived from the 5th percentile user spectral efficiency SE_{user}, by using equation (2) when one frequency band and one layer of TRxPs is applied. In case of carrier aggregation, the user experienced data rate is aggregated over the bands.

$$R_{user} = BW \cdot SE_{user} \quad \textbf{(3)}$$

In other words, the user experienced data rate is the 5% point of the CDF of the user throughput and is given in Mbit/s [ITU-M2410].

Area traffic capacity

In case one frequency band and one TRxP layer is applied, the area traffic capacity C_{area} can be derived from the achievable average spectral efficiency SE_{avg} as follows:

$$C_{area} = \rho \cdot BW \cdot SE_{avg} \quad \textbf{(4)}$$

where ρ is the density of TRxPs per m^2. As done for the user experienced data rate, the area traffic capacity is summed over all frequency bands, as long as carrier aggregation is used. It is measured in Mbit/s/m^2 [ITU-M2410].

9.3.2 Parameter settings

In this section the parameter settings of the scenarios evaluated in the context of this project are introduced.

The main common system level simulation parameter settings are listed in Table 9-2 for uplink in FR1 and in Table 9-4 for downlink and uplink in FR2. The scenario specific antenna parameters are provided in Table 9-3 and Table 9-5, for FR1 and FR2, respectively. The network layouts of the three different test environments, InH, UMa and RMa, are explained in Section 9.2.1.

NOMOR has performed system level simulations with Time Division Duplex (TDD) and a frame structure of DSUUD, where D is a subframe for downlink transmission, U a subframe for uplink transmission and S a "special" subframe used for a guard time.

In FR1, a system bandwidth of 20MHz and a subcarrier spacing of 15kHz is applied whereas in FR2, a system bandwidth of 80MHz and a subcarrier spacing of 60kHz is simulated. The selected transmission scheme for uplink is Closed-Loop Single User – MIMO (SU-MIMO) with rank adaptation and maximum rank two and for downlink Closed(-Loop) Multi User – MIMO (MU-MIMO) adaptation with maximum SU-rank two. Accordingly, for CSI two pre-coded Sounding Reference Signal (SRS) are transmitted by the UEs in downlink. In uplink the number of SRS ports depends on the number of UE antenna ports, which is two for RMa Config A and four for all other scenarios. As for the calibration, 3GPP channel model for frequencies from 0.5GHz to 100GHz specified in [3GPP-38901] is applied.

Table 9-2: System level simulation parameters settings in FR1 UL

Parameters	**Value**
Carrier frequency	4GHz (700MHz for RMa Config. A)
Duplexing	Time Division Duplex (TDD)
System bandwidth	20MHz
Frame structure	DSUUD, S (11D, 1G, 2U)
Subcarrier spacing	15kHz (μ=0)
Transmission scheme	Closed-Loop SU-MIMO with rank adaptation
SU dimension	up to 2 layers
SRS transmission	pre-coded SRS for UE 4 Tx ports (2 Tx ports for RMa Config. A)
Channel model	3GPP TR 38.901 [3GPP-38901] (= IMT-2020 model B)

In each scenario the same antenna parameters are used for downlink and uplink. The parameters *M*, *N* and *P* of the antenna configurations refer to the number of antenna elements at gNB or UE in vertical, horizontal and polarisation dimension respectively. The number of TXRU along with the number of antenna elements in vertical and horizontal directions per TXRU is indicated by the parameter "TXRUs at gNB/UE". Furthermore, the distance between the antenna elements in horizontal and vertical dimension (*dH*, *dV*) is listed.

For the UMa scenario in FR2, several panels, their numbers in vertical and horizontal direction being given by parameters *Mg* and *Ng*, respectively, are configured at gNB. The parameters *dgH* and *dgV* determine the distance between the antenna panels (centre to centre). The two panels at the UE in FR2 are positioned back-to-back.

These parameters are chosen according to the configurations applied during the self-evaluation of 3GPP towards IMT-2020, see documents of the folder "eMBB_SE.zip" which is attached to [3GPP-37910]. Note that for test environment InH two modes are applied, namely operating with one or three sectors per site.

Table 9-3: Scenario specific antenna parameters in FR1

	InH Config. A, 1sector	InH Config. A, 3sectors	UMa Config. A	RMa Config. A	RMa Config. B
gNB antenna config. [*M*, *N*, *P*]	[4,4,2]	[8,16,2]	[8,8,2]	[8,4,2]	[8,8,2]
TXRUs at gNB	32 (1×1)	32 (4×2)	32 (4×1)	8 (8×1)	32 (4×1)
antenna element spacing at gNB(*dH*, *dV*)	(0.5,0.5)λ	(0.5,0.5)λ	(0.5,0.8)λ	(0.5,0.8)λ	(0.5,0.8)λ
UE antenna config. [*M*, *N*, *P*]	[1,2,2]	[1,2,2]	[1,2,2]	[1,1,2]	[1,2,2]
TXRUs at UE	4 (1×1)	4 (1×1)	4 (1×1)	2 (1×1)	4 (1×1)
antenna element spacing at UE (*dH*, *dV*)	(0.5, –)λ	(0.5, –)λ	(0.5, –)λ	–	(0.5, –)λ

Table 9-4: System level simulation parameters settings in FR2

Parameters	**Value**	
	DL	**UL**
Carrier frequency	30GHz	
Duplexing	TDD	
Frame structure	DSUUD, S (11D, 1G, 2U)	
System bandwidth	80MHz	
Subcarrier spacing	60kHz (μ=2)	
Transmission scheme	Closed MU-MIMO adaptation (with analogue beam selection for UMa Config. B)	SU-MIMO with rank adaptation
MU dimension	up to 12 layers	–
SU dimension	up to 2 layers	up to 2 layers
SRS transmission	pre-coded SRS for UE 2 Tx ports	pre-coded SRS for UE 4 Tx ports
Channel model	3GPP TR 38.901 [3GPP-38901] (= IMT-2020 model B)	

Table 9-5: Scenario specific antenna parameters in FR2

	InH Config. B, 1sector	InH Config. B, 3sectors	UMa Config. B
gNB antenna configuration [*M*, *N*, *P*]	[4,4,2]	[4,16,2]	[4,8,2]
gNB panels [*Mg*, *Ng*]	[1,1]	[1,1]	[2,2]
TXRUs at gNB	32 (1×1)	32 (4×1)	8 (4×8)

antenna element spacing at gNB (*dH, dV*)	(0.5,0.5)λ	(0.5,0.5)λ	(0.5,0.5)λ
antenna panel spacing (*dgH, dgV*)	–	–	(4.0,2.0)λ
UE antenna configuration [*M, N, P*]	[2,4,2]	[2,4,2]	[2,4,2]
UE panels [*Mg, Ng*]	[1,2]	[1,2]	[1,2]
TXRUs at UE	8 (2×2)	8 (2×2)	8 (2×2)
antenna element spacing at UE (*dH, dV*)	(0.5, 0.5)λ	(0.5, 0.5)λ	(0.5, 0.5)λ
antenna panel spacing (*dgH, dgV*)	(0,0)λ	(0,0)λ	(0,0)λ

9.3.3 Simulation results

In the following subsections the Key Performance Indicator (KPI) values evaluated by NOMOR are discussed in comparison to the ITU-R requirements for IMT-2020 and the mean of the values submitted by different companies during 3GPP self-evaluation, see [3GPP-37910].

Indoor Hotspot (InH) test environment

For InH average spectral efficiency SE_{avg} and 5th percentile user spectral efficiency SE_{user} are considered as KPIs. In case of downlink, area traffic capacity C_{area} is evaluated additionally.

Table 9-6 shows that the ITU-R requirements for IMT-2020 are fulfilled in case of uplink InH Config. A (carrier frequency f_c= 4GHz) for both operation modes, 1 sector per site and 3 sectors per site, with respect to the two evaluation metrics. This is valid for NOMOR's results as well as for the results given during 3GPP self-evaluation.

It should be mentioned that the gNB antenna configuration of 3GPP self-evaluation and NOMOR differs for the mode with three sectors per site: 3GPP configured 32 TXRUs each of size 2×1 ([*M, N, P*] = [4,8,2]), whereas NOMOR applies 32 TXRUs each of size 4×2 ([*M, N, P*] = [8,16,2]) which is the same configuration as for downlink InH Config. A.

Table 9-6: InH Config. A, UL SLS results for IMT2020-evaluation

InH Config. A, UL		**1 sector/site**		**3 sectors/site**	
	ITU-R requirement	NOMOR	3GPP self-evaluation	NOMOR	3GPP self-evaluation
Avg. SE [bit/s/Hz/TRxP]	6.75	8.43	8.65	7.40	7.59
5%-tile UE SE [bit/s/Hz]	0.21	0.48	0.54	0.25	0.47

Considering Table 9-7 and Table 9-8, it can be observed that the ITU-R requirements in terms of average spectral efficiency and 5th percentile user spectral efficiency are met for InH Config. B for both modes of operation for downlink as well as for uplink.

Like in FR1, 3GPP self-evaluation uses a different gNB antenna configuration in uplink and downlink for the mode with three sectors per site, namely 32 TXRUs each of size 4x2 in case of uplink.

While for the evaluation of average spectral efficiency and 5th percentile user spectral efficiency, a frequency bandwidth of 80MHz is used in FR2, for area traffic capacity, system-level simulations are performed with a frequency bandwidth of 200MHz. The larger bandwidth provides a more efficient usage of bandwidth and a smaller overhead. Additionally, to achieve the ITU-R requirement of 10Mbit/s/m^2, carrier aggregation is applied. For the mode with one sector per site, NOMOR uses three component carriers resulting in an aggregated bandwidth of 600MHz and an area traffic capacity of 10.03Mbit/s/m^2. For the mode with three sectors per site, the density of TXRUs is three times larger and therefore two component carriers are sufficient to achieve the ITU-R requirement for area traffic capacity.

It should be noted that during 3GPP self-evaluation the TDD scheme DDDSU with S (10D, 2G, 2U) is used for the considered antenna configuration for the mode with one sector per site, while NOMOR

used DSUUD with S (11D, 1G, 2U). Therefore, the ratio of area traffic capacity, where the DL bandwidth is taken into account, differs in this case from the ratio of average spectral efficiency.

Table 9-7: InH Config. B, DL SLS results for IMT2020-evaluation

InH Config. B, DL		**1 sector/site**		**3 sectors/site**	
	ITU-R requirement	NOMOR	3GPP self-evaluation	NOMOR	3GPP self-evaluation
Avg. SE [bit/s/Hz/TRxP]	9	13.19	12.28	10.57	12.72
5%-tile UE SE [bit/s/Hz]	0.3	0.46	0.31	0.34	0.38
Area traffic capacity [Mbit/s/m2] (used BW)	10	10.25 (600MHz)	12.13 (600MHz)	16.44 (400MHz)	19.77 (400MHz)

Table 9-8: InH Config. B, UL SLS results for IMT2020-evaluation

InH Config. B, UL		**1 sector/site**		**3 sectors/site**	
	ITU-R requirement	NOMOR	3GPP self-evaluation	NOMOR	3GPP self-evaluation
Avg. SE [bit/s/Hz/TRxP]	6.75	6.90	7.04	6.74	7.09
5%-tile UE SE [bit/s/Hz]	0.21	0.35	0.4	0.29	0.39

Dense Urban (UMa) test environment

Average spectral efficiency SE_{avg}, 5th percentile user spectral efficiency SE_{user} and user experienced data rate R_{user} are the evaluation metrics considered for UMa test environment.

Table 9-9 shows that ITU-R requirements for IMT-2020 are met by far in uplink for scenario UMa Config. A (carrier frequency f_c = 4GHz). This is valid for the results of NOMOR as well as the mean of the companies contributing to the 3GPP self-evaluation and using the same simulation parameters.

In contrast to average spectral efficiency and 5th percentile user spectral efficiency, where a frequency bandwidth of 20MHz is applied, the evaluation of user experienced data rate is conducted with a frequency bandwidth of 40MHz and additional carrier aggregation in order to take the smaller overhead in a larger bandwidth into account as done for area traffic capacity. NOMOR concluded that with 14 CCs each of 40MHz bandwidth a user experienced data rate of 54.14Mbit/s/m^2 is achieved. Evaluating the mean of the results submitted during 3GPP self-evaluation, 20 CCs are necessary to fulfil the ITU-R requirement of 50Mbit/s/m^2 for uplink user experienced data rate. The need of a larger number of CCs is due to the fact that during 3GPP self-evaluation, TDD pattern DDDSU is applied, where S has distribution (10D, 2G, 2U), while NOMOR simulated with TDD pattern DSUUD where S has distribution (11D, 1G, 2U).

Table 9-9: UMa Config. A, UL SLS results for IMT2020-evaluation

UMa, Config. A, UL	**ITU-R requirement**	**NOMOR**	**3GPP self-evaluation**
Avg. SE [bit/s/Hz/TRxP]	5.4	8.21	7.18
5%-tile UE SE [bit/s/Hz]	0.15	0.22	0.288
User experienced data rate [Mbit/s] (used BW)	50	54.14 (560MHz)	55.98 (800MHz)

For UMa Config. B the ITU-R requirements are not met with the performed system level simulations (cf. Table 9-10, relevant results marked in red), even when simulating without channel estimation error.

Considering the CDF of geometry received during the calibration process, see Figure 9-16, this does not seem to be all that surprising because there are geometry values down to -30dB. Besides, it is general knowledge that for large frequencies the penetration loss and pathloss is significantly higher and therefore it is difficult to achieve high spectral efficiency in scenarios with outdoor-to-indoor coverage. Currently there is also an ongoing 3GPP discussion about this scenario. Many companies observed that some UEs with high penetration loss cannot be supported in the system. It is discussed to introduce additional assumption of a certain admission control scheme such that users with poor performance are not attached so that the other users can be assigned more resources leading to higher user data rates and a higher cell spectral efficiency [Sam-FR2].

Table 9-10: UMa Config. B, DL SLS results for IMT2020-evaluation

UMa, Config. B, DL	ITU-R requirement	NOMOR	3GPP self-evaluation
Avg. SE [bit/s/Hz/TRxP]	7.8	5.07	5.47
5%-tile UE SE [bit/s/Hz]	0.225	0.001	0.01
User experienced data rate [Mbit/s] (used BW)	100	2.3 (3200MHz)	–

Table 9-11: UMa Config. B, UL SLS results for IMT2020-evaluation

UMa, Config. B, UL	ITU-R requirement	NOMOR	3GPP self-evaluation
Avg. SE [bit/s/Hz/TRxP]	5.4	2.62	2.49
5%-tile UE SE [bit/s/Hz]	0.15	0.004	0.00
User experienced data rate [Mbit/s] (used BW)	50	2.31 (3200MHz)	–

Rural (RMa) test environment

For evaluation of the two RMa configurations sets, average spectral efficiency SE_{avg} and 5th percentile user spectral efficiency SE_{user} are considered. Note that for Config. A, where a carrier frequency of 700MHz is considered, the UE uses two TXRUs while for Config. B, where a carrier frequency of 4GHz is simulated, there are four TXRUs at UE side, see Table 9-3. A larger number of TXRUs at the UE means a larger potential for beamforming gain.

Considering Table 9-12, it is concluded that the 5G NR system specified by 3GPP outperforms ITU-R's IMT-2020 requirements for uplink RMa. This is valid for both configuration sets and according to NOMOR's evaluation as well as the 3GPP self-evaluation.

Table 9-12: RMa UL SLS results for IMT2020-evaluation

RMa, UL		Config. A		Config. B	
	ITU-R requirement	NOMOR	3GPP self-evaluation	NOMOR	3GPP self-evaluation
Avg. SE [bit/s/Hz/TRxP]	1.6	4.47	4.74	8.04	5.98
5%-tile UE SE [bit/s/Hz]	0.045	0.06	0.16	0.09	0.15

9.4 References

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