NEXT GENERATION INTERNET

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D7.3 Final dissemination, standardization and exploitation

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Abstract	This deliverable presents the work executed in the iNGENIOUS project with regards to dissemination, communication, standardization, exploitation, and innovation.
Keywords	3GPP, 5GAA, ETSI, Dissemination, Innovation, 5G, IoT

Document Revision History

Version	Date	Description of change	List of contributor(s)
V1.0	31/3/2023	Final version for EC submission	NXW

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Nature of the deliverable:	**to specify R, DEM, DEC, OTHER***	
Dissemination Level		
PU	Public, fully open, e.g. web	✓
CL	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to iNGENIOUS project and Commission Services	

** R: Document, report (excluding the periodic and final reports)*

DEM: Demonstrator, pilot, prototype, plan designs

DEC: Websites, patents filing, press & media actions, videos, etc.

OTHER: Software, technical diagram, etc.

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Executive Summary

This deliverable aims to give a complete look at the project's activities and achievements with regards to dissemination, standardization, and exploitation throughout the span of the project; and how they relate to meeting the **WP7 Objectives**:

- **Objective 7.1:** *Establishment of the communication mechanisms of the project outcomes to maximise the possible audience, including technical and non-technical audience.*
- **Objective 7.2:** *Maximization of the project impact by means of coordinated exploitation activities.*
- **Objective 7.3:** *Dissemination of the technical research outcomes of the project targeting industrial and academic communities.*
- **Objective 7.4:** *Planning of the exploitation activities to be performed after the end of the project.*
- **Objective 7.5:** *Monitor that the IPR and data management strategies are well defined and coherently executed.*

as well as the **Project Objective 7**:

> ***Objective 7:*** *To extend the work developed in the project and contribute to different NG-IoT SDOs*

Chapter 1 covers dissemination and communication activities. These activities include:

- contributions in the form of article and paper publications in journals, conference proceedings, magazines, and project deliverables; articles in external news and related outlets, and participation in conferences, workshops, training events, and other industrial and scientific events.
- the development and maintenance of the project website, the use of social media (Twitter, LinkedIn, Zenodo, and Slideshare), the project Blog, YouTube channel, and project news was used to approach the large professional communities of 5G stakeholders virtually.

The mapping to WP7 objectives is also given, and the associated impact target KPIs are reported.

Chapter 2 details the activities in targeted standardization bodies and industries for influencing the development of standards. As in Chapter 1, The mapping to WP7 objectives is also given, and the associated impact target KPIs are reported.

Finally, **Chapter 3** covers the innovation and exploitation produced within the project, and its links to the WP7 objectives. A detailed mapping scheme spanning from Background IP (BIP)to Innovation elements to Foreground IP (FIP) to Exploitable Elements (EEs) is presented. Detailed information on the 21 produced Exploitable Elements is given including:

- Description of Exploitable Elements (technical result / improvement)
- Where the Exploitable Elements will be used (e.g., product, research, etc., but try to describe specific ideas)

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- Sector of application and market potential (or technical impact for academic EEs)
- Commercialization maturity and/or TRL description
- Plan for exploitation
- How iNGENIOUS activities have contributed to EE's development.

Further information, including SWOT analyses, social and commercial impact, scalability and market penetration, as well as 5G-IoT value for 6 of the Exploitable Elements with high TRL levels can be found in D2.5 [1].

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Abbreviations

5G gNB	Next Generation Node B
AGV	Automated Guided Vehicle
AI/ML	Artificial Intelligence / Machine Learning
AIS	Automatic Identification System
API	Application Programming Interface
BIP	Background Intellectual Property
BLE	Bluetooth Low Energy
CIoT	Cellular IoT
CC	Component Carrier
CIR	Container Image Registry
CISM	Container Infrastructure Services Management
CRUD	Create, Read, Update, and Delete
DL	Down Link
DLT	Distributed Ledger Technology
DoA	Description of Action
DVL	Data Virtualisation Layer
E2E	End to End
EE	Exploitable Element
eMBB	enhanced Mobile Broadband
FIP	Foreground Intellectual Property
FPGA	Field-Programmable Gate Array
FSS	Fixed-Satellite Service
GEO	Geostationary or Geosynchronous Orbit
GUI	Graphical User Interface
GW	Gateway
I/O	Input/Output
IE	Innovation Element
IIoT	Industrial Internet of Things
IoT	Internet of Things
ISG	Industry Specification Group
JDBC	Java Database Connectivity
KETI	Korea Electronics Technology Institute
KPI	Key Performance Indicator
LAN	Local Access Network
LoRa	Long Range
M2M	Machine to machine
MAC	Medium Access Control Layer of the Open Systems Interconnection model
MANO	Management and Orchestration
MEC	Multi-access Edge Computing
MEO	Medium Earth Orbit
mMTC	massive Machine Type Communications
MSS	Mobile-Satellite Service
NB-IoT	Narrowband IoT
NEF	5G Network Exposure Function
NF	Network Function
NFV	Network Functions Virtualisation
NG-IoT	Next Generation Internet of Things
NoC	Network on Chip
NR	New Radio
NSMF	Network Slice Management Function
NTN	Non Terrestrial Networks
NWDAF	Network Data Analytics Function
O-RAN	Open Radio Access Network

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OCEAN	Open allianCE for IoT stANdards)
OData	Open Data Protocol
ODBC	Open Database Connectivity
PDCP	Packet Data Convergence Protocol
PHY	Physical Layer of the Open Systems Interconnection Model
QoS	Quality of Service
RAN	Radio Access Network
RDSS	Radiodetermination-Satellite Service
REST	Representational state transfer
RLC	Radio Link Control
RoT	Root-of-Trust
SBA	Service Based Architecture
SDK	Software Development Kit
SPI	Serial Peripheral Interface
ST	Survival Time
SW	Software
TCU	Trusted Communication Unit
ToD	Tele-operation Driving
TLS	Transport Layer Security
TPCS	Tuscan Port Community System
TSG	Technical Specification Group
TT	Truck Turnaround
UC	Use Case
UC1	Automated Robots with Heterogeneous Networks
UC2	Improve Drivers' Safety with MR and Haptic Solutions
UC3	Transportation Platform Health Monitoring
UC4	Inter-modal Asset Tracking via IoT and Satellite
UC5	Situational Understanding and Predictive Models in Smart Logistics Scenarios
UC6	Supply Chain Ecosystem Integration
UE	User Equipment
UL	Up Link
URLLC	Ultra-Reliable Low Latency Communications
VNF	Virtualized Network Functions
VSMF	Virtual Session Management Function
WGs	Work Groups
ZSM	Zero touch network and Service

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1 Dissemination and Communications

The work covered in dissemination and communications includes providing content to the scientific and industrial community on the achievements and work done in the project as well as the establishment of communication strategies and management of the project's communication channels to maximise the project impact during its lifetime and after its end. This chapter provides details on the activities and results pertaining to the associated work package objectives.

1.1 Objectives and KPIs

The dissemination and communication activities for the project have two associated WP7 objectives, as reported in the Description of Action (DoA):

- **Objective 7.1**: Establishment of the communication mechanisms of the project outcomes to maximise the possible audience, including technical and non-technical audience.
- **Objective 7.3**: Dissemination of the technical research outcomes of the project targeting industrial and academic communities.

A set of impact target KPIs for wide stakeholder engagement have been defined in the DoA to evaluate the performance of each objective. A summary of the KPIs, the target values, and the final achievements are listed in Table 1-1 below[1].

Objective 1 KPIs		
KPI description	**DOA Targets**	**Achieved**
Size of community (Twitter followers, mailing list subscribers, bloggers)	>1.000	>350
Media coverage (Partners' news clippings, NG-IoT coverage on the project, project coverage from external parties)	50	>100
Press releases (by the project)	>10	30
Blog posts, tweets including editorial and clippings (by the project)	>2.500	242 (16,971 impressions)
Unique Website visits	>4.000	>9,000
Objective 2 KPIs		
KPI description	**DOA Targets**	**Achieved**
Number of workshops	6	6
Number of webinars /showcasing events (demos + talks)	4	22
Number of webinar and workshop participants	250	>500
Journal and conference scientific papers	>20	22 + 2 in review
White papers, newsletters, success stories, factsheets	>10	14
Keynotes in major European and worldwide conferences events	10	7

[1] Numbers are as of 31/03/2023

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Summer schools, tutorials, online training modules	1	1
Public deliverables	18	21

Table 1-1 Summary of the KPIs, the target values, and the final achievements for dissemination and communication

The following sections provide details on the dissemination and communications activities throughout the project.

1.2 Dissemination Activities

Dissemination activities for the project provide content to the scientific and industrial community on the achievements and work done in the project. These include article and paper publications in journals, conference proceedings, magazines, and project deliverables; articles in external news and related outlets, and participation in conferences, workshops, training events, and other industrial and scientific events.

This includes **22 publications in journals (6,** plus 2 under revision**)**, **conference proceedings (13)** and **magazines (3)**, as well as **21 public project deliverables**. A complete list with links to the open access documents can be found on the website in [1] and [2], respectively, as well as in Annex 1 – Project Publications.

The project has also participated in a variety of **events targeting academic and industrial audiences**, **30 in total**. These include:

- 1 hackathon
- 1 webinar
- 5 workshops
- 14 conference and event talks, including 7 keynote presentations
- 9 Use Case demonstrations

More details on iNGENIOUS dissemination events can be found in Annex 2 - Dissemination Events.

Moreover, iNGENIOUS took part as an active contributor to the editing of the book promoted by EU-IoT and titled “Shaping the Future of IoT with Edge Intelligence”, specifically editing 3 chapters:

- AI-driven service and slice orchestration (NXW)
- Enabling Remote Controlled Factory Robots via Smart IoT Application Programming Interface (TUD, UPV, BI)
- Haptic and Mixed Reality enabled Immersive Cockpits for Tele-operated Driving (NOK, 5CMM, UPV)

In total, the project has been involved in **92 dissemination activities**.

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1.3 Communication Activities

Communication activities involved the efforts made by the project to engage with both technical and non-technical audiences. These include the development and maintenance of the project website, the use of social media (Twitter and LinkedIn), the project Blog, YouTube channel, and project news.

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The project website acted as the main platform to present the work and achievements of the project to the general public. To increase the audience viewing the content provided on the website, announcements were made via Twitter and LinkedIn platforms. Followers and connections on these platforms were maximized using collaborations with the NGIoT and EUCloudEdgeIoT.eu initiatives.
The landing page, shown on the right, provides high-level descriptions of the project's scope and vision including a top menu to navigate to more detailed content on:

- Project
  - Leaflet
  - Architecture
  - Use Cases
  - PoCs
  - Consortium
- Deliverables
  - Project Deliverables
  - Open Access Data
  - Open Source Material
  - Publications
  - Innovation and Exploitation
- Contacts
- News
  - Project News
  - Partner Highlights
  - Keynote Presentations
  - YouTube channel
- Blog

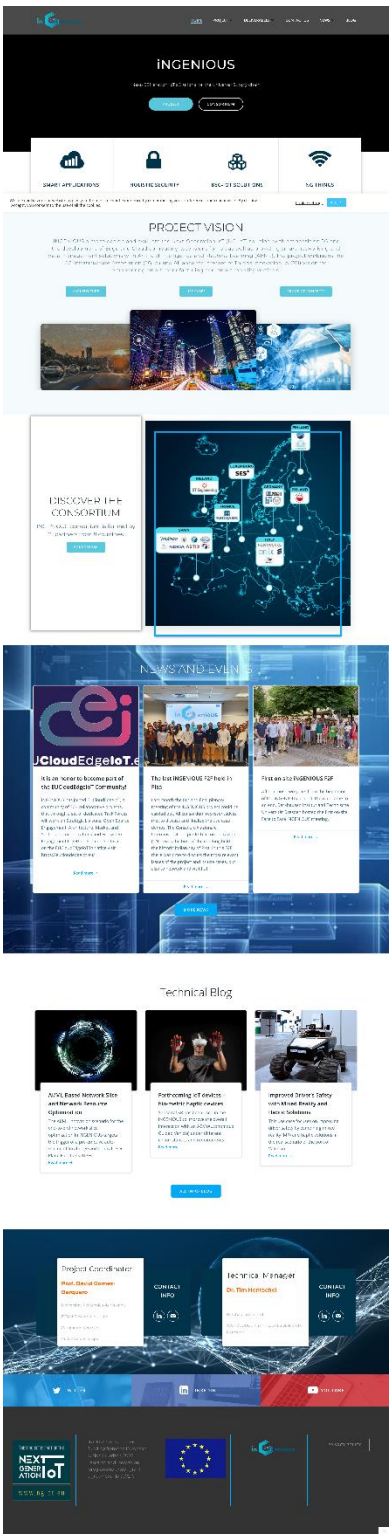

Figure 1-1 Project landing page

In total, there have been **>9,000 unique sessions** to the project website over the course of the project.

1.3.1 SOCIAL MEDIA

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The iNGENIOUS social media channels were used for the communication of research and innovation actions and have provided an effective communication and dissemination of project's results. The social media outlets include Twitter, LinkedIn, YouTube, the project Blog, Zenodo, and Slideshare.

Social Media[2]		
Communication Outlet	**Audience**	**Number of posts**
Twitter	Public (78 followers)	150 tweets
LinkedIn	Public (262 followers)	76 posts, 16,971 impressions
YouTube	Public (14 subscribers)	17 videos (601 views)
Zenodo	Public	19 (1,361 views, 1,027 downloads)
Slideshare	Public (2 followers)	8 SlideShares
Blog	Public	14 Blog posts
Press releases & news	Public	30

Table 1-2 Social Media overview

The material summarized in Table 1-2 can be accessed using the following links:

Twitter - https://twitter.com/ingenious_iot

LinkedIn - https://it.linkedin.com/in/ingenious-iot-8522a11b7

YouTube - https://www.youtube.com/@ingenious_iot345/videos

Zenodo - https://zenodo.org/communities/ingenious-iot/

Slideshare - https://www.slideshare.net/iNGENIOUSIoT

Blog Posts - https://ingenious-iot.eu/web/blog/

1.3.2 COLLABORATIONS, PRESS RELEASES, AND NEWS

iNGENIOUS has been an active member in the EU-IoT Communications Task Force – NGIoT [3]. NGIoT helped to further amplify our presence in the scientific and industrial communities by promoting our activities through their social channels and website, as well as hosting 7 workshops and community events in which iNGENIOUS has participated, and covering **Success Stories of 4 of our partners'** as they develop innovations in the project, as reported in Annex 3 – Success Stories.

In addition, there have been **9 partner press releases and external news** coverage of the project (as reported in the Annex 4 - Partner News and Press Releases), and **30 project news** coverages [4].

iNGENIOUS has also collaborated with the EUCloudEdgeIoT [5] project for dissemination of the activities and achievements to further increase the project's presence in the IoT community. EUCloudEdgeIoT, which runs until

[2] Numbers are as of 31/03/2023

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November 2024, will continue to showcase the iNGENIOUS solution well after the end of the project.

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2 Standardization and Open-Source Activities

2.2 Objectives and KPIs

The standardization activities conducted in the project involved the monitoring of proceedings within several SDOs (3GPP, ETSI, IEEE, SSIG) in the area of IoT technology and the coordination of the submission of technical results to targeted standardization groups to raise awareness and help in the adoption of the project innovations. These activities are associated with the Project Objective 7:

> **Objective 7**: To extend the work developed in the project and contribute to different NG-IoT SDOs

A set of impact target KPIs for international standards groups have been defined in the DoA to evaluate the performance of the objective. A summary of the KPIs, the target values, and the final achievements are listed in Table 2-1. The target of "white papers downloads" was revised as non-applicable (N/A) to standardization activities. SDOs mainly produce specifications and although few generic white papers may be produced occasionally to provide generic information on specified technology, they neither include specific contributions from companies nor the respective number of downloads can be tracked. "White papers" term is commonly used when individual organisation produces a less serious document to give info on technical topics, features etc.; but that is irrelevant to standardization.

International standards groups impact KPIs		
KPI description	**DOA Targets**	**Achieved**
Number of standards contributions	> 20	38
Number of companies involved	> 7	5
Number of white papers downloads	> 1.000	N/A

Table 2-1 Summary of the KPIs, the target values, and the final achievements for standardization activities

2.3 Work within Standards Organizations

Several iNGENIOUS partners are members of various standardisation bodies and have been monitoring activities relevant to iNGENIOUS in order to align the studies within the project for use case definition, characterizing performance evaluation methodology, and benchmarking of technical activities, as well as to promote the insights and results of the project. Additional bodies for standardisation or for influencing standards (e.g., NGMN, DSCA, ESA, GSOA) and work topics (e.g., 3GPP Release 18 SA work and RAN scoping topics, NR sidelink relay, Passive IoT, DECT2020 NR) of relevance to iNGENIOUS scope were brought into the consortium attention. Regular updates on IoT-related SDO activities have been organised to deliver insights to all partners. iNGENIOUS has also contributed to EU-IoT whitepaper and participated in EU-IoT online meetings for open-source and standardisation aspects.

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The Table below provides an overview of iNGENIOUS partners main activity within standards.

SDO	Current Activity
3GPP	Active participation with contributions to RAN, RAN1, RAN2
5GAA	Active participation at Tele-operation Driving rate and reliability communication requirements.
ETSI	Monitoring of ETSI NFV, ETSI ZSM and contribution to ETSI SES SCN
SSIG	Monitoring of Satellite Standardisation Interest Group (SSIG) group

Table 2-2 An overview of iNGENIOUS partners activity within standards.

A list of all the contributions submitted to SDOs during iNGENIOUS activities is provided in the Table below.

N.	Title of the contribution	Type	Document ID	Meeting Date	SDO, Group
1	Complexity reduction features for RedCap UE	Scoping views	R1-2008738	Oct-2020	3GPP RAN1
2	Coverage recovery for RedCap UE	Scoping views	R1-2008740	Oct-2020	3GPP RAN1
3	Reduced PDCCH monitoring for RedCap UE	Scoping views	R1-2008739	Oct-2020	3GPP RAN1
4	Framework and principles for RedCap UE	Scoping views	R1-2008741	Oct-2020	3GPP RAN1
5	Additional RLC and PDCP aspects for NTN	Proposals	R2-2010170	Oct-2020	3GPP RAN2
6	Additional PDCP aspects for NTN	Proposals (revision)	R2-2101532	Jan-2021	3GPP RAN2
7	On RLC t-Reassembly for NTN	Proposals	R2-2101518	Jan-2021	3GPP RAN2
8	On RLC t-Reassembly for NTN	Proposals (revision)	R2-2103964	Apr-2021	3GPP RAN2
9	On UL time and frequency synchronization enhancements for NR NTN	Scoping views	R1-2103687	Apr-2021	3GPP RAN1
10	On RLC t-Reassembly for NTN	Proposals (resubmit)	R2-2106055	May-2021	3GPP RAN2
11	On RLC t-Reassembly for NTN	Proposals (resubmit)	R2-2108460	Aug-2021	3GPP RAN2
12	ST handling with alternating CC allocations	Proposals	R2-2108457	Aug-2021	3GPP RAN2
13	Issues with UE Survival Time support	Proposals	R2-2110918	Nov-2021	3GPP RAN2
14	On RLC t-Reassembly for NTN	Proposals (resubmit)	R2-2110925	Nov-2021	3GPP RAN2

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15	Moderator's summary for discussion [RAN94-e-R18Prep-06] RedCap (Reduced Capability) Evolution	Scoping views within	RP-212665	Dec-2021	3GPP RAN
16	Considerations on UE Survival Time support	Proposals (revision)	R2-2201622	Jan-2022	3GPP RAN2
17	Correction to NR NTN epoch time definition	Correction Proposals	R2-2205999	May-2022	3GPP RAN2
18	Feature lead summary of AI 9.12.3 on improved GNSS operations [for IoT NTN]	Scoping views within	R1-2205553	May-2022	3GPP RAN1
19	FL summary on potential solutions to further reduce RedCap UE complexity	Scoping views within	R1-2205435	May-2022	3GPP RAN1
20	FL summary on simulation needs and assumptions for further reduce UE complexity	Scoping views within	R1-2205604	May-2022	3GPP RAN1
21	Feature Lead Summary for [109-e-R18-Pos-08] Positioning for RedCap UEs	Scoping views within	R1-2205636	May-2022	3GPP RAN1
22	Correction to NR NTN epoch time definition	Correction Proposals (resubmit)	R2-2205999	May-2022	3GPP RAN2
23	Correction on inter-RAT handover from E-UTRA to NR for RedCap	Spec Change Request (accepted)	R2-2207230	Aug-2022	3GPP RAN2
24	Issues related to NR NTN epoch time	Proposals	R2-2208657	Aug-2022	3GPP RAN2
25	NTN Configuration at Handover and CHO	Proposals	R2-2208659	Aug-2022	3GPP RAN2
26	NTN Configuration at CHO	Proposals	R2-2208681	Aug-2022	3GPP RAN2
27	FL summary #4 on Rel-18 RedCap UE complexity reduction	Scoping views within	R1-2210251	Oct-2022	3GPP RAN1
28	FL summary 3 on Rel-17 RedCap maintenance	Scoping views within	R1-2210247	Oct-2022	3GPP RAN1
29	FLS#2 on disabling of HARQ feedback for IoT NTN	Scoping views within	R1-2210330	Oct-2022	3GPP RAN1
30	Feature lead summary#2 of AI 9.11.4 on improved GNSS operations	Scoping views within	R1-2210261	Oct-2022	3GPP RAN1
31	Summary of [110bis-e-R17-IoT-NTN-01] Email	Scoping views within	R1-2210434	Oct-2022	3GPP RAN1

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	discussion to determine maintenance issues to be handled in RAN1#110bis-e				
32	FL summary#2 on Maintenance on NB-IoT/eMTC to support NTN: time and frequency synchronization	Scoping views within	R1-2210259	Oct-2022	3GPP RAN1
33	FL summary 2 of AI 8.14: Maintenance on Timing Relationships for IoT-NTN	Scoping views within	R1-2210300	Oct-2022	3GPP RAN1
34	NTN Configuration at Handover and CHO	Proposals (revision)	R2-2210729	Oct-2022	3GPP RAN2
35	HO/CHO Signaling Overhead Reduction by NTN-config omission	Proposals	R2-2212721	Nov-2022	3GPP RAN2
36	NTN Configuration at Handover and CHO	Proposals (resubmit)	R2-2212692	Nov-2022	3GPP RAN2
37	[98e-19-R18-eRedCap]	Scoping views within	RP-223551	Dec-2022	3GPP RAN
38	Preliminary 5GNR-DVBS2x LLS Efficiency comparison		SESSCN(22)000013	Mar-2022	ETSI TC-SES SCN

Table 2-3 Summary of iNGENIOUS contributions to SDOs.

The following subsections provide an overview of relevant activities carried out by each standardisation body, underlining what has impacted the project developments, as well as details on the relevant activity and outcome from iNGENIOUS partners that has impacted standards and their specifications.

2.3.1 3GPP

SEQ has been actively participating in Technical Specification Group (TSG) Radio Access Network (RAN) and its affiliated Work Groups (WGs) on several topics relevant to the project. In addition, 5CMM identified relevant 3GPP channel model to Factory use case (i.e. Industrial Channel Model) in order to obtain benchmarks, calibrate and implement for ns-3 to analyse system level performance of Factory use case.

The topics of provided contributions and their impact to 3GPP include the following:

- New Radio NTN and IoT NTN: 3GPP Release 17 work included adaption of NR features to support Non-terrestrial Network (NTN). At the same time with NR NTN specification, the feasibility of ensuring NTN connectivity of LTE-based C-IoT devices was studied, and respective specification work started which heavily inherited insights and features from NR NTN. The NTN topic has been of particular interest to iNGENIOUS which includes use cases expected to rely on satellite-based connectivity (e.g., Transport, Ship and Port use cases). Despite

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that NTN-based products will only be available well beyond iNGENIOUS lifetime, SEQ has been monitoring and contributed to these proceedings to ensure future advancement and applicability of relevant iNGENIOUS use cases. SEQ initially contributed several suggestions for keeping the various proposed NTN PHY features beneficial and of low complexity for end devices. Furthermore, several issues have been brought forward from RAN groups, mainly to address procedures in legacy link layer operations that could be problematic or inefficient if employed as currently specified for NTN communication. To this end, SEQ contributed proposals for efficient higher-layer techniques to improve delays and power consumption of NTN-based devices in scenarios with bursty small data traffic which can be typical in IoT applications of interest. In addition, SEQ identified issues within radio link control and handover procedures in NTN, and proposed respective solutions for efficient procedures' operation. The proposed specification designs can improve IoT connectivity via satellite in aspects such as latency and ease of implementation from device point-of-view.

- NR RedCap: 3GPP efforts within Release 17 for emerging cellular IoT (CIoT) solutions included the study and specification of reduced capability (RedCap) New Radio (NR) devices. This work targeted to enable devices of low cost and complexity, compared to legacy NR devices. NR RedCap can be viewed as NR-based C-IoT devices targeting use cases with requirements not adequately addressed by the LTE-based C-IoT solutions which are of particular interest to iNGENIOUS (e.g., Factory use case). SEQ contributed specifically to NR RedCap study item with views and proposals on the various PHY topics of the study to ensure that only necessary features with good trade-off between low-complexity and performance loss were scoped for specification. During maintenance phase of Release 17 RedCap specification, SEQ provided views on several open issues to ensure clarity of specification and proposed a correction on inter-RAT handover from LTE to NR which was accepted. Furthermore, Release 18 scoping discussions took place in 3GPP RAN, including NR RedCap evolution for further reduced cost and complexity devices via further user maximum bandwidth or peak rate reduction. SEQ contributed with suggestions on complexity reduction scope and device throughput targets to ensure non-overlapping markets between the various C-IoT solutions.

- NR IIoT: The Release 17 standardization work on NR Industrial Internet of Things (NR IIoT) enabled a new communication class covering industrial applications of high interest to iNGENIOUS. They are related to factory automation (i.e., logistics, sensor networks, robotics, and augmented reality) where both eMBB and URLLC features become vital elements to support high transmission reliability and performance. Within this scope, 3GPP investigated RAN enhancements for handling IIoT use cases based on new defined QoS parameters, including the so-called Survival Time parameter. SEQ contributed an analysis of other proposed solutions and provided a suggestion of how to efficiently use

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this information for more efficient (in terms of UE and spec impact) implementation.

2.3.2 5GAA

iNGENIOUS partners have been actively participating in the 5G Automotive Association (5GAA) in the field of Tele-operation Driving (ToD).

Tele-operated Driving technology assists, complements, and accelerates semi and fully automated driving in various scenarios. The 5GAA studies system requirements and corresponding enabler technologies for ToD services.

Nokia has contributed to the discussions of the data rate and reliability requirements of communication networks to support ToD services. The basis of the study that has been used are the Service Level Requirements (SLR) on information and reliability for ToD use cases.

The topics of current contributions include the following:

- Information requested/generated data and service level reliability data about uplink and downlink of:
    - Direct control ToD.
    - Indirect control ToD for max speed of 20 km/h.
    - Direct control ToD for max speed of 30 km/h.
- Information Requested/Generated data and service level reliability data about infrastructure-based ToD. Focusing on KPI for RADAR, cameras, and LiDAR.
- Information flows for ToD service, specifically:
    - Operator actuators/control DL information flow.
    - Operator biometric sensors DL information flow.
    - Vehicle actuators/telemetry UL information flow.
    - Video and audio UL information flow.

2.3.3 ETSI

The iNGENIOUS consortium dedicated special efforts to monitor and follow relevant ETSI standardization initiatives. Specifically, this has been done throughout the various technical activities carried out in the project, including: architecture definition (WP2), IoT devices and network and smart data management solutions and components development (WP3, WP4, WP5), Use Case implementation and validation (WP6). The primary goal has been to align the various research and development activities carried out in the project in the areas of network slice management and orchestration, 5G network functions virtualization, and satellite communications. Specifically, as anticipated in deliverable D7.2, the project carefully monitored and followed the standardization progress within the ETSI NFV, ETSI ZSM and ETSI SES groups. In addition, where possible, iNGENIOUS considered and evaluated direct contributions to specific relevant work items, like in the case of the ETSI SES SCN working as reported below.

ETSI NFV

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The ETSI NFV Industry Specification Group (ISG) has been the driver of the network transformation activities in ETSI, being at the core of the NFV technology definition and standardization, starting from the NFV term itself. The NFV scope is focused on the lifecycle of the Virtualized Network Functions (VNFs) and the services built by composing them. The ISG covered with its specification all of the aspects of the NFV framework, from architecture principles and design, to interfaces, information models, data models, APIs and testing procedures. While the telco industry already adopted and implemented relevant standards in the NFV products (starting from the late 2010s) targeting interoperability, the latest NFV specification release (Release 4) is now under finalization, with key capabilities and functionalities defined for what concerns the use of NFV technologies and their applicability in 5G and cloud-native environments.

As anticipated in deliverable D7.2, some of these Release 4 newly introduced capabilities, together with the overall ETSI NFV principles and architecture approach, have been the reference baseline for the design and implementation of the iNGENIOUS network slice orchestration framework and in general to the MANO capabilities in WP4. While iNGENIOUS did not directly contribute to ETSI NFV, monitoring and alignment was pursued in the specific areas of interest identified in D7.2, with concrete actions taken to comply with and implement some key features (as detailed in Table 2-4 below).

ETSI NFV area of interest	Description (from D7.2)	Relevant work done in the project (e.g., alignment, implementation)
Cloud-native VNFs and Container Infrastructure management	Enhance the NFV architectural framework to support VNFs which follow "cloud-native" design principles and the NFV MANO to support capabilities for container and container infrastructure management and orchestration	The iNGENIOUS MANO functionalities (part of the network slice orchestration framework developed in WP4) , for orchestration of the Cumucore 5G Core instances as NFV network services fully adopts the cloud-native approach, supporting NFs implemented as containerized applications and deployed in cloud-native infrastructures based on Docker and Kubernetes.
NFV enhancements for 5G	Enable automated deployment of 5G networks, supporting the various 5G capabilities and associated requirements for the various user and control plane network functions, at both RAN and core	The iNGENIOUS end-to-end network slice orchestration framework developed in WP4 is able to fully automate the deployment of the Cumucore 5G Core NFs, also with automated configuration and provisioning of network slices through 5G Core APIs. In addition, the end-to-end Network Slice Management Function (NSMF) allows to integrate and jointly coordinate RAN and core VNFs.

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SBA for NFV-MANO	Enable service exposure for 3rd party access to selected NFV MANO services following an SBA approach, through service independence, modularization, data separation/split, exposure, dynamic registration, and discovery of services	This capability for enhancing the NFV MANO services through an SBA approach was not covered in the ETSI NFV Release 4, and pushed for the upcoming Release 5. For this, iNGENIOUS did not implement any related functionality.
NFV-MANO automation and autonomous networks	Enable NFV MANO support for managing autonomous networks, with higher level of automation in the internal logic, exploring intent-based principles for external exposure of network services management	The iNGENIOUS end-to-end network slice orchestration framework developed in WP4 is augmented with closed loop functionalities to improve automation (through the AI engine) and integrates a monitoring platform for collection of heterogeneous data from NFV services and virtual functions to feed automated decisions.

Table 2-4 ETSI NFV areas of interest

ETSI ZSM

The ETSI Zero touch network and Service Management (ZSM) ISG aims at defining a new framework enabling agile, efficient, and qualitative management and automation of emerging and future networks and services. ZSM targets a network and service management architecture where all operational processes and tasks (e.g., delivery, deployment, configuration, assurance, and optimization) are executed with full automation in multi-vendor environments. As presented in D7.2, the ZSM approach and principles inspired iNGENIOUS in the definition and implementation of a generalized framework for composing different services and slices under a common flexible architecture, with tight cooperation of network and slice orchestration, data collection and storage, and analytics services with decoupled functions. In particular, throughout the whole project lifecycle iNGENIOUS actively followed the progress of ZSM activities, looking mostly at ZSM approaches for closed-loop automation and integration of AI techniques. While iNGENIOUS did not directly provided standard contributions to ETSI ZSM, a general alignment was implemented in the specific areas of interest identified in D7.2, with concrete actions taken to comply with and implement some of the relevant features (as detailed in Table 2-5 below).

ETSI ZSM area of interest	Description (from D7.2)	Relevant work done in the project (e.g., alignment, implementation)
Closed-Loop Automation	Investigate advanced topics related to closed-loop operations such as learning and cognitive capabilities (e.g., based on	iNGENIOUS considered closed-loop automation as a key requirement and principle for the end-to-end network slice orchestration framework definition. Specific AI-

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	different degrees of use and integration of artificial intelligence technologies)	driven cognitive capabilities have been integrated in the orchestration framework, from conceptual to software prototype, in the form of an AI agent/engine tightly linked to the network slice management functionalities.
Enablers for Artificial Intelligence-based Network and Service Automation	Support automation of management functionalities and operations based on AI, including data handling and analytics, interoperation, governance and execution environment, and related deployment aspects.	The AI agent/engine architected and implemented in WP4 to support the end-to-end network slice management and orchestration decision logic (mostly at runtime) represents a key enabler for AI-based network and service automation, providing integrated analytics capabilities for data pre-processing, feature detection and ML model performance evaluation.
Cross-domain end-to-end services lifecycle management: to	Investigate the management of end-to-end services across management domains (e.g., orchestration, data collection and analytics, assurance, etc), with identification of procedures and models to enable the automation of lifecycle management	The AI-assisted end-to-end network slice orchestration framework implemented in WP4 is fully aligned with the separation of management domains proposed by ZSM. The orchestration domain is indeed separated but assisted and tightly cooperating with the data collection domain, implemented by the monitoring platform which is able to expose and handle data from heterogeneous sources (5G Core NFs, virtual infrastructure). In addition an analytics/AI domain consumes data related services from the monitoring platform and in turn leverage on the orchestration domain APIs to provide full automation in network and service/slice management.

Table 2-5 ETSI ZSM areas of interest

ETSI SES SCN

The ETSI Satellite Earth Stations and Systems (SES) ISG group within ETSI is responsible for satellite earth stations and systems related topics. Within ETSI SES is the **Satellite Communications and Navigation (SCN)** working group is responsible for radio and transmission aspects related to Fixed, Mobile and Global Navigation Satellite Systems operating in any bands allocated to Fixed Satellite Service (FSS), Mobile Satellite Service (MSS) or Radio Determination Satellite Service (RDSS).

In particular:

- to produce and maintain harmonised standards for satellite earth stations

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- to produce and maintain technical specifications for satellite radio interfaces
- to encourage spectral efficiency on satellite links and harmonisation of satellite radio interfaces
- to produce specifications that promote integration and inter-working between satellite and terrestrial networks.

The SCN working group produces architecture and service requirements, interfaces (user, control, and management planes), transport and network protocols, service enablers. The SCN working group also encourages the development of network, transport, and service layers compatible with various fixed and mobile satellite access networks.

As part of the iNGENIOUS investigation into 5G and satellite integration, iDR contributed to ETSI SES SCN work item Satellite Earth Stations & Systems (SES) *a technical comparison for broadband satellite systems between* DVB-S2x/RCS2 *and* 3GPP New Radio protocol[3]. The contribution provided and initial comparison of the 5G NR and DVBS2x waveforms in terms of performance under certain radio conditions. The contribution was very well received by the group as it provided the first reference comparison for the group to review and critique.

SSIG

The Satellite Standardisation Interest Group (SSIG) was created under the ESA ALIX project and serves as a platform where a broad range of stakeholders can exchange information about satellite-related standards activities for the integration of satellite into the 5G ecosystem, with the aim of improving mutual understanding and collective effectiveness in pursuing the vision. The SSIG may also provide a platform/forum for garnering support by individual participating organizations for specific actions they wish to pursue. The SSIG was heavily involved in presented and supporting the Release 15 and Release 16 study items related to satellite and following on from that the Release 17 standardisation activities in 5G NR NTN and NB-IoT NTN.

At the time of closing out the iNGENIOUS project the current focus of the SSIG group is on supporting the maintenance of Release 17 work items, support Release 18 NR NTN and NB-IoT enhancements and new feature scoping and planning for Release 19.

iDR are active members of the SSIG group and within the context of iNGENIOUS have a special interest in the NB-IoT NTN activities supported by the SSIG. Being involved in the SSIG has allowed iDR to participate in many reviews and provide input and support for NB-IoT NTN related 3GPP contributions.

2.4 Opensource Outcomes and Results

[3] Preliminary 5GNR-DVBS2x LLS Efficiency comparison, SESSCN(22)000013 Preliminary DVB/5G LLS efficiency comparison, https://docbox.etsi.org/ses/ses/60-WGs/WG_SCN/05-CONTRIBUTIONS/2022/2022_04_12_WG_SESSCN%2334

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As part of the iNGENIOUS hardware and software development activities, some of the project outcomes and results have been (or will be in the short term) released as opensource. Specifically, this is applicable to two main project results: the BI M^3 platform, and part of the Nextworks AI-driven end-to-end network slice orchestration framework.

As an academic research institute, BI will further develop and exploit the M^3 platform and outcomes of the iNGENIOUS project for teaching and as a basis for future research and collaborations. Parts of BI's M3 computer hardware and operating system platform are already open source and therefore available to academia (https://github.com/Barkhausen-Institut/M3). After the end of the project, BI plans to release additional components developed within iNGENIOUS as open source. The availability as opensource also enables further collaboration with industry, which may pick up concepts or even building blocks in the future."

On the other hand, NXW released as opensource (specifically with an Apache 2.0 license) part of the software stack developed for the iNGENIOUS end-to-end network slice orchestration framework. This has been implemented on top of an existing opensource company research-oriented software prototype asset for network slice orchestration (named "slicer"), which has been enhanced to align it to 3GPP network slice management architecture and data models and to support a full management and operation of the 5G Core. In particular, the following software components (developed in WP4 and reported in D4.4 and D4.5) are released as opensource (and available at: https://github.com/nextworks-it/slicer/tree/ingenious-1.0):

- Network Slice Management Function (NSMF)
- 5GCore Network Slice Subnet Management Function (NSSMF)
- O-RAN NSSMF
- Flexible RAN NSSMF
- Emulated RAN NSSMF

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3 Innovation & Exploitation

The Innovation and Exploitation activities of the project are closely correlated. The outputs of the Exploitation activities are directly linked to the Foreground IP developed as part of the Innovation activities. The following sections detail the activities in Innovation Management, innovation development, and exploitation of the outputs of the project.

3.1 Innovation Methodology and Objectives

The project's Innovation Management activities have tracked the innovations generated in the project, analysed, and formalized their relationship with the Background and Foreground Intellectual Property elements brought and developed by the various partners. Finally, the FIPs were used as inputs to define the exploitable assets in the exploitation activities described in Section 3.3. The definition of these elements is as follows:

Background IP element (BIP)

Partner knowledge/Intellectual Property that is relevant to the iNGENIOUS project, supplied by partners at the start of the project

Innovation Element (IE)

Ideas, concepts, design patterns, or pieces of hardware/software that are used to produce Foreground Intellectual Properties (fundamental bricks of a Foreground Intellectual Property element)

Foreground IP element (FIP)

Partner knowledge/ Intellectual Property produced within iNGENIOUS project during the project's tenure

The Innovation Management activities are associated with the following WP7 objective:

- **Objective 7.5:** Monitor that the IPR and data management strategies are well defined and coherently executed.

To meet this objective, a living document was maintained during the project, and reviewed periodically, where partners could add and refine the following information:

- IE-ID
- IE description
- IE Type (sw, hardware, etc.)
- Associated project tasks where the IE is generated
- BIP(s) used if any
- Associated FIP(s)
- Partners involved in the work
- Patent(s) if any
- Ownership
- Access conditions

From this information, a mapping was done between the various elements, as described in Section 3.3.

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3.2 Innovation Elements

As stated above, Innovation Elements (IE) involve ideas, concepts, design patterns, or pieces of hardware/software that are used to produce Foreground Intellectual Properties (fundamental bricks of a Foreground Intellectual Property element). D7.1 first presented the 13 EEs that were determined during the first 18 months of the project. There have been a number of refinements and 12 new additions since the publication of D7.2. The following sub-sections give details on each of the 25 identified IE of the project.

3.2.1 IE-01 ORCHESTRATION AND DATA COLLECTION FROM 5G CORE

The iNGENIOUS network slice orchestration solution is based on the NXW slicer BIP-02, and enhances it for aligning it to the main relevant 3GPP Release 17 specifications in the area of network slice management. In particular, the monolithic NXW slicer approach is evolved towards a cross-layer solution where three highly cooperative, but independent orchestration functionalities are taking care of service orchestration, network slice and slice subnet orchestration, and resource orchestration. In particular an end-to-end network slice management function coordinates a set of network slice subnet management functionalities defined and implemented for each domain (e.g., RAN, Core Network, Transport Network). Specifically, for the 5G Core such solution envisage a dedicated network slice subnet management function to enable the automated deployment, configuration, and operation of 5G Core NFs part of end-to-end network slices, allowing to provision multiple slices in the same 5G Core instance. This innovative network slice orchestration solution also includes embedded monitoring functionalities that are able interact with the 5G Core NDWADF for slice, NFs and UEs related data collection. Similarly, for the RAN, dedicated network slice subnet management functions allow to coordinate resource provisioning and allocation for specific technologies and solutions (e.g., 5G gNB, O-RAN, iNGENIOUS flexible PHY/MAC RAN, etc.).

3.2.2 IE-02 AI-ASSISTED NETWORK-DATA BASED SLICE OPTIMIZATION

An AI/ML engine has been conceived to assist the service, slice, and slice-subnet management functions within the iNGENIOUS network slice orchestration solution in their decision logics. This approach leverages on external ML algorithms that are able to analyse and process network slice related data collected from various network sources. This results into an AI-assisted network-data based slice optimization solution that significantly improve the automation capabilities of the overall slice management functionalities. Given the cross-layer nature of the iNGENIOUS network slice orchestration solution, the ML algorithms outputs can assist decisions at different levels, including mapping of services into slices, arbitration of slice resources, optimized slice resource and network functions allocation, slice resource and network functions scaling. In practice, this approach is enabled by dedicated interfaces and workflows supported by the network slice management functions and the AI/ML engine for data acquisition and

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processing from the 5G Core Network Data Analytics Function (NWDAF) and the 5G infrastructure in general, and enforcement of ML-based decisions.

3.2.3 IE-03 FEDERATION OF DLTS BY MEANS OF A COMMON API

In order to have a common way to communicate with the different DLTs used in the crossDLT layer, a common interface implemented for every DLT connector was defined. This common interface defines the necessary methods to store an evidence of certain data into any DLT. The evidence that is saved in the different DLTs is named as the TrustPoint. The concept of TrustPoint is defined as a proof or evidence of certain information stored as a digital asset in the TrustOS platform. This common API, defines and supports three different methods (defined following the OpenAPI standard): 1) Get the TrustPoint data from the DLT, which allows to receive as input either the transaction ID or the asset ID and the timestamp of the evidence, 2) Store the TrustPoint data into the DLT, which allows to send all the data of a TrustPoint and save it into the specific DLT (this method returns the transaction ID where the data have been saved and, optionally, the smart contract address) and 3) Verify method to check the incoming data of a TrustPoint against the stored data of the same TrustPoint in a specific DLT. By means of this approach, the cross-DLT Layer allows to increase trust and extend the reach of the solution. The combination of multiple DLTs makes the solution attractive to a wider group of end-users and stakeholders as some will prefer some DLTs over the others. It also provides a way to ensure and verify the integrity of information coming from different systems (such as DVL and the underlying IoT platforms and devices).

3.2.4 IE-04 DLTS' EVENTS VISUALIZER (GUI FOR INGENIOUS)

In order to visualize the information stored in TrustOS and in the different DLTs, a Graphical User Interface (GUI) is provided. Through this interface, the end-user is able to visualize the different events recorded, as well as to verify the TrustPoints stored in each of the corresponding DLTs. Access to information (except for public information such as TrustPoints) is role-based. The interface is implemented through the Front-End tools and it is integrated with the cross-DLT Layer (TrustOS). The interface is able to perform the corresponding requests to TrustOS and to retrieve the requested information. In this regard, two different views are supported: i) Asset view, which displays asset information representing the different events stored in TrustOS such as GateIn, GateOut, VesselArrival, VesselDeparture and SealRemoved and ii) TrustPoint view, which displays the information of a given TrustPoint stored into a specific DLT.

3.2.5 IE-05 ROOT-OF-TRUST FOR SECURE CROSS-DEVICE COMMUNICATION AND SECURE SOFTWARE UPDATES

This IE comprises a simulated implementation of a Root-of-Trust (RoT) for the M^3 hardware/software co-design platform, with the goal of having an FPGA-based hardware implementation in the future. Associated system-software integration to enable remote attestation together with Transport Layer Security (TLS) and support for secure software update process is included as well.

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A minimal hardware Root-of-Trust (RoT) is the key development goal pursued by BI in iNGENIOUS to enable secure communication between IoT devices and (edge) cloud servers. The core feature of the RoT is a secret and unique device identity key embedded in the hardware. This secret key is used to create digital signatures that certify, using operating-system support, which software has been loaded. Such a certificate provides a cryptographic attestation proof of the current state of the execution environment, which enforced by the tile-based hardware/software co-design and the currently-in-place access-control policy. This proof can be verified remotely to establish whether an M³-based IoT device is in the expected and secure state (i.e., whether it is trustworthy). The RoT and associated system-software support is the foundational building block for this remote attestation, which will be integrated with Transport Layer Security (TLS) protocol. However, RoT-based attestation can also be utilized to implement security checks to ensure software updates are correct, with the potential for automatic cross-device compatibility checking.

3.2.6 IE-06 INTEGRATION OF REMOTE ATTESTATION WITH TRANSPORT LAYER SECURITY (TLS) PROTOCOL

Remote attestation is a known technique and multiple implementations exist. But it is difficult for application developers to deploy, because the available implementations do not easily integrate with system services that applications depend on. By combining remote attestation with TLS, BI created a combined protocol called RATLS. This combined protocol can be used as a drop-in replacement for the widely-used TLS, but with the additional security guarantees provided by remote attestation. The point where both protocols are joined is the connection-establishment phase. After successfully negotiating a cryptographically-secured connection with attestation between the two peers, RATLS behaves mostly like TLS.

3.2.7 IE-07 SMART IOT GATEWAY

The Smart IoT Gateway (GW) is the system/hardware element responsible for the appropriate routing and sorting of sensors data, coming from one or more sensor networks to higher layer data consolidation services and machine-to-machine (M2M) platforms. In order to perform these operations, the Smart IoT GW is able to interconnect multiple physical interfaces, extracting and transforming messages as data goes from one side to the other.

The Smart IoT GW exposes several physical and data-link interfaces to receive sensor data. Sensors can send messages to the Smart IoT GW either wirelessly (with technologies such as IEEE 802.11, LoRa or Sigfox), or directly connected to the device (via Ethernet, I2C or SPI). The Smart IoT GW is smart enough to manage the routing of the received messages to the right output interface in the right timing. Several factors have been taken in consideration in this operation:

- Context: such as the current geographical localization of the Smart IoT GW or its situation relative to potential recipients of messages.

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- Message prioritization: due to urgent messages that need to be forwarded immediately over other messages that can be grouped together for channel usage optimization.
- Channel availability: in cases where constrained communications impose a specific interface linked to a channel, such as a satellite link in situations where satellite networks provide the only means of ubiquitous connectivity.

Physical interfaces are added to the Smart IoT GW as plug-in modules, that allow to abstract most of the device functionality from the number and type of the interfaces installed in the Smart IoT GW.

3.2.8 IE-08 NETWORK SLICE MANAGEMENT MODULE

5G Core module that provides an interface to external orchestrator for automatic configuration and operation of 5G Core for deployment of network slices.

The 5G core includes 3GPP compliant network slice management (NSM) function which includes modules for allocation of resources for the slice at Radio, transport, and core. This unique modular solution allows to integrate radio access, transport network and 5G core modules from different vendors to configure end to end slices. The NSM provides REST interface for external network functions or network orchestrator to allocate network slices based on external application requirements. The NSM has been integrated with Nextworks orchestrator to validate the functionality of network management from external applications.

The NSM is fundamental component to create multiple instances of 5G networks to be allocated to different services that could be either group of IoT devices which traffic is separated from the rest of devices, or time sensitive network (TSN) devices that will be grouped under the same slice with low latency for sharing time information.

The NSM with the interface allows to create slices and reserve the necessary resources for different type of devices with own performance requirements.

3.2.9 IE-09 HAPTIC GLOVES FOR SAFE CONTROL OF REAL-TIME SENSORY FEEDBACK FROM TELE-OPERATED MACHINERY

Creation of a tele-operation feedback software that uses the haptic globes to provide an additional information layer for the operator. This way, the visual feedback is extended with the sensory feedback providing more complex stimulus to identify the surroundings of the machinery, and the status of different elements related to the operation.

In the one hand, in order to achieve a comfortable to wear experience, a redesign of the Sensorial XR HW architecture was necessary, replacing the original Bluetooth communication module by a new one compliant with the BLE 5.0 protocol. This redesign allows to improve the wireless capacities of Sensorial XR, having a direct impact in two key factors:

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- Battery drain: The low energy Bluetooth protocol allows to optimize the data transmission, and this has direct impact in the battery life. This was an important problem as operators may require using the haptic gloves for a long time, and this innovation allows to improve noticeably the performance of the energy consumption.
- Improved multi-device communications: A better management of the data transmission provides also a more stable communication channel, and this allowed Sensorial XR to stablish a more robust communication when more than one device is used in wireless mode.

However, in order to achieve that, a deep optimization of the transmission code was required because the BLE 5.0 protocol is focused on low latency - and low volume data communications. To fit it to the needs of Sensorial, the communication code was redesigned to make a full use of the BLE 5.0 capabilities, something not possible in previous software implementations.

In the other hand, the design of the feedback stimulus is performed by researchers that may not have coding knowledge, so in order to speed up the design process, a sensations suite is created so that a WYSIWYG environment is provided for this development stage.

3.2.10 IE-10 TELE-OPERATED DRIVING OF VEHICLES OVER LOW-LATENCY AND RELIABLE 5G WIRELESS FROM AN IMMERSIVE COCKPIT

In environments of autonomous AGVs operating at industrial areas, carrying material from place to place and performing different tasks, some unexpected problems may arise. Troublesome objects in the middle of the AGV path can be problematic and sometimes involve a stop in the system. In such cases, a human intervention is necessary.

The Tele-operation Driving (ToD) with MR and haptics devices is an innovative solution to have AGVs under control, being able to control them remotely without the need to be exposed to the dangers of the industrial environment.

In order to achieve the immersive ToD an E2E system is designed.

- Immersive cockpit: an innovative virtual reality application is designed to emulate an ordinary driving experience. A virtual cockpit is visualized in the VR glasses and a real time streaming video from the AGV surroundings is projected around the virtual car. The immersive application allows the operator to feel inside of the AGV and enables intuitive remote driving of the AGV.
- Connectivity requirements: in order to accomplish with connectivity KPIs some requirements must be fulfilled. The AGV connectivity is set through 5G with millimetre wave. This innovative connectivity enables low latencies at the highest throughput, especially focused on uplink. Those characteristics allow to send video streaming in real time and set the information flux required for the ToD.

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3.2.11 IE-11 AI SYSTEM FOR PREDICTING PORT–CITY CONTAINER TRAFFIC RATES

To be able to cope more efficiently with variation in inbound and outbound port road traffic volumes in city traffic management or port operations and resource planning, it is useful to be able to model and predict these over time as early and accurately as possible. The developed system predicts container traffic flow rates between the port and city by combining machine learning and stochastic models to implement predictive simulations. The predictions are based on integrated information from multiple data sources along the multimodal supply chain, from global vessel information systems to local port community systems providing port call plans to terminal and port operating systems providing cargo and hinterland carrier time event data. The produced traffic flow predictions can for instance be applied by port authorities and operators to plan resources according to predicted congestion, or by city traffic management to prepare in advance for peaks in truck traffic caused by port operations.

3.2.12 IE-12 AUTONOMOUS VEHICLES CONTROLLED WITH HAPTIC GLOVES AND XR GLASSES FOR IMMERSIVE EXPERIENCE

Haptic gloves and XR glasses integrated with Fivecomm's cockpit for immersive autonomous control in the iNGENIOUS framework.

3.2.13 IE-13 5G MODEM TO PROVIDE WIRELESS CONNECTIVITY

Fivecomm's 5G modem hardware used to connect AGVs, cameras or any object to the 5G network. This allows to interconnect different iNGENIOUS components through NR technology. It also includes a software part corresponding to the modem management and configuration options developed by Fivecomm and making it more flexible.

3.2.14 IE-14 SYSTEM-LEVEL SIMULATOR

Based on the ns-3 simulator and further developed by Fivecomm, a novel system-level simulator is used to evaluate 5G deployments in iNGENIOUS use cases. Ns-3 is a popular open-source network simulator based on C++ and Python. A new industrial channel model implemented by Fivecomm and the real iNGENIOUS scenarios have been added to this new release that is available for simulations.

3.2.15 IE-15 FLEXIBLE PHY/MAC IMPLEMENTATION FOR SDR PLATFORMS

A flexible end-to-end physical layer (PHY) implementation with multi-user capability that runs in a software defined radio (SDR) platform. Many of the common PHY functions were implemented in the field programmable gate array (FPGA) using LabVIEW which employs the universal software radio peripheral (USRP) for over-the-air transmission. This PHY implementation is based on the generalized frequency division multiplexing (GFDM) waveform that can be flexibly configured depending on the application scenario. Another software implementation was developed to match devices whose

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applications require security, since it has been developed for running on Barkhausen Institut (BI) M3 platform.

3.2.16 IE-16 CELLULAR IOT MODEM POWER ESTIMATOR & ANALYSIS

A realistic power consumption model of LTE-based cellular IoT (C-IoT) modem devices to understand respective IoT devices energy usage and assess energy-related KPIs depending on differently configured applications. Based on existing modem power breakdown model by Sequans (focused on legacy LTE Cat-M modem devices), an enhanced model has been developed to take into account NB-IoT technology, obtain insights of possible features for implementation that affect modem power and can lead to advanced power saving mechanisms, and to enable battery lifetime KPI assessment of typical C-IoT modem in the market with potential use within specific iNGENIOUS use cases (i.e., Transport and Ship use cases). Input from Sequans NB-IoT device field measurements was used to calibrate power model of platform and modem behaviour in various communication scenarios.

3.2.17 IE-17 ENHANCEMENTS FOR NON-TERRESTRIAL NETWORKS (NTN)

Solutions have been devised and proposed for specification to 3GPP standardisation groups in order to enhance radio link layer of cellular-based non-terrestrial networks. Suggestions for specification evolution take into account requirements of satellite-based connectivity for IoT as well as limitations and capabilities of respective communication devices. More specifically, issues have been identified within radio link control and handover procedures in NTN, and respective solutions have been proposed for efficient procedures' operation. The proposed specification designs can improve IoT connectivity via satellite in aspects such as latency and ease of implementation from device point-of-view.

3.2.18 IE-18 FEDERATION AND DATA VIRTUALIZATION OF HETEROGENEOUS DATA SOURCES BY MEANS OF DVL

The interoperability among heterogeneous Machine-to-Machine platforms and external data sources provides data aggregation functionalities based on custom implementation of the virtual databases, views, and procedures in order to enable data flows to data consumers. The functionalities include role-based access rights (CRUD model) as well as personal data management policies based on pseudonymization techniques. The DVL is the core component for such interoperability. The main purpose of data aggregation is to define maritime events (according to a defined data model) such as GateIn, GateOut, VesselArrival, VesselDeparture and SealRemoved which occur in both the Port of Livorno and the Port of Valencia. On one side data are used by the cross-DLT layer in order to guarantee data immutability and on the other side historical ones are used for predictive models. In order to meet data privacy requirements according to EU regulations, pseudonymization functionality is part of the DVL component so that sensitive data are pseudonymized before being used by applications on top. This approach allows different stakeholders from the supply chain to spend less on building and managing data integration processes for connecting

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distributed data sources, benefiting in terms of costs and time savings by quickly validating new business models relying on an agile approach for data integration.

3.2.19 IE-19 AI MODELS FOR ENHANCING SITUATIONAL UNDERSTANDING AT THE PORT OF VALENCIA

Development of AI-based models for predicting dwell times, truck traffic levels and truck turnaround times. These models use input data obtained from ValenciaportPCS and the Gate Access System integrated in PI System OSIsoft.

3.2.20 IE-20 API FOR THE PSEUDONYMIZATION OF PERSONAL DATA COMING FROM THE DVL

Pseudonymization has an important role in GDPR as a security measure (art. 32 GDPR), as well as in the context of data protection by design (art. 25 GDPR). The most obvious benefit of pseudonymization is to hide the identity of the data subjects from any third party in the context of a specific data processing operation. Still, pseudonymization can go beyond hiding real identities into supporting the data protection goal of unlikability, reducing the risk that privacy-relevant data can be linked across different data processing domains. Furthermore, pseudonymization (being itself a data minimization technique) can contribute towards the principle of data minimization under GDPR, for example in cases where the data controller does not need to have access to the real identities of data subjects but only to their pseudonyms. The Pseudonymization Module extends the native capabilities provided by the DVL component by supporting most common pseudonymization techniques such as Format Preserving Encryption (FPE) Blurring, Hashing Without Key (HWK) and Hashing With static Key. This capability allows then to process personal data in such a manner that these data sets can no longer be linked to a specific entity entering the seaport (e.g., trucks' plate numbers). Pseudonymized data can be then exploited by third-party applications for analytics by guaranteeing data protection requirements.

3.2.21 IE-21 SMART SHIPPING CONTAINER

20 feet dry shipping container equipped with an IoT tracking device able to measure temperature, humidity, acceleration, bump, and gate opening events.

3.2.22 IE-22 MICRO-EDGE ROTARY FAULT INTENSITY CLASSIFICATION ENGINE

Self-powered micro-edge sensors need to minimise computation and communication energy expenditures. Typically, communication energy, even via low energy BLE is more resource intensive than micro-processor computation activities. So, if the fault classification can be done reliably at the micro-edge than this is far more desirable than sensing compressed raw data or feature vectors NCG to cloud engines. NCG developed a robust micro-edge engine that cannot only differentiate good or bad rotary faults, but can also classify the fault intensity of such rotary faults, even when the signal is heavily

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signal noise polluted. NCG calls this the Micro-Edge Rotary Fault Intensity Engine. It enables highly efficient micro-edge condition monitoring and makes not only low power long-life applications like rail-health monitoring possible, but also has the potential to replace first generation conventional IoT sensors with require physical connections for power and/or data transfer.

3.2.23 IE-23 NEUROMORPHIC VIBRO-ACOUSTIC NOVELTY ENGINE

The Neuromorphic Vibro-Acoustic Novelty Engine converts raw data into feature vectors and clusters feature strings into event clusters. The event clusters can be linked to operation conditions so that a full spectrum of operational reference signals is recorded for subsequent data science analysis. This approach can be used with long-term data acquisition and sensor swarms to identify what signal events will be encountered over lifetime. The neuromorphic data logger logs a limited number of data points per event cluster so that excessively redundant data is avoided. This results in balanced datapoints which is one of the pre-required for unbiased machine learning. This approach greatly reduces the effort for data collection and data engineering, two major cost drivers in data science projects. NCG will market the Neuromorphic Vibro-Acoustic Novelty Engine as a Scientific Data Logger to simplify and accelerate Data Science projects with diverse, balanced, and context labelled data.

3.2.24 IE-24 IOT TRACKING APPLICATION/DASHBOARD

Dashboard developed to integrate and visualize data coming from tracking devices and sensors installed in trucks and containers. This application allows to visualize the data gathered from previously mentioned devices to enable a real-time and straight-forward tracking of goods in the E2E supply chain. In the dashboard, data from different ports (Valencia and Livorno in the case of iNGENIOUS project) can be visualized. Additionally, the application can integrate modules developed by other partners, such as the GAD developed by TEI, in order to add more information to the visualization and facilitate the analysis of the data in a glance.

3.2.25 IE-25 ANALYSIS OF NTN AIR-INTERFACE SOLUTIONS IMPACT ON DEVICE

An analysis of various solutions proposed for enhancing air interface of cellular-based non-terrestrial networks has been performed, regarding the solutions' potential impact on the hardware and software architecture design of communication devices. Based on this analysis, suggestions have been devised for efficient specification evolution as well as for modem device architecture implementation evolution.

3.3 Exploitation Methodology and Objectives

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The Innovation Management activities were used as a base-point for the management of exploitable assets stemming from the project. As depicted in **Error! Reference source not found.**the figure below, Innovation elements were used as building blocks to Foreground IPs (FIPs), and Exploitable Elements (EEs) were formed by using a number of FIPs as input. An EE has been defined as products, technologies, or activities, to improve products and services in new and existing markets. The relationships between the individual EEs of the project, FIPs, IEs, BIPS, and participants has been mapped, and can be viewed interactively on the project website[4] A snapshot of the mapping can also be found in Annex 5.

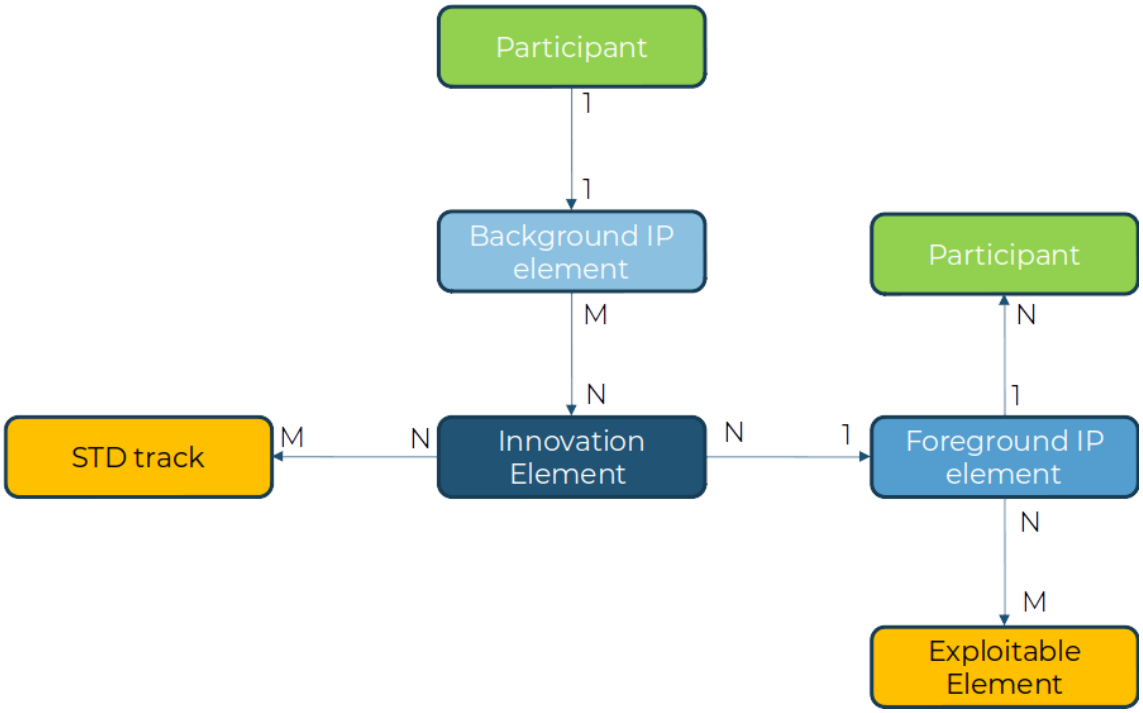

Figure 3-1 Mapping overview of Innovation and Exploitation relationships

Exploitation activities also included work towards two of the WP7 objectives:

- **Objective 7.2:** Maximization of the project impact by means of coordinated exploitation activities.
- **Objective 7.4:** Planning of the exploitation activities to be performed after the end of the project.

To meet Objective 7.2, iNGENIOUS identified and followed closely standardization groups of interest related to IoT solutions for the supply chain. This helped the consortium to accurately define several use cases and set up methodologies for the various performance evaluations. In addition, Sequans focused its contributions towards specific topics of 3GPP to promote obtained insights and results during project. Specifically, during technology analysis within early WP3, iNGENIOUS identified the topics of non-terrestrial (NTN), 5G Reduced Capability (RedCap) and Industrial IoT (IIoT) as of high interest to

[4] https://ingenious-iot.eu/web/innovation-and-exploitation-mapping/.

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targeted iNGENIOUS use cases. To this end, a coordinated effort was made to promote related technical solutions developed within 3GPP RAN specification groups with target to improve efficiency of NTN and RedCap as well as to ease the implementation at device for the faster realisation of these features into the future market.

For meeting Objective 7.5, iNGENIOUS first strived to identify clearly the various potential exploitatable elements resulting from project's innovations. In addition, iNGENIOUS members and use case teams contemplated to clarify key aspects of these exploitable elements such as the various products or research elements where they could be used, the sectors of application and their sustainability and market potential, and prepared activity plans for exploitation beyond the lifetime of the project. iNGENIOUS has also worked closely with the NGIoT and EUCloudEdgeIoT projects to ensure the Project continues to reach and impact a large industrial audience after the Project's end.

3.4 Exploitable Elements

Within the lifetime of the iNGENIOUS project, a number of exploitable elements (EE) haves been developed, maximising the technical and economic impact of the project, and its competitive advantage, helping to improve products and services in existing and new upcoming IoT markets. These EEs are the result of either individual or joint iNGENIOUS partner efforts, resulting in exploitable assets (i.e., commercializable products) or joint exploitation opportunities (i.e., arising from UCs joint developments. More concretely, a specific group formed by the EEs with higher TRL, that is, those that are considered market-ready, has been additionally considered in D2.5 [6]. Such deliverable provides a business analysis per component that includes potential competitors, customers, or niche market, among others.

The following two tables provide a list of these individual and joint EEs, along with brief information on aspects relevant to each EE, including: i) short description title of actual technical result or improvement, ii) the service (e.g. product, research) where EE will be used, iii) the relevant industrial sector/market of application, iv) the owner and involved beneficiaries, v) relevant iNGENIOUS deliverables, and vi) commercialization maturity in form of TRL level.

EE-ID	Title	Exploitable Service	Sector of application	Beneficiaries	Deliverables [5]	TRL
EE-1	5G Cellular IoT modem/chipset	Product	Vertical IoT device vendors	SEQ	D3.2	3

[5] References to deliverables can be found [2]

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EE-2	5G-Core	Product	Vendors, Operators	CMC	D4.3, D4.4, D4.5	7
EE-3	5G modem	Product	Vertical vendors	5CMM	D3.1, D3.2	7
EE-4	Immersive cockpit	Product, Services integration	Vertical stakeholders	5CMM	D3.4	7
EE-5	AI-assisted E2E Network Slice Management	Software prototype	Vertical industry, Operators	NXW	D4.4	4
EE-6	Satellite role enhancement	Product, Research	Vertical/IoT industry, Network/Satellite operators	iDR	D3.2, D4.5, D6.2, D6.3	7
EE-7	Micro-Edge Rotary Fault Intensity Classific. Engine	Software, Services integration	Rail Tech Industrial	NCG	D3.3, D6.2	6-8
EE-8	Scientific Novelty Data Logger	Product	Product Validation	NCG	D3.3, D6.2	6
EE-9	Self-Powered Vibro-Acoustic Micro Edge Sensor	Product	Rail Tech Industrial	NCG	D3.3, D6.2	5
EE-10	Flexible PHY/MAC implementation in SDR	Research	Local industrial wireless networks, mobile operators	TUD	D3.2, D4.2	3
EE-11	Cross-DLTs solution (TrustOS)	Product / service, Research	Industry, Logistics, Education. Circular economy, Agro and Food	TIOTBD	D5.2, D5.3, D6.2, D6.3	5
EE-12	Multimodal traffic prediction services	Product	Maritime logistics	AWA	D5.2, D5.3, D6.3	5-6
EE-13	Smart IoT Gateway	Research	Vertical industry, telecom network operators, satellite network operators, IoT industry	SES	D4.2, D4.5, D5.2, D5.3, D6.2	5-6

Table 3-1 List of iNGENIOUS commercializable products for exploitation.

EE-ID	Description	Exploitable Service	Sector of application	Beneficiaries	Deliverables[6]	TRL
EE-14	Smart container	Product, Research	Maritime port stakeholders	FV, COSSP	D6.2, D6.3	5-6
EE-15	IoT tracking application	Product, Research	Maritime port stakeholders	UPV, FV, SES, COSSP, iDR	D4.5, D6.2, D6.3	5

[6] References to deliverables can be found [2]

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EE-16	TT application	Product, Research	Maritime port stakeholders	FV, AWA	D5.3, D6.2, D6.3	4-5
EE-17	Secure Remote Attestation of Medical Devices	Product	Pharma & Medical	NCG, BI	D3.3, D5.3	6
EE-18	Industrial system with latest 3GPP standards for private networks	Product	Ports & industry	CMC, 5CMM	D3.2, D4.2, D4.5	4-5
EE-19	Solution for the interoperability in IoT domain (Data Virtualization Layer)	Product, Research	Maritime (including Port Authorities and Container Terminal operators).	CNIT, AdSPMTS	D5.2, D5.3, D6.2, D6.3	4
EE-20	Integration of IoT sensors and gateways with satellite networks	Research	Satellite and IoT integration	SES, iDR	D4.5, D6.2, D6.3	5
EE-21	Automated and orchestrated 5G Core and network slices for private networks	Product and Pilots	5G Labs, Vertical industry, telecom operators	NXW, CMC	D4.3, D4.4	4
EE-22	DVL with Cross-DLTs Solution	Research	Ports, IoT verticals	TIOTBD, CNIT, PJATK	D5.2, D5.3, D6.2, D6.3	4-5

Table 3-2 List of iNGENIOUS joint developments for exploitation.

In the following, a more detailed description of each EE is provided to describe the actual technical result and improvement as well as to explain how iNGENIOUS activities have contributed to EE's development, its expected impact, and the respective exploitation planned activities towards achieving its sustainability and bringing the solution to the market.

3.4.1 EE-01 5G CELLULAR IOT (CIOT) MODEM/CHIPSET

Within iNGENIOUS, SEQ has acquired improved knowledge on specific IoT use case definition, technology, and product requirements. More specifically, SEQ has improved their know-how in 5G IoT space and vertical applications, features for enhancing C-IoT modem/chipset, and expected impact of NTN communication on C-IoT device architecture design. This improved knowledge can help the development of new generation C-IoT products that can address from 2025 onwards a larger extend of industry verticals related to factory and transportation IoT applications, such as very energy efficient real-time asset trackers with ubiquitous coverage.

Insights from device energy analysis has already started being used by SEQ for internal communication and training, for experiment of some promising solutions in lab environment (thus, on TRL 3) as well as for planning future cellular IoT modem/chipset product development. With the power model estimator, SEQ can further analyse need, potential and feasibility of selected efficient solutions for low-power modem consumption (high-level, then lab, then field-tests) and plan transition to support those solutions within the next couple of years, i.e., for internal development and implementation integrated in product, either on the SW roadmap or to be integrated in a next generation product solution.

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The obtained knowledge on the impact of NTN solutions on chipsets has already been used internally in SEQ for initial assessment of changes required to legacy devices (TRL 2) and will further be used for defining future NTN-supporting product design and requirements. With this know-how basis set, SEQ can also continue contributing to relevant 3GPP studies and/or specification phases for NTN-based communication and advise accordingly on preferred features from device point of view, increasing at the same time our visibility and credibility amongst the community. Finally, the developed solutions for NTN air interface enhancement allow SEQ to be a useful player in 3GPP community by contributing proposals that can generally improve NTN-related technology and communications. If the proposed solutions are selected in standard specification, SEQ may plan support of the features and prepare future platforms for internal development.

3.4.2 EE-02 5G-CORE

CMC has been working extensively in developing latest 3GPP releases focusing on features designed specifically for industrial networks. CMC includes all the network functions defined by 3GPP standards and within INGENIOUS CMC tested the latest development supporting TSN and 5GLAN functionality. Thus, CMC has a competitive advantage with the 5G Core tailored for Non-Public Networks (NPN) where TSN and 5GLAN support is required. CMC key product consist of the 5G Core but not only with the basic connectivity functionality required for consumer traffic but with the 3GPP defined features for industrial verticals to support machine type communications. CMC current product was tested against latest User Equipment and base station that include support for Ethernet PDU specified in latest 3GPP standards and is not available commercially from other vendors, which brings CMC a competitive advantage.

3.4.3 EE-03 5G MODEM

The 5G modem from Fivecomm is an exploitable element derived from IE-13. The component is a hardware device that provides 5G connectivity to any other device connected through Ethernet or USB. During the project lifetime, it has been integrated, tested, and validated in several commercial and private networks, so its readiness to market is a reality. In order to bring this element to the market, Fivecomm is actively promoting a marketing campaign, showcasing the use of the 5G modem in different demos and trials, including those of iNGENIOUS. We also included a specific website in our domain where customers can download a datasheet with all its specifications, the configuration guidelines and 3D model in a rendered space. A future activity will be the inclusion of a catalogue and specific website for new units with customized orders.

3.4.4 EE-04 IMMERSIVE COCKPIT

The immersive cockpit of Fivecomm is a software platform that integrates different network applications that can be used for different types of vertical services such as remote driving, gesture recognition or haptics integration. Its current market is oriented towards real-life demonstration of such services in big events and conferences. The product can be considered mature since it

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has been used already in some contracts. It has been developed thanks to its integration and final validation in the context of the AGV UC. This not only includes the services showcased in iNGENIOUS such as the use of haptic gloves or 360 VR glasses. The cockpit is also ready for inclusion of new services and peripherals in the future. We continue to promote this product through different marketing campaigns that include news related to demos, a specific website in our domain and promoting videos, among others.

3.4.5 EE-05 AI-ASSISTED END-TO-END NETWORK SLICE MANAGEMENT

As part of the iNGENIOUS work, Nextworks implemented an end-to-end network slice orchestration and management framework, which integrates AI/ML functionalities to introduce full automation in how network slices spanning across 5G RAN, Core and edge/cloud domains are operated. In particular, the AI-assisted end-to-end network slice management exploitation element is made by the integration of the two innovation elements IE-01 (Orchestration and data collection from 5G Core) and IE-02 (AI-assisted network-data based slice optimization) reported in section 3.2. This exploitation element can be considered as an improvement of an already existing company research-oriented software prototype asset for network slice orchestration (called “Slicer”, https://github.com/nextworks-it/slicer). Specifically, in iNGENIOUS, Nextworks has enhanced the Slicer software tool to align it to 3GPP network slice management architecture and data models and to support a full management and operation of 5G Core and related Network Functions (deployment, configuration, scaling). Moreover, an AI/ML engine (and an ML model for 5G Core UPF predictive scaling) has been developed and integrated with the enhanced orchestration software stack introduce zero-touch and full automation principles in the runtime operation and optimization of network slices.

The AI-assisted end-to-end network slice management solution developed and validated in iNGENIOUS is perfectly aligned with the company strategy and interest of looking towards beyond- 5G and 6G service orchestration frameworks with native integration of in-network analytics, AI and ML capabilities and services. From a research and innovation perspective, the software prototypes developed by Nextworks (orchestration stack, monitoring platform to collect data from the 5G Core, AI engine for slice management automation) provide concrete innovation and contribution to the existing company research-oriented network and service management portfolio. On top of these heterogeneous results and assets, Nextworks lays the foundation of its R&D group knowledge and technical background, which is fundamental to be competitive also in the telco consultancy market with cutting-edge beyond 5G and 6G ideas and solutions. This highly contributes to position the company as an ideal partner for carrying out third party software development activities (specifically targeting 5G vertical pilots), when compared with global innovation and engineering consulting competitor firms (e.g., Accenture, Altran Technologies, and Replay) which offer strategy and consulting services for a wide range of functions and industries in Europe, but often without the required innovative technical vision and capacity.

Beyond these pure research and innovation exploitation opportunities, Nextworks has also recently identified the 5G Non-Public-Networks (NPN)s

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as a key area to look at to exploit the company assets and knowledge in the 5G network management. In the short/mid-term, as the AI-assisted end-to-end network slice management asset has been currently validated and demonstrated in lab environments only (through the deployments in UPV and TUD testbeds in iNGENIOUS), the commercialization maturity is low and the related TRL can be set to 4. For this, in the short/mid-term, Nextworks aims at performing mostly pilots targeting 5G NPNs in industrial scenarios involving vertical players and small-medium scale telco operators. In this direction, an initial concrete joint exploitation opportunity has been identified and is already in place with Cumucore, as explained in section 3.4.21. On the other hand, in the long term, Nextworks plan to integrate these assets with the company's Symphony generalized IoT platform to provide a comprehensive technology solution for enterprise and IIoT private networks through 5G in several scenarios, including smart building and events, holiday resorts, residential parks, industry 4.0, hospitals. For this, the AI-assisted end-to-end network slice orchestration asset is required to reach higher levels of commercialization maturity, specifically through an engineering phase to consolidate the solution (i.e., involving the internal company product division) towards a production-ready asset, considering engagement with potential customers to understand their needs and customize to offer. A more effective impact in the market could be achieved by considering specific activities for business plan development, investor introduction, legal advice, and if required partnership with other SMEs.

3.4.6 EE-06 PROMOTE AND ENHANCE THE ROLE OF SATELLITE IN NEXT GENERATION UBIQUITOUS NETWORKS

The objective of this exploitation element was to engage with satellite and terrestrial network operators along with the IoT eco system to promote and enhance the role of satellite in next generation ubiquitous networks.

Throughout the project iDR worked very closely with our valued customer and partner SES in researching IoT relates topics and solutions. iDR have gained valuable insight into the satellite requirements for both backhaul and direct access over satellite NG-IoT use cases. The iNGENIOUS project also gave iDR excellent insight into the IoT market and end-to-end value chain which will help iDR in understanding the market needs going forward. iDR plans to continue working with direct customers but also the new partners gained from the project.

3.4.7 EE-07 SCIENTIFIC MICRO-EDGE LOGGER

The exploitation of IE-22 is its market introduction. Condition monitoring may not be a new field, but it can be significantly improved and extended from the current state-of-the-art. Typical IoT edge sensors are hard-wired for power and communication signal transfer. This is both installation expensive and sometimes not feasible for mobile applications. The Mirco-Edge Rotary Fault Intensity Classification Engine is an efficient low computation algorithm for precisely quantifying rotational defects. This approach enables remote micro-edge classification which enables minimal communication bandwidth usage. This is essential for energy and communication starved environments. This is

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the case for most battery powered IoT sensors and is a basic pre-requisite for making the development of harvester based IoT sensors economically feasible. NCG will introduce the Mirco-Edge Rotary Fault Intensity Classification Engine into its own product line of micro-edge sensors for rail- and engine-health condition monitoring and work with selected SaaS partners on domain specific micro-edge solutions.

3.4.8 EE-08 SCIENTIFIC NOVELTY DATA LOGGER

The exploitation of IE-23 is a commercial Scientific Novelty Data Logger. Data collection and data engineering are significant cost and time factors in conventional data science projects. This process can largely automated with NCGs context based neuromorphic cluster engine. The Scientific Novelty Data Logger is used to collect diverse signal clusters during long-term product validation testing. The output is diverse, balanced, and context labelled datasets which are used as input for simplified and accelerated Data Science projects. The development and commercialization of the Scientific Novelty Data Logger will be driven by NCG over the coming months. Market introduction is planned for late 2024.

3.4.9 EE-09 SELF-POWERED VIBRO-ACOUSTIC MICRO EDGE SENSOR

IE-22 is the prerequisite for enabling the development of harvester based IoT sensor. Even the most innovative and economically attractive vibro-acoustic energy harvesting solutions generate only low energy levels. Therefor reducing the energy consumption requirements is the main pre-requisite. With IE-22 achieved, the development self-powered triboelectric IoT sensors for vibro-acoustic applications can move forward. NCG will push this development with research and application partners.

3.4.10 EE-10 FLEXIBLE PHY/MAC IMPLEMENTATION IN SDR

The flexible PHY/MAC implementation, which can be considered TRL 3, allows real-time experiments of new PHY/MAC algorithms, e.g., modulation waveforms and error correcting codes, under realistic channel conditions instead of using simulations. With such technology, performance evaluation with hardware-in-the-loop can be easily carried out. Moreover, experiments done in realistic scenarios yield metrics that are highly correlated to the scenario under investigation, which is particularly useful for complex indoor environments such as factory plants.

During the project timeline, technology integration was carried out among the Flexible PHY/MAC with a 5G core and MANO allows for a unique testing platform where the interaction and coexistence of non-3GPP radio access technologies can be investigated, and further developed in the context of heterogeneous wireless IoT networks. Furthermore, The PHY modules coded by TUD that carry out the radio signal processing tasks that are executed by the M3 platform allows for research and experimentation of hardware and communications co-design aiming at secure wireless communication. The integration among the aforementioned components required the investigation and usage of an application programming interface (API). This

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API can contribute to the design of heterogeneous wireless networks that can be served by a common system at its network core. Moreover, the developed API will serve as easy connector for devices with heteronomous radio access techniques.

3.4.11 EE-11 CROSS-DLTS SOLUTION (TRUSTOS)

The iNGENIOUS project has provided a cross-DLT solution that favours interoperability in different networks or blockchain platforms for the registration of relevant information on which traceability, transparency and integrity are to be offered. The implementation of this cross-DLT layer involves the development of two elements of innovation already described in section 3.2.3 and 3.2.4, cross-DLT Common Interface and the DLT's events visualizer. In short, the first element allows to have a common way to communicate with the different DLTs used in the cross-DLT layer because it defines the necessary methods to store evidence (TrustPoint) of certain data related to an event into any DLT. The DLT's Events Visualizer is the graphical user interface that allows the visualisation of event-related information that has been stored in the different DLT providers.

Telefónica markets TrustOS as a B2B product with the aim of providing the business world with Blockchain features in a simple way. Before participating in iNGENIOUS, TrustOS already offered the ability to operate with different DLT platforms such as Ethereum, Polygon, Hyperledger Besu, Hyperledger Fabric or Corda. After the participation, integration with other DLT platforms has been added to increase the interoperability of the product such as Bitcoin, IOTA and a new permissioned Hyperledger Fabric network.

The scope of TrustOS encompasses different sectors or markets in today's business ecosystem. Some of them are listed below:

- Industry: the main use cases are the efficient management of plants, vendors and supplies with an approach based on end-to-end visibility of the processes and the different participants in the value creation chain. Another main line is the accreditation with legal certainty and easily verifiable by third parties (regulator, auditors, clients, etc.) of any documentation or information generated or received. Can also be applied in quality control, digital twins, smart metering,
- Logistics: it is possible to benefit from DLT features in cold chain, transport contracts, service route accreditation and delivery management.
- Circular economy: recycling traceability and waste management.
- Industrial property: Business secret, software deposit, brand protection, engineering projects.
- Agro and food: guarantees of origin, food traceability and sustainable certifications.

Telefónica also participates in different standardisation forums and consortia such as ETSI where we have a specification group on blockchain that is working on challenges related to distributed permissioned ledger operation, business use cases, functional architecture, and solutions for distributed

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permissioned ledger operation, including interfaces/APIs/protocols and information/data models as well as other topics. The cross-DLT solution could certainly be used to propose the generation of a standard for interoperability between DLT platforms or at least the work done could contribute to the proposal of new standards for this purpose.

In relation to research (at both the business and educational levels), Telefónica offers a laboratory environment called TrustOS Lab that any company can use and test free of charge to explore whether DLT or Web3 technologies add value to their business processes and solutions. In fact, this will be the environment that will be used to perform the final demonstration of the UC6 (Supply Chain Ecosystem Integration).

In terms of technology readiness level (TLR) we can say that it is at level 5 until we demonstrate for use case 6 where it will be tested in an operational environment.

3.4.12 EE-12 MULTIMODAL TRAFFIC PREDICTION SERVICES

The developed solution consists of prediction services to estimate Truck Turnaround Times (TTT) in sea ports using data from various IoT and general information and planning systems in the port. Prediction functionalities are developed by training Machine Learning (ML) models based on vessel activity, cargo operations, and truck traffic data in the port. The developed prediction services are deployed using cloud-based microservice architectures. The outcomes of the analytics and predictions are visualized in web service user interfaces composed of dashboards and maps. The developed components are implemented as new services in the commercial Awake.AI smart port platform, and are aimed to be developed into new products serving the maritime logistics sector globally.

Existing and potential customers for the solution include national vessel traffic authorities, terminal operation system providers, shipping companies, port traffic authorities, city traffic planning organisations, and hinterland logistics providers. This kind of analytics solutions are not yet commonly available in the maritime sector, and will be needed in the industry to enable more efficient planning of operations, e.g., in the form of Just-in-Time (JiT) arrivals, which is recognized by the International Maritime Organization (IMO) as one of the main steps toward improving the efficiency and sustainability of the industry [7].

First components of the developed system (related to vessel schedule predictions) are already provided using a commercial Software as a Service (SaaS) model to multiple organisations globally. These are on technology readiness level 8, and are being scaled as global B2B products during 2023. Other components of the EE (regarding models for predicting port operations, cargo event rates, and truck turnaround times) are currently implemented as service demonstrations in a port environment, but not yet providing inputs directly to external planning systems, and are thus on TRL 6. These are

[7] https://greenvoyage2050.imo.org/just-in-time-arrivals

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targeted to be piloted with first commercial customers during H2 2023 – H1 2024.

The EE has been developed as part of the iNGENIOUS use case Situational Understanding and Predictive Models in Smart Logistics Scenarios. The project has provided critical contributions to the development of the EE especially in the form of use case planning and specifications, historical reference datasets for machine learning model development and validation, and access to online application programming interfaces enabling testing the developed functionalities as live cloud-based services.

3.4.13 EE-13 SMART IOT GATEWAY

The iNGENIOUS project helped SES to develop a Smart IoT GW. The Smart IoT Gateway ensures the connectivity for a vast number of heterogeneous IoT devices, by harmonizing different IoT technologies and application protocols and formatting data to be transferred across the network, terrestrial either satellite. Therefore, the IoT interoperability enables the federation of different IoT platforms within heterogeneous domains, overcoming the compatibility issues between both standard and non-standard, proprietary, and custom M2M solutions. Furthermore, it enables the better exploitation of data in optimization and prediction, which provides the greatest business value.

Moreover, SES will leverage the iNGENIOUS developments in the Smart IoT GW to increase and customise SES service offering for commercially attractive IoT use cases and for multiple market verticals, such as Fixed Data, Aero, Maritime, Energy, Government, Cloud, and Video.

For example, one of the main business lines of SES Techcom (entity of SES) is the emergency disaster response. SES Techcom is committed to developing innovative solutions for e-health and disaster response. It has executed on this mission through its emergency.lu programme, a mobile, satellite-based telecommunications platform dedicated to disaster response. It was created to re-establish communication (Internet, phone) after a disaster, to support the coordination efforts of humanitarian organisations in the field and to contribute to saving lives during humanitarian emergencies. The Smart IoT GW will help in the asset monitoring for emergency.lu equipment/sites. The edge-computing capabilities of the Smart IoT GW can be used to monitor equipment which is deployed in emergency.lu sites and can provide an alerting interface for the on-site personnel by sending notifications to the smartphones or other smart devices, in case there are issues with monitored devices. Also, it can prepare a direct monitoring interface for emergency.lu equipment for the emergency.lu network management system (NMS), giving alternative data source.

In addition, the knowledge gained from the conducted R&D work for the development of the Smart IoT GW within the iNGENIOUS project is intellectual property that SES will exploit as background knowledge in bidding for and acquiring additional innovation related contracts. Moreover, it allows SES to acquire the necessary skills and know-how to proceed to potential future investments as necessary.

As an illustration, building upon the iNGENIOUS Smart IoT GW background experience, SES kicked-off the **COMMECT** (EC funded) project with aim to

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bridge the digital divide and addressing the need of rural communities with cost effective and environmentally friendly connectivity solutions. SES will further develop the Smart IoT Gateway to be able to gather and process big data from drones helping in the digitalisation of the viticulture.

3.4.14 EE-14 SMART CONTAINER

20 feet dry shipping container equipped with an IoT tracking device able to measure temperature, humidity, acceleration, bumps, and gate opening events. The IoT device installed on the container is able to provide connectivity via NB-IoT and LoRa for communicating the information collected in real-time conditions when the container is in both terrestrial and maritime segments. LoRa communication protocol is exploited in iNGENIOUS to exchange data collected during the maritime trip with the Smart IoT GW developed by SES. The smart container solution was tested in collaboration with CSSP in a round trip shipment performed between the port of Valencia and the port of Piraeus. The shipment included both inland and maritime transportation. In terms of exploitation, the goal is to leverage this innovation in further research projects in order to enhance its capabilities and ensure the scalability of the solution within the shipping industry.

3.4.15 EE-15 IOT TRACKING APPLICATION

Dashboard to integrate and visualize data coming from tracking devices and sensors installed in trucks and containers has been developed. As explained in Section 3.2.24, the application allows to visualize the data gathered from previously mentioned devices. Several tabs have been developed within the same dashboard to enable visualization of data from the ports of Valencia and Livorno, as they are the ones involved in iNGENIOUS project. In the interface, meteorological data is shown together with data from NB-IoT-based IoT tracking devices installed in trucks in the port of Valencia and in staff vehicles in the port of Livorno. The data shown includes temperature, humidity, pressure, the speed of the tracked vehicle and the path followed over an interactive map of the associated port. Additionally, a functionallity to enable the integration of modules developed by other entities has been included. In the project case, it has been the GAD module developed by TEI. In terms of exploitation of this element, as UPV is an academic partner, the goal is to keep it for further research integration activities, as a means of visualising data from external modules developed in future activities.

3.4.16 EE-16 TRUCK TURNAROUND TIME APPLICATION

Application developed by AWA and FV to provide real-time predictions for the truck turnaround times (TTT) expected in the port of Valencia and Livorno. The application integrates a visualization framework where TTT estimates can be provided on demand for specific date and time ranges. The application ingests real-time information from PCS and Gate Access Systems to provide accurate predictions based on the situational understanding of the port operative. The output provided by the application (TTT prediction) can be used to estimate the congestion expected in the port environments due to the arrival of vessels and the presence of trucks and other vehicles. AWA aims at exploiting the solution commercially, while FV will exploit the solution for

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further research purposes and for providing consultancy services in other ports or logistics environments.

3.4.17 EE-17 SECURE REMOTE ATTESTATION OF MEDICAL DEVICES

Sensors collect inherently sensitive information. To ensure unauthorized access of personal or commercial information, TLS and data encryption are not enough. Remote attestation stops unauthorized access and prevents brute force attacks. It is an ideal security extension for financial and medical IoT applications. NCG will demonstrate remote attestation on medical edge applications with medical device makers via further research projects.

3.4.18 EE-18 INDUSTRIAL SYSTEM WITH LATEST 3GPP STANDARDS FOR PRIVATE NETWORKS

CMC in cooperation with 5CMM can provide end to end system including the 5G Core and user equipment integrating 5GLAN and TSN functionality. These features are specifically designed for machine communications and requires network functions in both the core and the end device. Thus, to provide a plug and play solution the component integrated to the end device needs to be interoperable with the counterpart in the 5G Core to deliver TSN functionality. CMC and 5CMM together can deliver together a system that is tested and can guarantee end to end interoperability.

3.4.19 EE-19 SOLUTION FOR THE INTEROPERABILITY IN IOT DOMAIN (DATA VIRTUALIZATION LAYER)

The use of the DVL component, by serving as a single access point for disparate data sources, provides a capability to accessing, managing, integrating and delivering data without replicating it in a physical repository. The DVL is used as an intermediate component between the underlying data sources (e.g., M2M platforms) and applications (e.g., TrustOS, Awake.AI, etc.) by abstracting their complexity and by providing an effective tool for data access and aggregation through the most common interfaces. Although the use of the DVL was limited to the maritime context in the scope of the iNGENIOUS project (e.g., DVL/DLT, Port Entrance and Ship use cases) its capabilities can be easily exploited in other IoT verticals such as Smart Cities, Smart Agriculture, Industrial IoT, Transport & Logistics and other Smart Systems: analytics, real-time reporting, data aggregation and exploration are common aspects of all scenarios and use cases based on distributed monitoring and tracking. Nowadays, the DVL solution is a mature technology widely adopted as a part of a company's data integration strategy. In the project it was used an open source data virtualization platform (namely Teiid) which allowed to perform further customization of the existing solution according to the needs of the iNGENIOUS project. Although the achieved TRL is 4, this platform is already part of the ICT infrastructure of the Port of Livorno and it is used as a single access point to the underlying data sources (e.g., M2M platform, Port Community System and Port Monitoring System) in all R&D activities. The continuous validation of this solution in maritime scenarios is expected to lead the DVL to be considered as a best practice to be adopted also in other National and European seaports in the next 5 years. Moreover, iNGENIOUS project allowed to further extend the typical capabilities of a DVL-based

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solution: a set of most common pseudonymization techniques have been integrated to met privacy and security aspects of this solution when it comes with data management and data governance.

3.4.20 EE-20 INTEGRATION OF IOT SENSORS AND GATEWAYS WITH SATELLITE NETWORKS

Within iNGENIOUS

iDirect and SES successfully conducted two live over-the-air demonstrations of the Ship Use Case using iDirect's 5G-enabled Velocity™ Intelligent Gateway (IGW) solution and satellite capacity from SES on ASTRA-2F GEO Ku-band satellite. iDirect and SES partnered with other iNGENIOUS consortium members FV and COSSP and the system demonstrated efficient communication between the IoT devices, installed in the iNGENIOUS container, and the Smart IoT Gateway as well as seamless connectivity between the Smart IoT Gateway, the remote satellite terminal, the hub platform and the SES cloud.

The first live over-the-air demonstration (mid-term demo, April 2022) was initially not a target for the project, but the partners proactively and enthusiastically decided to use it to kick start the project collaboration. The mid-term demo was used as a proof-of-concept for initial integration and laid the foundation for the rest of the project and also had practical benefits as it allowed the iNGENIOUS partners involved to focus attention onto the basic logistics and configurations that would be needed for the second live over-the air demonstration (final demo, November 2022).

Beyond iNGENIOUS

Participation in iNGENIOUS project allowed SES and iDirect to acquire the necessary skills and know-how to proceed to bid for and acquire additional innovation related contracts as well as to proceed to potential future investments as necessary. Therefore, the testbed remains in place and goes on to become an integral part of several follow-up projects, such as:

- **5G-EMERGE**: Satellite Media delivery Micro Edge (ESA funded)
  - Aim: The efficient distribution of popular media content using satellite broadcast beyond the DTH delivery of linear TV channels. Live and on-demand content will be provided thanks to the 5G-EMERGE micro-edges that are deployed in cars, trains, ships, planes, homes, hotels or at the access of 4G and 5G networks.
- **MICRO5G**: Mobile Edge Computing for 5G Drone Systems (SMC-Luxembourg funded)
  - Aim: MICRO5G focuses on the research of URLLC and MEC for the support of drone services in 5G through storage/processing offloading of the tasks to mobile edge.
- **COMMECT** (EC funded)
  - Aim: Bridging the digital divide and addressing the need of rural communities with cost effective and environmentally friendly connectivity solutions.

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3.4.21 EE-21 AUTOMATED AND ORCHESTRATED 5G CORE AND NETWORK SLICES FOR PRIVATE NETWORKS

The work carried out in iNGENIOUS (mostly in the context of the Automated Robots with Heterogeneous Networks) proved the added-value of integrating and combining the 5G Core solution provided by Cumucore, with the AI-assisted end-to-end network slice orchestration solution provided by Nextworks.

Specifically, while the Cumucore 5G Core represents an innovative product per-se and offers added-value features for 5G NPNs and network slice deployments, the Nextworks AI-assisted orchestration asset augment these 5G network and slicing capabilities providing crucial automation, zero-touch, monitoring and AI/ML driven runtime operation functionalities.
Nextworks and Cumucore plan to explore joint commercialization activities, in the short-term targeting the implementation of 5G NPN pre-commercial pilots supporting either vertical industry players or small-scale telco operators to validate specific 5G and network slicing features in small-scale private deployments. Indeed, the combination of Nextworks and Cumucore technologies and assets, which happened within iNGENIOUS and was not previously available as an integrated solution, is still validated in lab environments only (thus achieving an overall TRL 4 at the moment). However, it is worth to mention that a concrete exploitation opportunity already materialized for Nextworks and Cumucore, to support the implementation of a 5G lab for an Italian university, which includes the realization of a fully virtualized 5G private network infrastructure for industry 4.0 trials, enabled by the Cumucore 5G Core, and managed, orchestrated and monitored by the Nextworks orchestration solution. This activity started in Q1-2023 and is planned to be completed by Q3-2023.

Moreover, Cumucore and Nextworks are analysing the usage of recent network functions added into the Cumucore 5G Core from latest 3GPP Rel 17. These new components consist of NWDAF and latest MEC architecture modules such as EASDF, ECS and EAS as defined in 3GPP Rel 17 23.548, which enhanced with Nextworks AI-assisted orchestration can achieve optimized edge computing deployments.

For the long term, Nextworks and Cumucore plan to investigate further on a potential consolidation of the integrated solution, at the technical level first with the aim to achieved a higher combined TRL, as well as at the marketing and business levels.

3.4.22 EE-22 DVL WITH CROSS-DLTS SOLUTION

The combination of DVL with cross-DLT Layer solution can be exploited as a joint solution to secure information from different sources such as IoT devices. In addition, the integration between TrustOS and Hyperledger Fabric, and the DVL and PI System OSIsoft will be exploited in future projects to enhance the interoperability of the IoT systems of the port of Valencia and other external systems.

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It is also possible to switch from testnet environment to the mainnet after success of the iNGENIOUS project, so that it would be possible to store the data permanently, including the handling of the cryptocurrency in a correct way from the legal point of view (tax laws and accounting).

Moreover, the DLTs' Events Visualizer could be exploited in any future project that needs a graphical user interface that visualizes all the information that is being recorded in the different DLT providers. In this way, all the information is unified in a single interface with references (external links) to the block explorers corresponding to each DLT provider to verify the information in each of them.

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4 Conclusions

This deliverable aimed to give a complete look at the project's activities and achievements with regards to dissemination, standardization, and exploitation throughout the span of the project, as well as at the opportunities beyond its lifetime.

Chapter 1 covered dissemination and communication activities. The project has produced **43 contributions** in the form of article and paper publications in journals, conference proceedings, magazines, and project deliverables. There have also been **14 articles** in external news and related outlets, and the project was involved in **30 participations** in conferences, workshops, training events, and other industrial and scientific events.

Through the development and maintenance of the project website, the use of social media (Twitter, LinkedIn, Zenodo, and Slideshare), the project Blog, YouTube channel, and project news, the project was able to approach large professional communities of 5G stakeholders virtually.

Although not all target impact factor KPIs for communication material were reached by the project, the activities covered a broad range of outlets, providing a large exposure of the project activities and outcomes.

Chapter 2 detailed the activities in targeted standardization bodies and industries for influencing the development of standards. An overview of the relevant activities to IoT solutions for the supply chain within each standardisation body has been presented. We highlighted what impacted the project developments as well as how technical activities and resulted solutions from iNGENIOUS partners have been promoted to standardization bodies and impacted their specifications. In total, **5 iNGENIOUS members** participated in standardization activities (SEQ, NOK, NXW, iDR, 5CMM), and contributions from these activities during the project were included in **38 standards documents**.

Finally, **Chapter 3** covered the innovation and exploitation produced within the project. A detailed mapping spanning from Background IP to Innovation elements to Foreground IP to Exploitable elements was presented, as well as details on the individual elements, and how the exploitation will carry on after the project completion. In total, **25 Innovation Elements** and **21 Exploitable Elements** have been developed during the project.

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4 References

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[3] “NGIoT,” [Online]. Available: https://www.ngiot.eu/.

[4] “iNGENIOUS News,” [Online]. Available: https://ingenious-iot.eu/web/news/.

[5] “EUCloudEdgeIoT,” [Online]. Available: https://eucloudedgeiot.eu/.

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Annex 1 – Project Publications

Journals

N.	Journal	Title	Date	Partners	Open Access Link
1	IEEE Communications Letters	A Robust and Low-Complexity Walsh-Hadamard Modulation for Doubly-Dispersive Channels	Oct 2020	TUD	https://vodafone-chair.org/pbls/roberto-bomfin/A_Robust_and_Low-Complexity_Walsh-Hadamard_Modulation_for_Doubly-Dispersive_Channels.pdf
2	IEEE Transaction on Wireless Communications	A Robust Baseband Transceiver Design for Doubly-Dispersive Channels	Dec 2020	TUD	https://www.vodafone-chair.org/pbls/roberto-bomfin/A_Robust_Baseband_Transceiver_Design_for_Doubly-Dispersive_Channels.pdf
3	IEEE Transactions on Green Communications and Networking	Alternative Chirp Spread Spectrum Techniques for LPWANs	Feb 2021	TUD	https://www.vodafone-chair.org/pbls/ivo-bizon/Alternative_Chirp_Spread_Spectrum_Techniques_for_LPWANs.pdf
4	EURASIP Journal on Wireless Communications and Networking	Machine type communications: key drivers and enablers towards the 6G era	June 2021	UPV	https://jwcn-eurasipjournals.springeropen.com/articles/10.1186/s13638-021-02010-5
5	IEEE Open Journal of Communications Society (OJ-COMS), Low-Power Wide-Area Networks (LPWANs)	A Novel Approach for Cancellation of Non-Aligned Inter Spreading Factor Interference in LoRa Systems	Oct 2021	TUD	https://www.vodafone-chair.org/pbls/qiaohan-zhang/A_Novel_Approach_for_Cancellation_of_Non-Aligned_Inter_Spreading_Factor_Interference_in_LoRa_Systems.pdf
6	Journal of Mega Infrastructure & Sustainable Development	Reducing port city congestion through data analysis, simulation, and artificial intelligence to improve the well-being of citizens	Mar 2022	AWA	https://www.tandfonline.com/doi/epdf/10.1080/24724718.2022.2133524
7	IEEE Access	System-Level Performance Evaluation of 5G Use Cases for Industrial Scenarios (UNDER REVIEW)	Feb 2023	5CMM	n/a
8	Journal of Network and Computer Applications	A transparent distributed ledger-based certificate revocation scheme for VANETs (UNDER REVIEW)	Jan 2023	CNIT	n/a

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Magazines

N.	Magazine	Title	Date	Partners	Open Access Link
1	HiPEAC	iNGENIOUS: Next-GENeration IoT sOlutions for the Universal Supply chain	June 2021	BI	https://www.hipeac.net/magazine/7157/
2	Waves Magazine	5G-enabled AGVs for industrial and logistics environments	2021	UPV, 5CMM	http://www.iteam.upv.es/waves/2021/00-Paper.pdf
3	IEEE Communications Magazine	Choose, not Hoard: Information-to-Model Matching for Artificial Intelligence in O-RAN	Dec 2023	UPV	https://arxiv.org/abs/2208.04229

Conference Papers

N.	Conference	Title	Date	Partners	Open Access Link
1	ICC2021	Channel Estimation for MIMO Space Time Coded OTFS under Doubly Selective Channels	June 2021	TUD	https://www.vodafone-chair.org/pbls/roberto-bomfin/Channel_Estimation_for_MIMO_Space_Time_Coded_OTFS_under_Doubly_Selective_Channels.pdf
2	WCNC 2022: IEEE Wireless Communications & Networking Conference	Iterative Receiver for Power-Domain Non-Orthogonal Multiple Access with Mixed Waveforms	April 2022	TUD	https://www.vodafone-chair.org/pbls/martin-sigmund/Iterative_Receiver_for_Power-Domain_NOMA_with_Mixed_Waveforms.pdf
3	WNS3 2022: Workshop on ns-3	Implementation and Calibration of the 3GPP Industrial Channel Model for ns-3	June 2022	5CMM	https://zenodo.org/record/6553701#.Y_XfInaZO5c
4	CCNC 2022 WKSHPS: 6G: What to expect from 6G: visions, use cases and technologies	A Study on Iterative Equalization for DFTs-OFDM Waveform under sub-THz Channels	Jan 2022	TUD	https://www.vodafone-chair.org/pbls/roberto-bomfin/A_Study_on_Iterative_Equalization_for_DFTs-OFDM_Waveform_under_sub-THz_Channels.pdf
5	IEEE 95th Vehicular Technology Conference: VTC2022-Spring	Waveform Design for Asynchronous Power-Domain NOMA	June 2022	TUD	https://www.vodafone-chair.org/pbls/martin-sigmund/Waveform_Design_for_Power-Domain_Asynchronous_NOMA.pdf

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6	Conference: 27th ACM International Conference on Architectural Support for Programming Languages and Operating Systems (ASPLOS'22)	Efficient and Scalable Core Multiplexing with M3v	March 2022	BI	https://www.barkhauseninstitut.org/fileadmin/user_upload/Publikationen/2022/20220 2_Asmussen_ASPLOS_M3v.pdf
7	Conference: EuroSys'22	Slashing the Disaggregation Tax in Heterogeneous Data Centers with FractOS	April 2022	BI	https://www.barkhauseninstitut.org/fileadmin/user_upload/Publikationen/2022/20220 4_Vilanova_EuroSys_FractOS.pdf
8	Conference Workshop: SPMA'22	Fast Privileged Function Calls	April 2022	BI	https://www.barkhauseninstitut.org/fileadmin/user_upload/Publikationen/2022/20220 4_Miemietz_SPMA_FastCalls.pdf
9	Workshop: Cloud S&P 2022	RATLS: Integrating Transport Layer Security with Remote Attestation	June 2022	BI	https://www.barkhauseninstitut.org/fileadmin/user_upload/Publikationen/2022/20220 6_Weinhold_CloudSP_RATLS.pdf
10	29th IEEE International Conference on Electronics Circuits and Systems 2022 (ICECS'22)	A Trusted Communication Unit for Secure Tiled Hardware Architectures	Oct 2022	BI	https://www.barkhauseninstitut.org/fileadmin/user_upload/Publikationen/2022/ICECS 2022_paper_final.pdf
11	2022 IEEE Global Communications Conference GLOBECOM	Experimental Performance of Blind Position Estimation Using Deep Learning	Dec 2022	TUD	https://www.vodafone-chair.org/pbls/ivo-bizon/Experimental_Performance_of_Blind_Position_Estimation_Using_Deep_Learning.pdf
12	2023 IEEE Wireless Communications and Networking Conference WCNC	Blind Transmitter Localization Using Deep Learning: A Scalability Study	March 2023	TUD	https://www.vodafone-chair.org/pbls/ivo-bizon/Blind_Transmitter_Localization_Using_Deep_Learning_A_Scalability_Study.pdf
13	2022 IEEE/ACM International Workshop on Runtime and Operating Systems for Supercomputers (ROSS)	Towards Efficient Oversubscription: On the Cost and Benefit of Event-Based Communication in MPI	Nov 2022	BI	n/a

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Annex 2 - Dissemination Events

Use Case Demonstrations

N.	Event	Venue	Title	Date	Partners	Links
1	Valencia 5G Day	Valencia	5G-enabled AGV control with haptic gloves	June 2021	UPV, 5COMM, NED	http://www.upv.es/noticias-upv/noticia-12998-v5g-day-es.html https://v5g.es/evento-v5g-day/
2	Traffic - Salón Internacional de la Movilidad Segura y Sostenible	IFEMA, Madrid, Spain	UC2 Telo-operation driving with immersive cockpit Demo and Poster	Nov 2021	NOK	https://www.ifema.es/trafic
3	Feindef - international defense fair	IFEMA, Madrid, Spain	UC2 Telo-operation driving with immersive cockpit Demo	Nov 2021	NOK	https://www.feindef.com/
4	4K HDR SUMMIT	Polo de Contenidos Digitales, Málaga, Spain	UC2 Telo-operation driving with immersive cockpit Demo and Poster	Nov 2021	NOK	https://www.4ksummit.com/es/
5	IEEE 5G++ Summit Dresden 2022	Dresden, Germany	Towards a Trustworthy Internet of Things with Remote Attestation	May 2022	BI	https://5gsummit.org/dresden/
6	Output.DD 2022	TU Dresden Department of Computer Science	Towards a Trustworthy Internet of Things with Remote Attestation	July 2022	BI	https://output-dd.de/
7	Valencia 5G Days 2022	Oceanogafic, Valencia	Immersive remote control of a robot using haptic gloves	May 2022	UPV, NED	https://v5g.es/v5g-days-2022/
8	COSMO Science Forum	COSMO Science Forum - Kulturpalast Dresden	Interactive demo about BI's research in iNGENIOUS: Exhibit Secure Communication through Attestation	Oct 2022 - Mar 2023	BI	https://www.barkhauseninstitut.org/en/interactive-exhibit-remote-attestation-cosmo-wissenschaftsforum https://www.kulturpalast-dresden.de/de/ve

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						ranstaltungen-cosmo-wissenschaftsforum.html
9	Satellite 2023	Walter E. Washington Convention Center Washington, DC	IoT backhauling using 5G Core enabled satellite network (included an animated overview of the iNGENIOUS Ship use case testing and demonstration)	March 2023	iDR	https://www.satshow.com/

Workshops

N.	Event	Presentation Title	Date
1	1st Workshop of the H2020 EU-IoT Project on AIoT and Edge Machine Learning	Applications of Machine Learning and Edge Computing in Maritime Logistics	May 2021
2	2nd Workshop of the H2020 EU-IoT Project on Enabling the Tactile Internet	AR+VR for remote control over Tactile Internet	July 2021
3	2nd Workshop of the H2020 EU-IoT Project on Enabling the Tactile Internet	Cross-layer framework for tactile applications	July 2021
4	Cloud S&P workshop, co-located with ACNS conference 2022	RATLS: Integrating Transport Layer Security with Remote Attestation	June 2021
5	4th Workshop of the H2020 EU-IoT Project	iNGENIOUS: An IoT Architecture for the Universal Supply Chain	Nov 2021

Conference and Event Talks

N.	Conference/ Event	Title	Date	Partners	Keynote

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1	Container Terminal Automation Conference 2020	5G in Maritime Ports and Terminals: An Unlocked Potential	Dec 2020	FV	
2	Global Maritime Week 2021	IoT, AI and 5G: Prediction in the Port of Valencia	Jan 2021	FV	
3	Microwave and Radio Electronics Week 2021 (MAREW 2021)	iNGENIOUS: Next Generation IoT for the Next-Generation Supply Chain	April 2021	UPV	X
4	Wireless Networks in Ports 2021 (PORTCOMMS 2021)	5G In Next Generation IoT: A Key Enabler for Smart Ports	October 2021	FV	X
5	Industrial 5G Uncovered: Spotligh on manufacturing and logistics	iNGENIOUS: Next Generation IoT for the Next-Generation Supply Chain	November 2021	UPV	X
6	Smart Digital Ports of the Future 2022 - IoT Panel	Next Generation IoT: A Key Enabler for Smart Digital Ports	May 2022	FV	
7	IoTweek 2022 Session: Advancing at the Edge of Convergence	iNGENIOUS: manufacturing and port logistics use cases	June 2022	UPV	X
8	5G-LOGINNOV-ALICE Collaborative Day	iNGENIOUS: Next Generation IoT for the Next-Generation Supply Chain	October 2022	UPV	X
9	5G-LOGINNOV-ALICE Collaborative Day	5G in Maritime Ports and Terminals: Port of Valencia case	October 2022	FV	
10	Open presentation on PJATK campus	Bitcoin and iNGENIOUS Project (the content is in polish)	May 2022	PJATK	
11	Wireless Networks in Ports 2022 (PORTCOMMS 2022)	From Standards to Maritime Ports: First 5G Applications at the Port of Valencia	10th November 2022	FV	X
12	European Network on High Performance and Embedded Architecture and Compilation (HiPEAC 2023)	Role of AI/ML in the Supply Chain: Spotlight on iNGENIOUS Use Cases	January 2023	UPV	X

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13	NGIoT Community Events: Evolving manufacturing in Europe – the role of Edge Computing	iNGENIOUS: Improved Driver's Safety with Mixed Reality and Haptic Solutions	February 2023	NOK	
14	Fachgruppentreffen Betriebssysteme (Special Interest Group Operating Systems)	RATLS: Integrating Transport Layer Security with Remote Attestation	January 2023	BI	

Webinars and Hackathons

N.	Event	Title	Partners	Date
1	Shipbrokers Finland Webinar	Satamaoperoinnin tehostaminen koneoppimismalleilla (Improving the efficiency of port operations using machine learning models)	AWA	Feb 2021
2	CONASENSE2022 and EU-IoT/EFPF Hackathon	iNGENIOUS Use cases and cross-layer architecture	NXW	June 2022

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Annex 3 – Success Stories

N.	iNGENIOUS partner	Link to NG-IoT success story
1	5CMM	https://www.ngiot.eu/fivecomm/
2	Awake	https://www.ngiot.eu/awake-ai/
3	ASTI/ABB	https://www.ngiot.eu/asti-mobile-robotics/
4	Cumucore	https://www.ngiot.eu/cumucore/

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Annex 4 - Partner News and Press Releases

N.	Date of Release	Location	Link
1	01/05/2020	FV web news	https://www.fundacion.valenciaport.com/en/news-events/2020/05/the-fundacion-valenciaport-participates-in-a-european-project-that-will-design-the-supply-chains-of-the-future/
2	10/07/2020	Press release fivecomm	https://fivecomm.eu/2020/10/07/fivecomm-is-part-of-ingenious-project/
3	08/03/2021	UPV web news	http://www.upv.es/noticias-upv/noticia-12744-hacia-los-puer-en.html
4	26/03/2021	FV web news	https://www.fundacion.valenciaport.com/noticias-eventos/2021/03/hacia-los-puertos-conectados-del-futuro/?reload=653109
5	30/03/2021	Press release AWAKE.ai	https://www.awake.ai/awakeai-is-optimizing-truck-turnaround-times-at-ports-of-valencia-and-livorno
6	12/05/2021	UPV news	https://www.linkedin.com/pulse/hacia-los-puertos-conectados-del-futuro-david-gomez-barquero/
7	26/10/2021	Barkhausen Institute - Web News	https://www.barkhauseninstitut.org/en/ingenious-projekt
8	21/12/2021	AARHUS UNIVERSITY	https://dbd.au.dk/blog/case-studies/asti-mobile-robotics/
9	13/01/2023	Barkhausen Institute - Web News	https://www.barkhauseninstitut.org/en/interactive-exhibit-remote-attestation-cosmo-wissenschaftsforum

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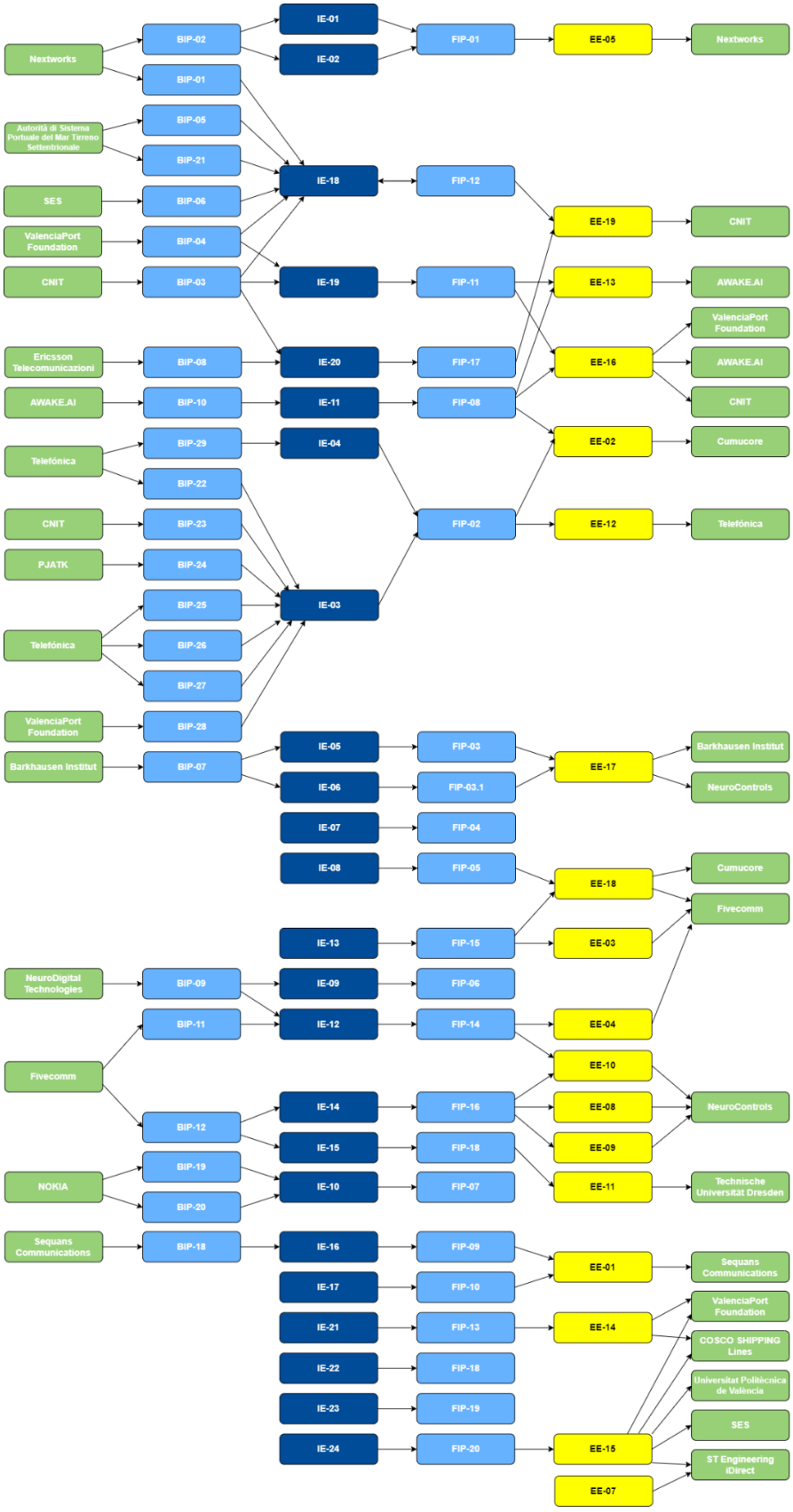
Annex 5 - Innovation and Exploitation mapping



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