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5G technology and strategic investment sectors in Industry 4.0

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Glossary

Abbreviation / Term	Description
3GPP	3rd Generation Partnership Project
5G-NR	5G New Radio
5G-PPP	5G Infrastructure Public Private Partnership
AR	Augmented Reality
BB	Baseband
CP	Control Plane
CPE	Customer Premises Equipment
CPS	Cyber-Physical Systems
CSP	Communication Service Providers
CUPS	Control and User Plan separation
E2E	End-to-End
eMBB	Enhanced Mobile Broadband
ExFa	Experimentation Facility
I4.0	*Industrie 4.0* (Industry 4.0)
IoT	Internet of Things
LTE	Long Term Evolution
mMTC	Massive Machine-Type Communications
MIMO	Multiple Input, Multiple Output
ML/AI	Machine Learning / Artificial Intelligence
NFVI	Network Functions Virtualization Infrastructure
NPN	Non-Public Network
NS	Network Service
NSA	Non-standalone
OFDM	Orthogonal frequency-division multiplexing
OWD	One-Way Delay
PLC	Programmable Logic Controller
RTT	Round-Trip Time

Abbreviation / Term	Description
SA	Stand-Alone
UE	User Equipment
UP	User Plane
URLLC	Ultra-Reliable Low Latency Communication
VR	Virtual Reality
VM	Virtual Machine
VNF	Virtual Network Function
VPN	Virtual Private Network

Executive Summary

Industrie 4.0 (I4.0) is introduced as a next revolution related to the way that processes are deployed executed and further improved in manufacturing environments. In principle, this even extends today to cross industry sectors, as well as to a broader range of services including security, worker safety, quality control and in general any automation process that improves quality, productivity, employment satisfaction and security. The 4.0 concept managed to match perfectly with the advances that were envisioned by the introduction of 5G leading to a strong connection between the two concepts. 5G technology is seen as a key enabler for the 4.0 vision while 4.0 is the most renowned and rapidly growing vertical sector for 5G deployments.

By reviewing key concepts, status, and trends for I4.0 and 5G, a side by side analysis can lead to the identification of major opportunities associated on one hand with the key I4.0 principles of Interconnection, Information Fusion, Human to Machine Collaboration, and Flexible Decision Making and on the other hand with the 5G enabling capabilities in terms of eMBB-URLLC-mMTC services, the flexible 5G spectrum usage, and the advanced 5G virtualisation, slicing, edge processing, and deployment/connectivity capabilities. Such analysis reveals the immediate present and the future trends in the various fields and associated enabled principles highlighting the areas of focus as the 5G technology moves towards more advance capabilities.

The view of the I4.0 vertical stakeholders is important and complementary to the generic trends and opportunities since it provides an actual insight on the expectances from 5G solutions in their business sector. In this context, a detailed 11-question survey has been conducted among all stakeholders in order to identify: the competitive advantages, applications and areas of interest for the adoption of 5G in their plans; the expected adoption/transition time; the identification of critical 5G network services for their applications; the importance of human-machine collaboration; the investment model that best matches their industry needs; the key requirements and expectations for non-public 5G networks; and the requirements for security and privacy. Such an analysis reveals the major trends and expectations with respect to the aforementioned criteria and in terms of both 5G NetApp deployments and support by a targeted 5G infrastructure.

Next the key capabilities in support of the 5G-INDUCE use case validation can be identified and split per infrastructure level: 5G-Access, 5G-Core, and 5G-Edge.

Finally, the three experimentation facilities at Spain, Greece and Italy are characterised according to their deployment plans and in view of supporting the 5G-INDUCE platform for the NetApp deployment, testing and validation.

1 Introduction

The objective of this document is to provide a survey of the current state of the art and emerging technologies in 5G applied to I4.0 scenarios within the 5G-INDUCE project, leading to justified decisions on technology alignment with the project objectives and requirements. In consequence, the overall 5G release roadmaps, the provision of new functionalities in the radio-access and core parts, their inclusion into the 5G-INDUCE facilities and their potential exploitation in the vertical industry use cases are evaluated. The outcomes of this report provide timely feedback to the technical work packages of the 5G-INDUCE project, and also constitute relevant technical inputs to the Market Analysis, Exploitation and Business Planning work in task 7.3. Special attention is dedicated, but not restricted, to these four relevant and recurring aspects across the various use cases in the scope of the project: performance, productivity, safety and security.

The approach selected for carrying out the technology survey and analysis considers and analyses the complementary viewpoints and plans of I4.0 vertical stakeholders, MNOs and technology providers participating in the project, for seeking the alignment among them towards a shared common view and agreed roadmap for 5G technology investments, solutions and deployments. On the one hand, the expectations and plans stemming from the respective domains of each I4.0 vertical stakeholders involved in the project are surveyed, and, on the other hand, MNOs and technology providers participating in the project at each Experimentation Facility (ExFa) come out with roadmaps for a sustainable deployment of 5G evolving technologies and solutions that meet the demands of the I4.0 use cases in the scope of 5G-INDUCE project.

About the scope and strategy of analysis, it is important to remark that the research performed extends far beyond the case-by-case analysis at use case level (initially covered in the project at deliverable [1]) into identifying commonalities of needs, challenges, solutions and plans at three incremental levels:

a. At ExFa level, considering the expectations of vertical stakeholders and plans of MNOs at each specific ExFa. This level of analysis is mandatory for identifying the key 5G enablers for a solid technology blueprint and roadmap at each ExFa, that may cater with the needs of the various targeted use cases
b. Across all ExFas, identifying common needs and common solution approaches across the three ExFas in the project. This level of analysis is highly advisable for identifying more general and, therefore more robust and flexible, solutions and plans for the 5G deployments at the ExFas.
c. Into the general I4.0 space, elevating the view beyond the scope of 5G-INDUCE into the broader space of I4.0 expectations of the vertical stakeholders of the project. This extra level of exploration considering a wider scope of scenarios can bring additional insights on the assessment of certain aspects and choices for 5G solutions and roadmaps, with the intent of not only adequately supporting the needs of the use cases in scope but also those of evolved and similar use cases in I4.0 of interest to the vertical stakeholders of the 5G-INDUCE project and also outside the project consortium, untapping potential economies of scope and scale in the long run, for the related ecosystem.

Finally, regarding to the type and nature of the outcomes pursued by the research work performed and documented in this report, the guiding principles have been:

a) Striving for concreteness and applicability of the recommendations and proposals, so as to provide clear feedback and inputs to the technical work packages of the project and tasks at each ExFa,
b) Addressing both short-term and near-term needs, over a high-level consistent roadmap for 5G deployments, and
c) Explaining the key concepts and rationale behind the recommendations and proposals put forward.

The structure and flow of this document is as follows:

1. Section 1 is a necessary introduction to the scope, ambition, general approach, research strategy and structure of this report,
2. Section 2 provides an overview of the current landscape of both I4.0 and 5G, highlighting their state of art, maturity, and evolutionary trends, for, then, identifying synergies, opportunities and challenges for their integration into innovative technical and business solutions,
3. Section 3 reflects the viewpoint of the vertical stakeholders, surveying their specific and general plans on I4.0 as well as their key expectations on 5G technologies and their evolution,
4. Section 4 identifies and explains the key enablers and levers of 5G with major influence for supporting the scenarios of I4.0 in the scope of analysis,
5. Section 5 illustrates the current and planned deployments of 5G for each and every ExFa in the project, and
6. Section 6 captures the major conclusions, key outcomes and contributions from the research work carried out and documented in this report.

2 State of the art on 5G technology application to I4.0 use cases

The general and common application business domain of the 5G-INDUCE project across its three ExFas and eight use cases is the I4.0, being one of the fastest growing and most impactful sectors in European economy.

Before moving on to further sections of this report, an overview of the current landscape of both I4.0 and 5G is deemed convenient. An overview of the state of art, maturity and evolutionary trends, for both I4.0 and 5G is provided in sub-sections 2.1 and 2.2, followed by the identification of synergies, opportunities and challenges for their integration into innovative technical and business solutions reflected in sub-section 2.3.

2.1 I4.0: General concepts, state of the art and major trends

The term *Industrie 4.0* was first used and coined in 2011, as the next revolution for Industry, expected to deliver fundamental improvements to the industrial processes involved in manufacturing, engineering, material usage and supply chain and life cycle management.

Curiously enough, even though I4.0 is a major (and most likely, the most) influential trend in Industry transformation, the concept of I4.0 was never formally defined. Instead, as a German initiative, the *Industrie 4.0 Working Group* developed and published a first comprehensive vision and early visualization of the I4.0 phenomenon, revolving around three so-called components of I4.0 (IoT, Cyber-Physical Systems and Smart Factories) and including examples of potential use cases and references to identified enabling and disruptive technology trends (IoT, Sensors and Actuators, Big Data, Virtual world, …) in 2013 [2].

Ever since then, exponential technologies such as IoT, Big Data, VR, AR, ML/AI, Cloud and 5G, have developed and reached a maturity stage that may very well provide many Industry sectors with a solid foundation to build upon for tackling the implementations of their vision and interpretation of I4.0. Even more importantly, such technology advancements in the ICT space have concurred with intense exploration and innovation across many and varied Industry sectors and processes, materializing into the execution of more and more trials and pilot of concrete I4.0 use cases.

Such a context provides new incentives for attracting more and more players and talent from various disciplines to collaborate for realising the vision of I4.0, for the benefit of all parties involved, the industry sectors and the (European) economy as a whole. Indeed, either in the form of individual or bilateral projects promoted by Industry players, or, more commonly, through I4.0 focused research and innovation consortia of Industry leaders, large technology companies, specialised SMEs and Research Centres/Universities, with the support of EU H2020 and Horizon Europe programmes, I4.0 is accelerating as it is consolidating a new innovation ecosystem. For further reference on this context please read 5G-PPP publication [3].

After that short introduction to I4.0, from its inception to its acknowledged potential and momentum nowadays, a high-level review (as of 2022) of I4.0 technology trends spotted, with major focus on their influence for the near and mid-term future, follows.

Our objective is to extract useful conclusions on the status, key levers, and also potential road-blockers for I4.0 realization and evolution, from a 360-degree perspective, trying to avoid or prevent the bias that could be introduced by the consideration of only a few selected use cases and specific technologies. So, for analysis purpose going forward, and given the large number and extreme variety of I4.0, a segmentation of I4.0 is proposed here, with four clusters of I4.0 complementary *Design Principles*, derived from the early research work performed in [4], and being updated and assessed over the evolution of I4.0 and the considered in the period from 2016 to 2022.

The four I4.0 clusters (or Design Principles) considered are the following:

a) Interconnection
I4.0 scenarios are characterized by the generalized interconnection of machines, sensors, systems, processes and people.
    a. Such interaction is based on communication standards, with Wireless communication technologies playing a prominent role in the increasing interactions as they allow for ubiquitous Internet access and higher flexibility for the foreseen dynamicity of Industry environments.

b) Information Fusion
    a. I4.0 applications leverage the possibility that the fusion of intertwined information from both the Physical and the Virtual World constitutes a common base of information for supporting Industry processes.
    Such fusion is facilitated by advancements in information systems and sensors, real-time communication technologies and, finally, its essential visualization is highly supported by VR and AR technologies.

c) Human-Machine Collaboration
    a. I4.0 promotes that repetitive and, especially, unsafe tasks, are delegated to (smarter) machines, which implies that a new role for the workers evolving to planning, supervision, decision making and collaboration with the machines is instrumented. Remarkably, this collaboration may very well go beyond the boundaries of the factory environment, extending across the value chain.
    b. Such a new model for delegation, coordination and collaboration in industrial tasks must be supported by ubiquitous communication technologies, advanced robotics and sensing technologies, intuitive visualization and actuation devices like smartphones and tablets and evolving to AR&VR tools and wearables. Additionally, the increased level of processing and intelligence required on the machines taking on more and more complex tasks calls for the support of ML/AI technologies.

d) Flexible Decision Making
    a. In I4.0 scenarios people and, especially, machines may have the possibility to either take decentralized decisions or surrogate to centralized decisions, as ways to respond to the demands of better decision making for increased global productivity.
    b. Such flexibility is enabled by interconnection, thus relying on communication standards, and realized to its full potential with the CPS (involving distributed systems approaches and autonomous systems), leveraging embedded systems, cloud-edge paradigm and ML/AI.

Table 1 normalizes and visualizes the expected level of relevance (Minor – Significant – Critical) of the key ICT technology enablers for I4.0 identified in the above-described clustering (namely IoT&5G, Cloud&Edge, VR&A and ML/AI) onto each of the complementary I4.0 Design Principles.

	Key ICT Enabling Technologies for I4.0			
I4.0 Design Principles	**IoT / 5G**	**Cloud&Edge**	**AR&VR**	**ML/AI**
Interconnection	Critical	Significant	Minor	Minor
Information Fusion	Critical	Critical	Significant	Minor [1]
H-M Collaboration	Critical	Significant	Critical	Significant
Flexible Decision Making	Critical	Critical	Minor	Critical

Table 1. Landscape of key influencing ICT technologies on I4.0.

Three straightforward conclusions can be extracted from the analysis of Table 1.

a) The influence of IoT&5G technologies is critical to the realization of most I4.0 design principles. In addition, it can be observed that the influence of Cloud-Edge continuum paradigm and the associated technologies is significant for the fulfilment of I4.0 design principles. Therefore, both IoT&5G and Cloud&Edge seem to constitute the horizontal technology platform for I4.0.
b) AR&VR and ML/AI are, respectively, critical technologies for supporting the fulfilment of H-M Collaboration and Flexible Decision Making I4.0 design principles. They may also have a potential for further influence into the other I4.0 design principles, for use cases most likely yet to be identified and explored.
c) The high impact reflected in Table 1 allows to assert and even prescribe that I4.0 implementation is bound to these four key enablers, implying that extensive knowledge build and technology integration skills constitutes a top priority for securing the take-off of I4.0.

Putting it altogether the level of development of I4.0, with regards to both use case innovation at varied industry sectors and undergoing integration of diverse technologies in countless trials and pilots in execution, is already remarkable. The proliferation of I4.0 projects and use cases at this stage reflects, equally, the determination of all parties involved (private and public) to invest in the area and the necessity of completing learning cycles and fulfilling validation processes before moving onto exploitation of developed solutions, given the strong dependency with -and complexity behind the integration of-advanced and evolving ICT technologies.

If the aforementioned summary may account for the current situation of I4.0, then a further look into the near future of I4.0 may indicate that two differentiated streams of activities will very likely coexist. On the one hand as the key enabling technologies consolidate and become mainstream -not only for I4.0 but for many other application purposes industrial sectors will be reassured to integrate them into the addressed and validated use cases and into exploitation, in alignment with deploying the innovations and transformation in their own processes, with the likely time horizon of 2025. On the other hand, the continued scan and creation of new value-adding and more demanding I4.0 use cases, along with the paced and sustainable evolution of the key ICT enabling technologies of I4.0, will propel new cycles of early investments in research and collaboration, that might extend to, at least, the end of this decade.

[1] The influence of ML/AI in the Information Fusion design principle is rated, as for the present development of I4.0 as "*Minor*" even though as it is expected that for upcoming use cases in the area of, for instance, digital twins and cobots in general, its role may become, at least, "*Significant*".

2.2 5G: Standards and solutions of general applicability to I4.0

As just explained, I4.0 realization is bound to current IoT and Cloud-Edge technologies and their evolution. IoT communications have been a horizontal enabler for I4.0 from its very inception, and more so in particular IoT over wireless networks, for meeting both common mobility support requirements of machines and people and flexibility demands for planning new processes that should not be *fixed* to the floors or walls of a floor shop or warehouse anymore.

Both LTE and 5G technologies (3GPP standards with worldwide, generalized, and rapid adoption) provide with the key underlying technology for IoT connectivity over both public and non-public (private) mobile networks. It is important to remind the type of services and performance, flexibility and state of maturity of LTE and, especially, 5G:

- Type of services and performance:
    - LTE was designed, and has been deployed worldwide, for providing Mobile Broadband services, available over frequency bands that guarantee good levels of range and penetration. It is consolidated as the dominant technology for, especially, person to content services including browsing, streaming and contents downloads. That said, and given the standardized optimizations for latency of LTE, as well as the possibility to implement advanced QoS control policies, LTE has also been used for enabling enterprise IoT use cases of sectors like utilities (e.g., smart metering)
    - 5G standards, since 3GPP release 15 (Rel-15), diversified its offering into specific types of services defined as (see [5]):
        - Enhanced Mobile Broadband (eMBB), with "human-centric use cases for access to multi-media content, services, and data",
        - Ultra-reliable Low-Latency Communications (URLLC) -also frequently referred to as Critical IoT-, with "stringent requirements for capabilities such as throughput, latency and availability", and
        - Massive Machine-Type Communications (mMTC) -also sometimes referred to as Massive IoT, with the specificity to address "a very large number of connected devices typically transmitting a relatively low volume of non-delay sensitive data", with low cost and long battery life devices.

      Following that disruptive approach, the same mobile communication standard can provide, to distinct mobile users and applications, the so-called network slices so as to deliver the performance that best adapts to their distinct needs, which normally fall into one of the three categories of services featured.

      ITU also specifies the operation of 5G New Radio (NR) over distinct frequency ranges, with the intent to support scenarios for, respectively, wider range and higher capacities.

      As a final and key consideration, the bandwidth available within these frequency ranges is broader than that assigned to LTE, which makes it possible to deliver higher speed (throughput) for both Uplink and Downlink communications over 5G.

- Flexibility
    - 5G standards incorporate the adoption of a number of advanced features and mechanisms that provide Communication Service Providers (CSPs) with greater levels of flexibility than those of previous generations of mobile communication standards. Among all of them it is worth covering, at least, the following:
        - NFV: All 5G Network Functions are virtualized, thus allowing for multiple options of cloud-like deployments of 5G. NFV transforms the way in which networks will be

designed and built by allowing to consolidate many network equipment types onto industry-standard high-volume servers, switches, and storage, which could be located in data centres, network nodes, end-user premises, etc… This is particularly interesting for benefitting from cloud economics of scale, as well as for reducing the footprint of 5G deployments for non-public dedicated networks, for instance.

- Control-User Plane separation (CUPS): 5G network topology and connectivity between the different network elements are implemented in a way that the CP and UP follow different paths. Even though anticipated as an optional LTE feature, CUPS is generalized and stretched to its full potential with 5G. A major benefit of CUPS is to bring the UP node closer to the UE, in order to reduce latency of the service and to offload the backhaul. More generally CUPS allows for flexibly distributing CP and UP functions all along the cloud-edge continuum, from the central office DC of a CSP down to the far edge, as close as needed to the UE.
- Edge Computing: Generally referred to as a distributed computing paradigm where computation is largely or completely performed on distributed low-power device nodes located closer to the users, as opposed to a centralized cloud environment: edge computing pushes applications, data and computing power (services) away from centralized points to the logical extremes (closer to end-user) of a network. The benefits of this kind of paradigm may be summarized as Latency reduction (since the time needed by data to travel from source device to the place where they are elaborated is shorter) and bandwidth demand reduction (as the more localized elaboration of big amounts of data, may provide a significant reduction of the data otherwise moved all across the whole network). 5G, by embracing NFV and CUPS, is perfectly fitted to support multiple options of Edge Computing, for optimizing performance and resources for both network functions and virtualized verticals applications.
- Network slicing: 5G includes native support of such feature. It allows to set up multiple virtual slices of the RAN, core and transport networks to meet specific service requirements, e.g. radio access technology, bandwidth, end-to-end latency, reliability, guaranteed / non-guaranteed QoS, security level. With Network Slicing, over the same physical core and radio-access networks, different slices can run as, for example, one supporting mobile broadband application in full mobility, as provided by the legacy LTE system, and another slice delivering as, e.g. non-mobile, latency-critical industry-automation application. In other words, despite such slices are running on the same physical network, from the end-user point of view they appear as independent networks and each of them may provide different network capabilities.
- 5G NR: First, 5G supports, as already introduced, several frequency ranges that can help meet the specific demands of coverage range, penetration, and capacity (from lower bands to higher bands). On top of that, densification of access networks in mid and high bands allows for providing both high capacity and customized range, for, e.g. enterprise or industrial indoor deployments.
- 5G specifies several architecture options, which can be summarized for simplicity as legacy architectures (full compatibility with LTE), NSA architecture option (CP is anchored to a supporting LTE network, while UP communications fully leverage 5G-NR) and SA architecture option (with full independence of 5G from LTE legacy networks). SA option is a natural choice for non-public networks since it can be smoothly deployed, independently of LTE networks.

  - 5G also allows to select a variety of configurations for the modulation, beam forming, MIMO layers, TDD/FDD patterns, among other aspects of 5G-NR numerology that go beyond the scope of this report. This flexibility can be helpful in various scenarios, e.g. for prioritizing uplink communications throughput, or for improving capacity or coverage.
  - Finally, the bandwidth used within the frequency ranges assigned to 5G can be increased, or adapted in general, by using features such as carrier aggregation and dynamic spectrum sharing (DSS), to meet the actual needs of speed (throughput) of the use cases supported.
  - More detail of these features is provided in section 4.2.

- State of maturity
  LTE is widely deployed and remains, performance wise, a suitable and affordable option for non-time-critical applications, also benefiting from wide availability of compatible UEs, CPEs and modems. 5G is being broadly deployed, for providing eMBB experience to a rapidly growing base of subscribers all over the world and complemented with LTE through NSA options. Being eMBB the mainstream for 5G commercial deployment -for obvious economics of scale-, 5G is also being deployed, more and more often, for supporting enterprise scenarios in non-public (dedicated) networks adopting the SA architecture option (please see [6] for further reference on this subject). On the downside, the ecosystem of 5G CPE manufacturers is still developing, delivering low volumes of functionality limited devices, since the major focus (as of the date of writing this report) is on 5G UE manufacturing and supply at the very high volumes demanded by commercial 5G roll-outs.
  Regardless of the difficulties and complexity involved, a review of the general state of maturity also reflects that the full potential of performance and flexibility of 5G is already being unlocked in multiple pilots, and also initial exploitations, of a variety of applications of Transport, Energy, Logistics, Education, Tourism and Agriculture, and Manufacturing.
  In order to put these trends in context with concrete and up-to-date figures, we refer to the research conducted by GSA and reported in [7]. In such study, first of all GSA defines -based on the consensus of its Executive Members- the term *private mobile networks* as “3GPP-based 4G LTE or 5G networks intended for the sole use of private entities, such as enterprises, industries and governments”, and then extracts and organizes information on actual deployments classified into such category, provided by Executive Members of GSA such as Ericsson, Huawei and Nokia. The outcome of their research outlines that private mobile networks have been deployed (by 2022) in 68 countries and territories and amount to 794 distinct deployments (with 5G being used by 296, or 37% of these customers). Also, GSA’s reported data suggest that the manufacturing sector is a strong adopter of private mobile networks (either LTE or 5G based) in terms of the number of customer deployments, with 140 identified companies involved in known pilots or deployments.
  Finally, the overall picture for the state of maturity of 5G NPN for Industry 4.0 applicability must be necessarily completed with a few considerations on regulatory aspects and plans, at global and national levels, related to the spectrum for the frequency bands considered for 5G NR. In this regard, we refer to the up-to-date review on the spectrum for local industries published by Ericsson [8]. Such report not only updates on the diverse spectrum availability models and specific frequency bands enabled for industrial applications in countries all around the globe but, even more importantly, it highlights the influence of such heterogeneous context on the adoption of Private/NPN 5G by Enterprise -and therefore I4.0- customers. The major requirement of “access to spectrum must be predictable over a long period of time to support uninterrupted operation and major investments in production processes and industrial facilities”, calls for the need of well-established national policies about spectrum access allowing for a variety of models, ranging from direct access by the Enterprise

itself to SLA-ed access to spectrum of CSPs, in order to flexibly meet the varied needs of Industrial sectors. It is expected that, as the relevant regulation is in place and the adequate business models emerge taking that fundamental requirement of predictability in mind, the adoption of private/NPN 5G by Industry sector shall precipitate towards a scenario where, in the long run, up to 1 million factories in the world could leverage 5G technology for their critical business processes. Then the report also points out the major influence that the diversity of national regulatory frameworks on the selected spectrum bands for Industrial use has on the pace of scaling of the ecosystem of the manufacturers of 5G devices for Industrial applications. Indeed, the higher the harmonization of such regulation across markets, the faster 5G device manufacturers can produce and deliver larger volumes of units, therefore securing the levels of supply and the diversity of devices required by Industry customers deciding on large investments associated to I4.0 and 5G. As a key example of coordinated action addressing the introduced aspects, the report outlines that "the European Commission has identified the demand for mid-band licensed spectrum, … and issued a mandate to CEPT to investigate the shared use and harmonized frequency arrangement of the 3.8-4.2 GHz frequency for local area connectivity." The work is tasked to finish by March 2024".

2.3 I4.0 and 5G: Synergies, Opportunities and Challenges

Having reviewed the key concepts, status, and trends for I4.0 and 5G, in the two previous sections, now we can complete a side-by-side analysis of their intersection, trying to identify major synergies for the present moment and for the near future, and highlight some opportunities and challenges associated.

Following the methodological framework of I4.0 Design principles used in section 2.1, and leveraging on the key 5G concepts (or enablers) explained in section 2.2, the relevance of each key 5G enabler on each I4.0 design principle has been assessed for the present (P) and the near future (F), and reflected in Table 2.

	5G Services				5G Spectrum				5G Architecture			
I4.0 Design Principles	**eMBB**	**URLLC**	**mMTC**	**Low Bands**	**Mid Bands**	**High Bands**	**NFV**	**CUPS**	**Edge**	**Slicing**	**NSA**	**SA**
Interconnection	P+F	P+F	F	F	P+F	F	P+F	P+F	P+F	F	P	P+F
Information Fusion	P+F	F	F	F	P+F	F	P+F	P+F	P+F	F	P	P+F
H-M Collaboration	P+F	F	F	F	P+F	F	P+F	P+F	P+F	P+F	P	P+F
Flexible Decision Making	F	F	F	F	P+F	F	F	F	P+F	F	P	P+F

Table 2. Assessed relevance of key 5G enablers on I4.0, for both its Present (P) and near Future (F).

This table allows us to extract three relevant insights, that may be fundamental input to technology and strategic investments of actors involved in 5G-enabled I4.0 initiatives, and, more concretely, on 5G-INDUCE partners (especially Industry verticals, MNOs and SMEs):

1. 'P alone' matches: Very few cells (only 4 out of 48) in the table show a match for the present, alone. It is the case for the role of NSA for I4.0 (and it would have also been the case for legacy LTE, if it had been analysed and included in the table). That reflects the fact that NSA may have been used for some early 5G trials and pilots of I4.0, as 5G SA was maturing and until 5G SA CPE manufacturers are fully activated to serve new devices to the market, but the future of 5G for I4.0 will talk SA, unlocking increased performance levels (URLLC) and other flexible 5G features such as slicing and flexible edge

computing support. Therefore, the recommendation for new 5G-enabled I4.0 initiatives is going for investments on 5G SA architecture option from scratch.

2. 'P+F' matches: A large number of cells (22 out of 48) in the table indicates a match of 5G and I4.0 for both present and future. This is the case of, among other 5G Key enablers, eMBB, mid bands frequency for 5G-NR, NFV, CUPS, Edge and SA. It illustrates the current feasibility, along with the future/sustained potential, of such 5G enablers for realizing I4.0. Those 5G enablers can be regarded as the "safe bets" of investment (through knowledge build, to technology integration, validation and exploitation) for actors engaged in I4.0 5G-enabled endeavours now and in the near future. Even if the entry barrier can seem high due to the involvement of several technologies and the potential complexity of integration, the investments are likely to pay off over time through evolution and reuse of the associated knowledge and technology base.

3. 'F alone' matches: A large share of cells (20 out of 48) in the table indicate matches of 5G and I4.0 expected to be materialized in the near future (i.e., not yet in the Present). That can be seen as a fair illustration of the high potential that 5G technology status and regulation still hold for the future, as well as of the still long innovation journey ahead of I4.0 revolution. As remarkable cases of 5G enablers falling into this category URLLC, mmWave, Slicing and (also potentially) low bands can be clearly spotted. A rushed conclusion out of this situation could be that technology and strategic investment for learning/deploying/integrating/using these 5G enablers should be put on hold, but a more careful analysis considering the viewpoints of both I4.0 and 5G may lead to another conclusion: these matches for the near future indeed represent a huge opportunity for differentiation and increased competitiveness through timely research and innovation on the identified intersections. So, the recommendation could be, instead, to start new cycles of knowledge build and collaborative projects aiming at properly exploring them. As an additional and final observation, it can also be seen that the row for I4.0 Design principle "Flexible Decision Making" is particularly dense on 'F' matches (8 out of 12) also suggesting that the potential for innovation yet to be unlocked in this field can be extremely high.

A synthesis of this analysis, and the derived recommendations could be visualized as a most likely (and desired) scenario for the I4.0-5G ecosystem: to have a coexistence of mature I4.0 pilots leveraging the 'P+F' matches safely moving to business exploitation, while brand-new research activities start exploring and roadmapping the opportunities around the 'F' matches. The challenges to overcome for reaching that sweet spot scenario are not negligible though. There is the need for ramping up engineers with the skills talent required for this ecosystem, managing the transformation of industrial processes triggered by I4.0 advancements and establishing effective business models and supply chains for 5G services. Moreover, it requires the integration with other key technologies, to be smoothly delivered to, and widely used, by I4.0 solutions. If the associated challenges are overcome, then the establishment of such type of ecosystem dynamics would represent the inflection point for I4.0 take off, and the start of its promise being delivered.

3 Analysis of requirements of the 5G-INDUCE vertical stakeholders

3.1 Introduction: scope and methodology

If the previous section focused on a top-down analysis of I4.0 status, trends, and general synergies with 5G and other technologies, now the analysis in this section is all about direct inputs from the vertical stakeholders of the 5G-INDUCE project. We will analyse their views on I4.0 and the enabling role of 5G, for the purpose of extracting general conclusions, that are more correlated to their specific context, as businesses, of applicability to their decisions on strategic and technology investments.

For that purpose, a survey (see Annex I) has been elaborated and distributed to such vertical stakeholders. The aim of this survey is to collect information that reflects the verticals' point of view on I4.0 motivations, trends, challenges as well as on the role and considerations on 5G as enabler for I4.0 evolution. The questions were designed to motivate that the vertical stakeholders are not only considering the specific scope of 5G-INDUCE use cases they are involved in, but providing, more generally, their firm's viewpoint on the general subjects of analysis. The survey consists of eleven questions, allowing the vertical stakeholders answering them for both providing free textual answers and explanations questions (summarized in 3.2), and also tabulated questions for the selection and scoring of factors over multiple-choice boxes (being its aggregated analysis documented in 3.3).

3.2 Survey to 5G-INDUCE I4.0 vertical stakeholders

The textual answers of PPC, Whirlpool, Ford and ASTI to the open questions included in the survey are reported here:

PPC

With regards to the envisaged I4.0 5G-enabled applications for the near future PPC considers that the adoption of 5G networks enables the deployment of applications with stringent requirements. The strict timing determinism and low latencies, the high bandwidth and the massive machine to machine communications provide the necessary means to make the deployment of these application feasible. Examples of such applications are Factory automation processes within ms and Real-Time high-quality video streaming accompanied with AR/VR.

PPC estimates that the generalized adoption of 5G in their industry sector is to come within the period 2025 to 2029, indicating the following as key milestones in that process:

- Adoption of new technologies (AI, big data analytics)
- Hardware support (AI processors)
- Innovative solutions on data exploitation (Digital Twin)

With regards to the options on deployment models, the main scenarios being considered are the local on-prem Data Centre (far Edge) and the Central Office (Telco cloud). A more elaborated analysis of deployment options follows:

- The on-premises Data Centre that can satisfy the needs for process automation and monitoring, and can operate securely in an isolated environment.
- The Central office can provide the cloud capabilities needed to support the applications.
- Near edge can become feasible in more advanced use cases for example in the case of distributed energy resources regarding the energy sector.
- Hyper-scalers' services should be considered as a next step considering the needs for more storage and computation capabilities.

On the analysis of Non-Public Networks (NPNs), PPC gives special attention to both their security and reliability capabilities. For PPC, reliable communications in critical processes and the protected environment of a non-public network can enable seamless operation under an isolated environment.

Regarding security and privacy, PPC has identified and shared the following key aspects and requirements of their I4.0 initiatives:

- Reliable communications in critical infrastructure's processes.
- Integrity and confidentiality in all the communications.
- Authentication mechanisms and access control mechanisms.
- Intrusion detection system (e.g. DoS attack detection).
- Privacy preserving approaches for user sensitive information that can be derived from tracing or monitoring the activities and location.
- GDPR and company's policies compliance

And finally, in relation to them, PPC states their belief that by adopting 5G technologies along with implementing disruptive technologies (such as AI) many of the above introduced requirements are expected to be satisfied.

WHIRLPOOL

In Whirlpool's view, 5G technology, applied to I4.0 solutions may enable new applications not possible until today, mainly boosted by the possibility to achieve improved performance in terms of higher throughput and faster E2E response time, while also enabling the possibility of a reliable and cheaper assets' connectivity at the shop floor.

Commenting on the factors motivating the adoption of 5G for I4.0. Whirlpool makes a special remark to the security management that 5G connectivity implies vs. traditional Wi-Fi connectivity

Whirlpool expects that the generalized adoption of 5G for I4.0 in their industry is to start on year 2025 and, highlighting the following milestones along the journey towards its full adoption:

- Key assets connectivity achievement
- Disruptive technologies piloting (collaborative robotics, AI, big data, ...)
- Massive data analytics for process monitoring at shop floor level (vertical integration)
- Pilots' extension and roll-out
- Predictive analytics with horizontal integration within enterprise
- Prescriptive analytics supporting decision making

Whirlpool shares on the 5G application of Bosch Rexroth in the Fraunhofer Test Center Hannover, that it demonstrates the great advantage of 5G solutions in logistics for manufacturing companies, not only for autonomous navigation but also for the horizontal integration with other connected assets (machines, equipment, ...) in the industrial ecosystem.

With regards to deployment model options, for Whirlpool the preferred option for vertical applications deployment remains the local server in protected production network and edge implementation for process monitoring and control. Then, for analytics applications the central office solution with cloud technology is the preferred option. Finally, the hyperscaler option is often considered for Cloud applications to increase computation capabilities, when required.

About their view on NPNs, Whirlpool remarks that all the performance requirements have to be strictly comply with its security and privacy requirements, as a precondition for decisions on deployments.

In the subject of security and privacy challenges, Whirlpool shares that full compliance with internal security and privacy policies is a mandatory condition to proceed in the implementation for confidential and privacy data management and for GDPR compliance. The I4.0 5G solutions currently in the market or in development phase are under evaluation to validate their compliance with targeted requirements and their application limitations. Key requirements for additional security and privacy mechanisms are:

- Logical isolation mechanisms and physical radio layer protections mechanisms (ex. jamming protection).
  Actually, the current perimeter protection and access control have been widely used to protect the confidentiality of processes, operational data, users and equipment. While access from outside is strictly controlled, operational data flows to the outside have also been restricted. With 5G, this physical isolation is no longer maintained.
- Encryption and integrity protection mechanisms reinforcement. This is because a 5G telecommunications operator would not be part of the internal trust domain defined within a "closed" organization by the perimeter, the users, equipment and processes. Third parties are not typically allowed within the perimeter, except for certain remote maintenance tasks that do not impact real-time operations. Further operational boundaries within factories may be used to ensure segregation of operational duties and to protect privacy (need-to-know principle) in accordance with regulatory requirements.
- Regulatory compliance and associated certifications are major business imperatives. Each network configuration change or update needs to ensure continuity of compliance.
- Any 5G security mechanisms to be introduced need to interact and interoperate with legacy systems and processes over a long transition period, since in a production environment equipment and processes have long lifecycles.

FORD

With regards to the potential that 5G can unlock for new I4.0 applications and use cases, Ford stresses the importance of these 3 factors:

- Increased bandwidth for 5G: It enables considerably bigger data flows between machines and servers than earlier networks
- Very low delay of communications: The very low delay (or latency) of 5G communications allows the company to use remote processing servers and rely less on local or embedded computing as it was conventionally done.
- Outdoor and Indoor coverage: 5G enables smoother transition of outdoor-indoor communication between machines, systems and the network. That can open wide areas of applicability for AGV applications and traceability of asset parts.

Ford remarks that, above all, 5G is a wireless technology that removes the painful dependency of industry equipment to wired infrastructure (not flexible and very expensive, if available at all at the location). Then, 5G can also guarantee the levels of high reliability (for securing smooth synchronization of control processes within their set time-outs), and optimized UL date rates (to allow concurrent streaming of video from machines in the factory, such as AGVs) that I4.0 applications of many types demand.

Ford indicates that an especially relevant example of application of 5G to I4.0 is the E-BEAT project developed at Final Assembly plant, focused on battery and headlight traceability using 5G.

Ford foresees that the generalized adoption of 5G for I4.0 in their industry will take place between 2025 and 2029.

With regards to the deployment models considered, Ford focuses on Edge Computing (both Near and Far Edge computing options) and Hybrid Cloud models, as they could best adapt to the diverse requirements in performance, flexibility, security and costs of different I4.0 use cases.

ASTI

ASTI considers that especially the following I4.0 use cases do leverage 5G technologies:

- Remote control and remote maintenance of AGVs
- Remote commissioning
- Virtualization, and deployment of hardware controllers as MEC applications
- Wireless industrial field communications
- Safe collaboration between cells with robotic arms and AGV's

The following picture shows an example of the new PLC virtualization paradigm enabled by 5G, in the view and the experience of ASTI in this field.

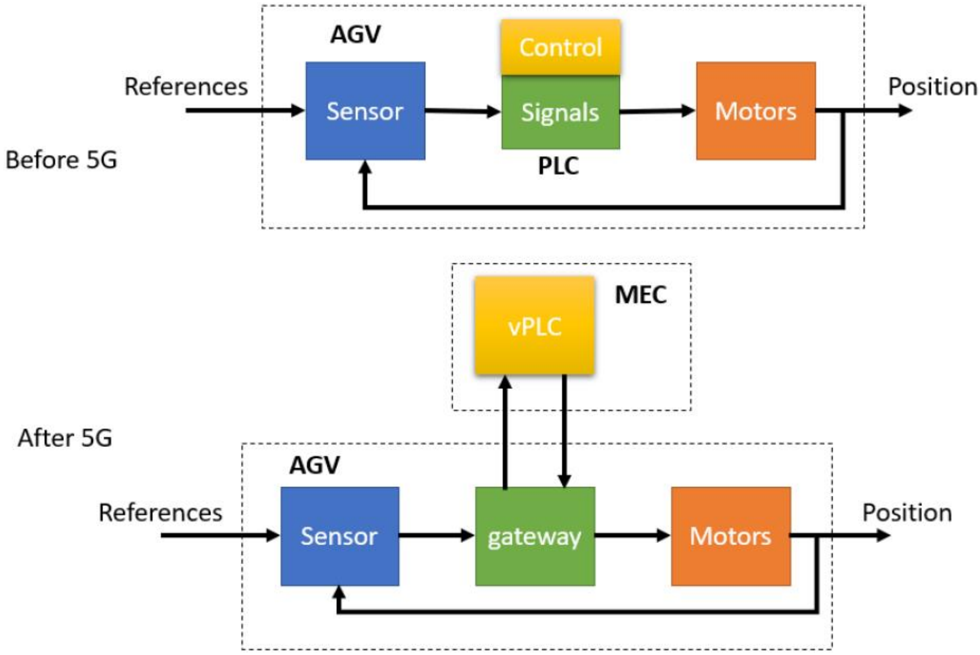

Figure 1. PLC virtualization paradigm enabled by 5G.

ASTI estimates that the generalized adoption of 5G for I4.0 will take place in the period 2025 to 2029, and shares that their key milestones in the process are the following:

- Development of software and hardware adaptions in the AGVs to enable the deployment of AGV and fleet management services as Edge applications (some relevant advances have been carried out in research projects)
- Experimental validation of software and hardware adaptions in laboratory and test networks (some relevant advancements have been carried out in research projects)
- Deployment of 5G networks in non-public networks providing 5G services to their customers
- Pilot tests in end user facilities progressing from involving a small number of AGVs to a large number of AGVs
- Long-term validation in end users' facilities in production, verifying 99% reliability reached.

With regards to deployment models, in ASTI's view, near edge deployments are considered for virtualization of hardware controllers currently embedded in the AGVs and other machines, such as PLCs and industrial PCs, and implementing AGV fleet management systems. These applications require low latency and high reliability, therefore 5G-URLLC would be beneficial. On the other hand, central offices and hyper-scalers are more suitable options for monitoring AGVs working in plants located in separated geographic areas, store information, analyze statistical trends, and apply machine learning techniques and forecast failures and future performance.

When addressing security and privacy requirements, ASTI comments that the internal data produced by the AGVs can provide very valuable information about how the production lines are working in real time. Moreover, the unauthorized access to the AGVs could cause stops of the production line and huge profit losses. Thus, security and privacy are two key aspects to enable AGV-based Industry 4.0 applications. The key security requirements indicated by ASTI are:

- All information transmission must be encrypted
- Any unauthorized access to the AGVs must be blocked
- It must be ensured that information flows between two systems cannot be manipulated.
- It must be possible to guarantee the authorship of all information flows.

The current plan to address this issue is to include specific communication devices and small embedded systems to incorporate encryption and security in all AGV communications.

3.3 Analysis of common requirements

The aggregated inputs provided by PPC, Whirlpool, Ford, and ASTI, responding to the tabulated questions included in the survey, are included in Annex II and also reflected here, along with a basic statistical analysis aiming at extracting the common and highest priority aspects and requirements of the ecosystem of vertical stakeholders of 5G-INDUCE.

Before proceeding to the review of the results and a basic analysis, a few words on the adopted methodology follow. As can be seen in the survey distributed to the vertical stakeholders of 5G-INDUCE (see Annex I) some questions allow for providing either selection (Yes/No) or scoring (1 to 5) inputs. The specific answers, from each respondent to these tabulated questions are kept private and not included in this report. Instead, the focus is on the aggregated/statistical analysis of all the answers. For that purpose, the following data is included in the Tabulated Answers Summary (see Annex II), being obtained through these simple procedures:

- For selection (Y/N) check boxes, the percentage of positive answers is obtained and displayed.
- For scoring (1-5) boxes three intervals have been established and are displayed in the report:
    - Score = 1-3: "Minor"
    - Score = 4: "Significant"
    - Score = 5: "Critical"

The results (available in Annex II) are included and briefly commented here, question by question.

Q1. What are the main competitive advantages that a company may achieve by adopting Industry 4.0 with 5G?

Q1: ADVANTAGES ADOPTING INDUSTRY 4.0	POSITIVE ANSWERS
PRODUCTION TIME REDUCTION	50.0%
OPTIMIZATION OF RESOURCES	100.0%
COST SAVINGS	75.0%
SECURITY	75.0%
EFFICIENT DATA FLOW	75.0%
MAINTENANCE THROUGH VR INTEGRATION	75.0%
OTHERS	

Table 3. Advantages of adopting I4.0.

100% of vertical stakeholders of 5G-INDUCE believe that the main competitive advantage that a company may achieve by adopting Industry 4.0 is the Optimization of resources. Also, very high consensus (75%) is expressed on Cost savings, Security, Efficient data flow, and Maintenance.

Q3. In what areas of the industrial process do you embrace Industry 4.0 with 5G?

Q3: INDUSTRIAL PROCESS	PLAN TO USE POSITIVE ANSWERS	UNDER EVALUATION POSITIVE ANSWERS
FACTORY AUTOMATION	75.0%	75.0%
SUPPLY CHAIN	100.0%	50.0%
QUALITY CONTROL	50.0%	50.0%
CUSTOMIZATION	25.0%	75.0%
MAINTENANCE	100.0%	50.0%
PLANNING	25.0%	50.0%
OTHERS		

Table 4. Industrial process.

100% of vertical stakeholders of 5G-INDUCE plan to embrace I4.0 with 5G for innovating on their industrial processes of Supply Chain and Maintenance. Also, very high consensus (75%) is expressed on having plans for Factory Automation processes, and on evaluating Customization processes.

Q4. When will Industry 4.0 with 5G have been mostly adopted by your industrial sector?

Q4: ADOPTION BY YOUR INDUSTRIAL SECTOR	POSITIVE ANSWERS
2022-2024	0.0%
2025-2029	100.0%
2030-2040	25.0%

Table 5. Adoption timeline.

100% of vertical stakeholders of 5G-INDUCE estimate that I4.0 enabled by 5G will be generally adopted, for their respective industrial sectors[2], in the period from year 2025 to year 2029.

Q5. What technologies do you consider critical for the Industry 4.0 transformation?

Q5: CRITICAL TECHNOLOGIES	% MINOR	%SIGNIFICANT	%CRITICAL	%SIGNIFICANT + %CRITICAL
EDGE COMPUTING	0.0%	25.0%	75.0%	100.0%
HYBRID CLOUD	50.0%	25.0%	25.0%	50.0%
PUBLIC CLOUD	100.0%	0.0%	0.0%	0.0%
5G eMBB	25.0%	50.0%	25.0%	75.0%
5G mMTC	0.0%	50.0%	50.0%	100.0%
5G URLLC	25.0%	25.0%	50.0%	75.0%
IOT/IIOT	0.0%	50.0%	50.0%	100.0%
WIFI	50.0%	0.0%	50.0%	50.0%
NETWORK SLICING	75.0%	0.0%	25.0%	25.0%
NETWORK EXPOSURE	75.0%	0.0%	25.0%	25.0%
TSN AND DETNET STANDARDS	50.0%	50.0%	0.0%	50.0%
AR/VR/XR	50.0%	50.0%	0.0%	50.0%
BLOCK CHAIN	50.0%	25.0%	25.0%	50.0%
QUANTUM COMPUTING	100.0%	0.0%	0.0%	0.0%
COMPUTER VISION	0.0%	50.0%	50.0%	100.0%
MOBILE ROBOTICS	25.0%	25.0%	50.0%	75.0%
MACHINE LEARNING	0.0%	0.0%	100.0%	100.0%
TACTILE INTERNET	75.0%	25.0%	0.0%	25.0%
3D PRINTING	25.0%	50.0%	25.0%	75.0%
OTHERS				0.0%

Table 6. Technologies.

[2] This question polls for the estimate for a reasonable timeline for the *generalized adoption of I4.0 over 5G at the respective Industry sectors* of the participants in the survey. Therefore, participants are not answering this question only for themselves (being most of them pioneers in I4.0 and 5G adoption, already nowadays) but assessing the trend for their Industry sector in general and considering the adoption of these new paradigms at large scale (i.e., becoming the new established standard). In that sense the answers to this question are not contradicting but complementing the state-of-the-art analysis featured in section 2, since it seems a coherent scenario that, evolving from the 140 classified mobile private networks by 2022 (as per GSA study [7]), the trend of continued adoption of 5G at I4.0 at the hundreds of thousands of large and medium manufacturing firms can lead to a foreseeable generalized adoption fulfilled in the period proposed by the participants (2025-2029).

The following technologies have been regarded as either Significant or Critical by 100% of vertical stakeholders of 5G-INDUCE: Edge Computing, mMTC, IoT, Computer Vision, and Machine Learning. Then, the following technologies have been regarded as either Significant or Critical by 75% of vertical stakeholders of 5G-INDUCE: eMBB, URLLC Mobile Robotics and 3D Printing

Finally, the highest ranked (most critical) technology enablers for I4.0 are, as per the inputs of the vertical stakeholders of 5G-INDUCE, Machine Learning (for 100% of respondents) and Edge Computing (for 75% of respondents).

Q7. What benefits can a company get by having human resources and machines cooperating with one another?

Q7: BENEFITS	% MINOR	%SIGNIFICANT	%CRITICAL	%SIGNIFICANT + %CRITICAL
REDUCE THE NUMBER OF EMPLOYEE HOURS DEDICATED TO THE MANAGEMENT OF REPETITIVE PROCESSES	25.0%	50.0%	25.0%	75.0%
INCREASE AUTOMATION OF THE PRODUCTION PROCESS	0.0%	75.0%	25.0%	100.0%
INCREASE PRODUCTION CAPACITY	25.0%	25.0%	50.0%	75.0%
INCREASE FLEXIBILITY	75.0%	25.0%	0.0%	25.0%
MULTIPLY PRODUCT QUALITY	50.0%	0.0%	50.0%	50.0%
INCORPORATE CUSTOMIZATION CAPABILITIES	100.0%	0.0%	0.0%	0.0%
DEDICATE THE WORK EFFORT OF HUMAN RESOURCES TO ACTIVITIES WITH GREATER ADDED VALUE	25.0%	0.0%	75.0%	75.0%
RAISE THE CAPACITY TO INNOVATE IN PRODUCTS AND SERVICES	25.0%	50.0%	25.0%	75.0%
HEALTH AND SAFETY	25.0%	50.0%	25.0%	75.0%

Table 7. Benefits.

The following benefits expected from the adoption of I4.0 for implementing new models of Human-Machine cooperation have been regarded as either Significant or Critical by 75% of vertical stakeholders of 5G-INDUCE:

- Reduce the number of employee hours dedicated to repetitive tasks
- Increase production capacity
- Dedicate the work effort of human resources to activities with greater added value
- Raise the capacity to innovate in products and services
- Health and Safety.

Then, more specifically, 75% of vertical stakeholders of 5G-INDUCE concur to regard the adoption of I4.0 as a critical factor for being able to dedicate the work effort of human resources to activities with greater added value.

Q8. If you are considering to engage in Industry 4.0 with 5G projects, what investment model would you consider?

Q8: INVESTMENT MODEL	% MINOR	%SIGNIFICANT	%CRITICAL	%SIGNIFICANT + %CRITICAL
OWN INVESTMENT	75.0%	0.0%	25.0%	25.0%
CO INVESTMENT	0.0%	100.0%	0.0%	100.0%
PUBLIC FUNDING	50.0%	0.0%	50.0%	50.0%
INVESTING IN EXTERNAL VENTURES	100.0%	0.0%	0.0%	0.0%

Table 8 Investment model.

100% of vertical stakeholders of 5G-INDUCE believe that the Co-investment model is significant for realizing 5G-enabled I4.0 initiatives, while 50% of vertical stakeholders of 5G-INDUCE regard public funding as critical for taking on I4.0 initiatives.

Q9. What options do you consider for vertical application deployment in the context of Industry 4.0 with 5G?

Q9: DEPLOYMENT OPTIONS	POSITIVE ANSWERS
LOCAL DATA CENTER (ON-PREM)	75.0%
NEAR EDGE	100.0%
CENTRAL OFFICE (TELCO)	100.0%
HYPERSCALER	75.0%

Table 9. Deployment Options.

100% of vertical stakeholders of 5G-INDUCE consider Near Edge and Central Office options for vertical applications' deployments for supporting I4.0, and 75% of vertical stakeholders of 5G-INDUCE additionally consider on-prem and hyper-scaler application deployment options.

Q10. What are your key requirements and expectations on non-public networks for Industry 4.0 and 5G projects?

Q10: REQUIREMENTS ON NPN	POSITIVE ANSWERS
NETWORK PERFORMANCE	100.0%
OPTIMIZE NETWORK RESOURCE UTILIZATION	100.0%
CUSTOMIZATION AND FLEXIBILITY	75.0%
SECURITY AND PRIVACY	75.0%

Table 10. Requirements on NPN.

100% of vertical stakeholders of 5G-INDUCE consider Network performance and Optimized network resource utilization as key requirements on NPN's for supporting I4.0, and 75% of vertical stakeholders of 5G-INDUCE also regard Customization and Flexibility as well as Security and Privacy as key I4.0 requirements for NPN's.

4 Identification of key 5G features in support of 5G-INDUCE

5G technology offers a high level of flexibility and programmability in network performance. In this section the key capabilities of the 5G infrastructure that will be deployed for 5G-INDUCE use cases validation will be presented, not only providing the overall approach but also focusing on the access, the core and the edge specific capabilities.

4.1 General 5G-INDUCE capabilities framework

5G technology plays an important role in networks, supporting demanding requirements such as high throughput, low latency, high reliability etc., allowing the design of advanced services. More details about the 5G-INDUCE requirements were provided in [9] and [1], where the need for 5G networks was clearly shown. The 5G network Infrastructure for the testing and evaluation of the 5G-INDUCE service platform is designed and implemented in view of fulfilling certain I4.0 end user requirements as well as supporting several complex and heterogeneous components, and technologies, with advance 5G capabilities such as network slicing, Network Function Virtualization Management and Orchestration, Slice Management and KPIs Monitoring. The targeted framework capability levels for 5G-INDUCE are depicted in Figure 2.

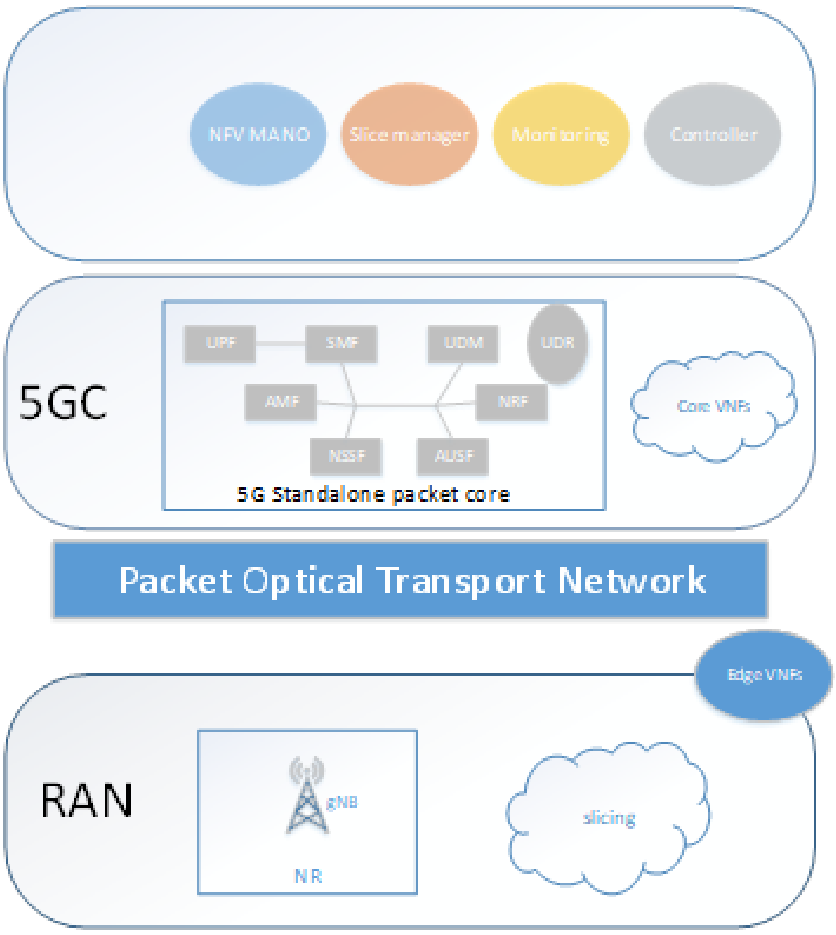

Figure 2. High-level presentation of the targeted infrastructure framework for 5G-INDUCE

The three main layers of the 5G-INDUCE infrastructure are: the Radio Access Network, which includes the gNB based on the NR technology and the Edge Cloud Computing infrastructure; the 5G Core, which includes functions such as AMF, NSSF UPF etc. and all the services that are hosted; the applications, such as orchestration, KPIs monitoring and slice manager.

This infrastructure is intended to support:

- 5G SA RAN Rel.15 and Rel.16
- 5G Core SA Rel.15 and Rel.16
- NetApps orchestration
- Network Orchestration
- Slicing support
- Edge computing
- Network KPIs monitoring
- 5G Virtualized Infrastructure (OpenStack/K8s)

4.2 Key 5G access capabilities

Within the scope of ITU recommendations for IMT-2020 systems, 3GPP provides complete system specifications for the 5G new radio (5G NR) access.

While initial 3GPP specifications enabled non-standalone (NSA) 5G radio systems integrated into previous-generation LTE networks, the scope of Release 15 expanded to cover 'standalone' (SA) 5G, with a New Radio system (NR) complemented by a next-generation core network.

- The 5G NSA architecture can be seen as, and has proven to be, an early and safe step towards "full 5G" deployment, where the 5G Access Network is connected to the 4G Core Network. In the NSA architecture, the (5G) NR base station (logical node "en-gNB") connects to the (4G) LTE base station (logical node "eNB") via the X2 interface.
- In the 5G SA architecture the NR base station (logical node "gNB") connects with each other via the Xn interface, and the Access Network (called the "NG-RAN for SA architecture") connects to the 5GC network using the NG interface. The NG-RAN consists of a set of gNBs connected to the 5GC (5G Core) through the NG interface, based on (and very similar to) the LTE's S1 interface. The overall architecture for the Access Network is shown in Figure 3.

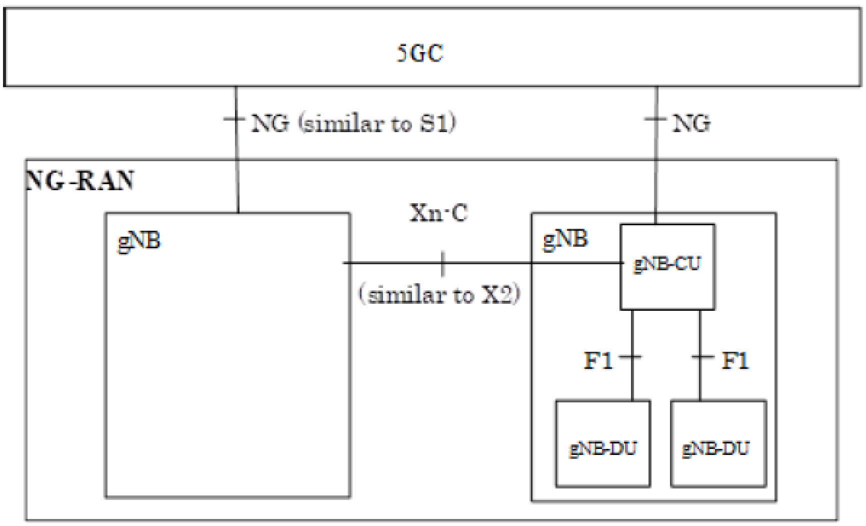

Figure 3. Overall Architecture of the Access network for 5G SA option.

An overview of key features of 5G NR follows

- New bands and increased bandwidths: NR can be deployed in a very wide range of bands both in existing IMT delivered intervals and in future bands. The differences between bands are very

pronounced for NR due to the very wide range of frequency bands. Frequency bands are divided into two frequency ranges:
    - Frequency range 1 (FR1) includes all existing and new bands below 6 GHz.
    - Frequency range 2 (FR2) includes new bands in the range 24.25-52.6 GHz.
- Massive MIMO & beamforming: Multiple-input and multiple-output (MIMO) is a key technology to improve throughput. It uses multiple antenna arrays both on the transmitter and on the receiver sides, as to enable multi-layer data transmission.
  NR supports multi-layer data transmission for a single UE (single-user MIMO) with a maximum of eight transmission layers for DL and four ones for UL. NR also supports multi-layer data transmission with multiple UEs on different layers (multi-user MIMO) with a maximum of twelve transmission layers for DL and UL transmission.
  Since NR supports multi-beam operation where every signal/channel is transmitted on a directional beam, beamforming is an important technique for achieving higher throughput and coverage especially, in high-frequency range.
- Multi-Services transmission: A very wide range of deployment scenarios can be considered for 5G; from large cells with sub 1 GHz carrier frequency up to mm-wave deployments with a large spectrum allocation.
  A flexible OFDM numerology (µ) with subcarrier spacings ranging from 15 kHz (used in LTE) up to 240 kHz is considered. Different numerologies can be used simultaneously in a cell. Compared to LTE, higher carrier spacing allows achieve lower latency in the air interface.
- Native end-to-end support to Network slicing: 5G and in particular NR support and facilitate Network Slicing serving simultaneously very different business or customer needs from a single service-based architecture.
  The characteristics of each slice are defined in terms of QoS, bit rate, latency, etc. For a given slice, these characteristics are either predefined in the 3GPP Standard or are operator-defined. There are three types of pre-defined slices:
    - Type-1 - dedicated to the support of eMBB,
    - Type-2 - designed for URLLC, and
    - Type-3 - meant for mMTC support.

  These predefinitions allow inter-PLMN operation with reduced coordination effort between operators.
  As for the operator-defined slices, they may enable more differentiation among Network Slices.
  A dedicated Network Function in 5G Core Network is introduced for handling slices, the Network Slice Selection Function (NSSF), which enables the selection of the appropriate slice(s).

For further information and full details on the standards above summarized please refer to [10] and [11].

After reviewing the key architectural concepts and technology innovations for 5G Access capabilities, it is also important, especially considering the NetApps developer viewpoint and the end-user verticals, to understand the performance implications of the introduction of 5G, and the potential optimization when selecting specific configurations and frequency ranges and bandwidth allocations.

To get a glimpse into this aspect the research performed by 5G-PPP TMV Working Groups is leveraged and recommended since it provides detailed specification of KPIs enabled by 5G NR, along with best practices of configurations and their learnings, across several 5G-PPP projects (see [10]). For the purpose of this report, a high-level summary of basic concepts involved and key indications related to KPIs, which are thoroughly described in such 5G-PPP literature, follows here. As a necessary clarification for this subject, introduced within this section of 5G access capabilities, the delivery of the performance levels described is only possible through the cooperation and integration of a 5G full chain from the access to the transmission and core, but due to great influence of the access capabilities they are reviewed in this subsection.

The broad set of 5G KPIs considered by 5G-PPP projects extend to the following: peak data rate for uplink, peak data rate for downlink, user experience data rate for uplink, user experienced data rate for downlink, user plane latency, control plane latency, reliability, and area traffic capacity.

- Peak data rate is the maximum achievable data rate under ideal conditions (in bit/s), which is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e. excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times).
- User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e., the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time.
- The user plane (UP) latency is defined as the delay necessary to transmit data between the gNB and the UE. It consists of the transmission (τ1), HARQ request (τ2) and retransmission (τ3) between both entities.
- The control plane (CP) latency in 5G NR refers to the UE transition time required from inactive to connected state. Reliability relates to the capability of transmitting a given amount of traffic within a predetermined time duration with high success probability.
- Reliability is the success probability of transmitting a layer 2/3 packet within a required maximum time, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface at a certain channel quality.
- Area traffic capacity is the total traffic throughput served per geographic area (in Mbit/s/m2). The throughput is the number of correctly received bits, i.e., the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time.

So, there are, theoretically, a space of 6 dependent variables and 7 independent variables. That implies relevant flexibility, but at the expense of a degree of complexity associated that may be overwhelming.

For the scope and priorities of 5G-INDUCE such space is simplified to the one delimited by the selection of KPIs under common consideration across ExFas (UL and DL User Data Rate, Coverage and Latency and Reliability), and of the influencing factors enumerated within the values and ranges advised/supported by regulation and technology availability (for both networks and UEs). The basic considerations for this applied context are:

- User data rate: First of all, this KPI is clearly correlated to the allocated bandwidth (in turn limited in practice by regulation and auctioning by the national Governmental organizations, commonly restricted to values in the order of 20 MHz to 80 MHz for Sub 6 GHz, and typically up to 100 MHz on mmWave). The more the bandwidth the higher the level of both peak and User Data Rate that can be delivered. This correlation is a double-edged sword to be carefully dealt with, since the potential availability of larger bandwidth for experimentation activities can lead to performance levels of User Data Rate that may not be further replicated in the actual exploitation environments subjected to a more limited bandwidth (due to national regulation and auctioning processes, mainly). So, the recommendation for 5G-INDUCE access capabilities configuration in this regard is that a set of BW configurations are used for reaching a safer evaluation of the performance of the network and the induced effect on the behaviour and performance of the E2E use cases.

Along the same line of thinking special attention has to be paid to the selection of the frequency ranges to deploy/utilize in 5G-INDUCE. The attractiveness of mmWave as a frequency range potentially offering much higher bandwidth than Sub 6 GHz bands has to be balanced with the lack of regulation and licensing processes in place in most EU countries, and also with the slow uptake of CPEs supporting these bands and delivering acceptable performances for large bandwidths. Those considerations make us recommend Sub 6 GHz, and more specifically bands in 3.5 GHz and 3.7 GHz as the priority option for deployment that can secure a good enough level of bandwidth for guaranteeing high user data rates.

Then, the effect on user data rate levels induced by subcarrier spacing, modulation and MIMO configurations is veery well assessed in [10]. The recommendation for 5G-INDUCE is to configure these parameters within values that may be comparable to those of commercial deployments of 5G networks (establishing a safe baseline for estimates that can be extrapolated to the environments of exploitation) and whenever necessary explore on the influence of some of these parameters.

Finally, a most interesting factor to consider is the configuration of TDD patterns, given their straight influence on the optimization of UL and DL peak and user data rates. For some I4.0 scenarios DL should be optimized, whilst for others a minimum DL should be guaranteed. So, the recommendation is that 5G-INDUCE 5G infrastructures may allow for flexible configuration of this parameters, so as to better adapt to the use cases in scope.

- Coverage: it is an essential aspect to be considered and planned for from the onset of projects. In a project like 5G-INDUCE the variety of vertical locations and characteristics advises careful planning of the choices of frequency ranges and the location of access network elements, among other factors, especially when the majority of the traffic is expected in indoor areas.

  As already commented, and given that the higher the frequency ranges the lower the penetration and range, the trade-off solution for the types of premises and scenarios like those of 5G-INDUCE is to prioritize the deployment of access network systems operating on mid bands, and planning for indoor coverage and power, etc. as well as considering potential densification for meeting the demands in other KPIs, such as Data Rates
- Latency and Reliability: for these KPIs, the access network plays a central role, achieving an unparalleled level of performance for a mobile communication technology serving multiple users. The contention of latency (and reliability, as defined above) in the air segment is a native benefit of 5G NR, and the effect of access network configurations on it is limited, only remarking the influence of Scheduling and that higher bandwidths favour lower latencies.

  Complementarily, for these KPIs, when considering the E2E and RTT latency of communications of the actual uses cases, the major factor of influence will not be radio access parameter but mainly, the choices of deployment of UP functions and applications (on-prem, far-edge, near-edge, central office). The analysis of scenarios on that dimension included in [10] provides with clear segmented recommendations for consideration in projects like 5G-INDUCE, advising near-edge options as a good trade-off for maximizing performance and efficiency of resources and expenditures.

4.3 Key 5G core capabilities

The main part of the 5G-INDUCE architecture is the 5G Packet Core. It is based on the SA architecture option, as it is presented in Figure 4 for the case of Rel16 The 5G system is designed to offer flexibility and virtualization capabilities including multiple slices, Virtual Network Functions and the ability of adapting to the services as network slices for each type of usage.

The main functions of the 5G Core are:

- AMF (Access and Mobility Management Function: It is similar to MME in 4G networks. It manages UE registration and initiates authentication.
- AUSF (Authentication Server Function): It retrieves authentication vector from UDM and passes it to AMF.
- SMF (Session Managements Function): It is similar to P-GW in 4G networks.
- UPF (User Plane Function): It is similar to P-GW in 4G networks. It is responsible for data routing and QoS enforcement.
- UDM (Unified Data Management): It is similar to HSS in 4G networks. It holds the subscribers information and the security keys for access authorization.
- PCF (Policy Charging Function): It is similar to PCRF in 4G networks. It is responsible to decide how a flow is charged.
- AF (Application Function): It is an external server which could be a node of another network. For example, it could be an IMS node which connects IMS to a 5G network.
- NSSF (Network Slice Selection Function): it selects the set of slices that the UE uses.

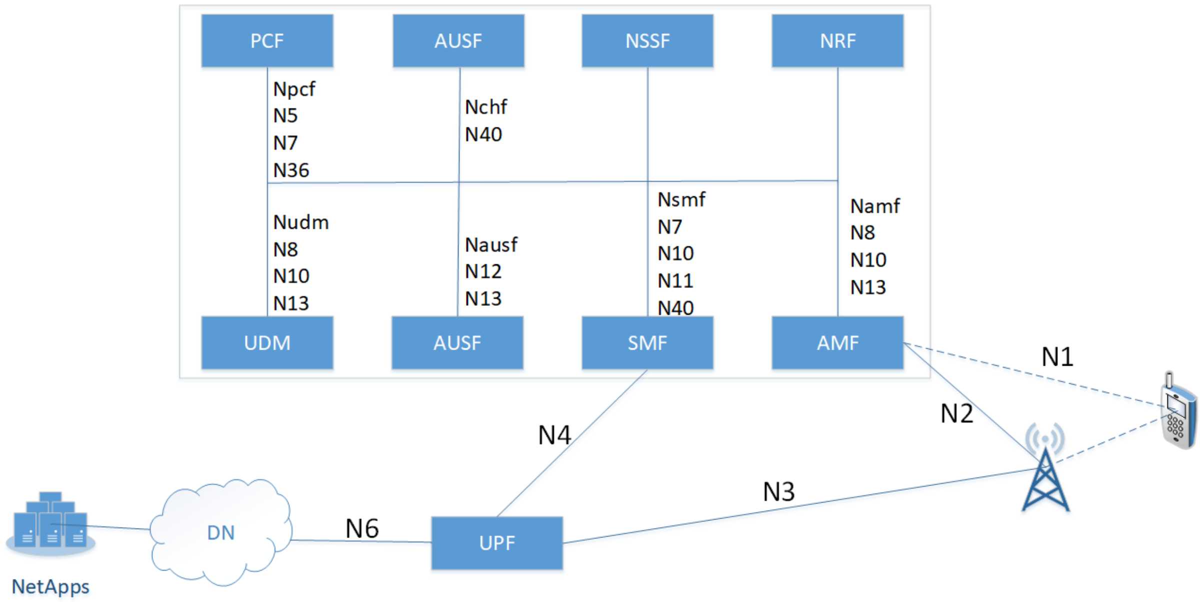

Figure 4. 5G Core functions and supported interfaces.

5G Core will also support APIs and interfaces in order to be interconnected with the 5G-INDUCE platform and the network Orchestrator, allowing the slicing and the NetApps management:

- N1: Interface between the UE and the AMF
- N2: Interface between the RAN and the AMF
- N3: Interface between the RAN and the UPF
- N4: Interface between the SMF and the UPF
- N6: Interface between the UPF and a Data Network

Additionally, monitoring tools are planned to be installed in order to measure networks KPIs and confirm the network performance. In cases where testbeds do not include a default monitoring mechanism, several external monitoring tools (probes and a management server) are planned to be installed. The monitoring tools could allow the accurate measurement of both the network parameters monitoring and the time relevant parameters (such as packet loss or latency).

4.4 Key 5G edge capabilities

Edge computing brings application hosting from centralized data centers down to the network edge, and closer to users. Therefore, edge computing plays an important role in low latency applications such as AI, IoT, AR and VR and cloud applications. Moreover, edge computing is essential for Industry 4.0 services since many intense processes within the industries are strongly dependent on low latency handling approaches.

There are two main categories of edge computing:

- The edge data centers with application processing features are edge nodes where application developers could create their application components and be hosted.
- Multi-access Edge Computing (MEC) is a network edge computing architecture standard which provides network features and functionalities closer to the end user.

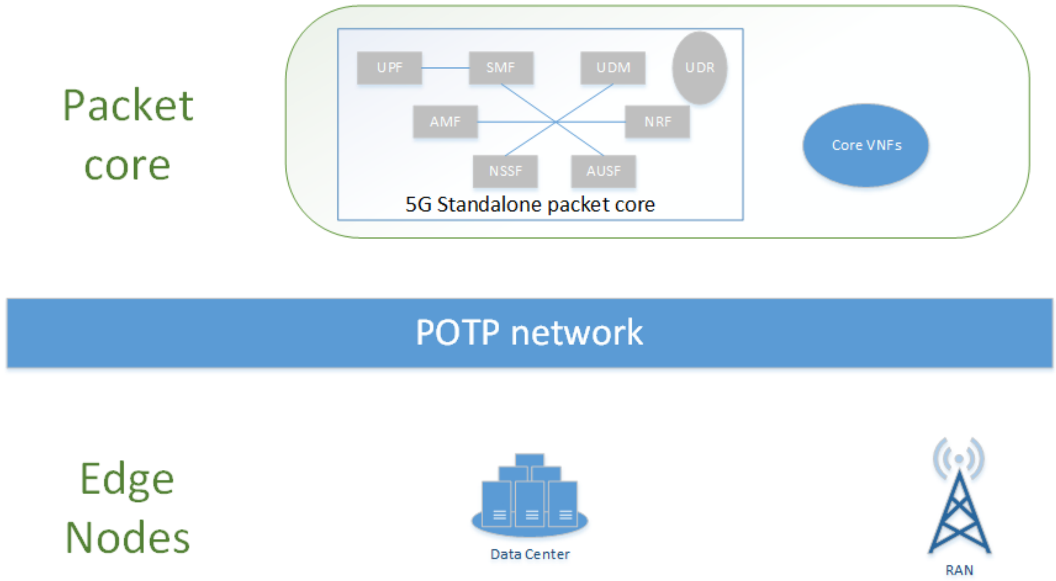

Figure 5. System topology with different edge nodes.

Focusing on MEC, it may be located in the edge, as it was mentioned before. However, there is also a possibility to be hosted in a central data network, depending on the network operator's design. The decision is based on several parameters such as the available site facilities, supported applications and their requirements, measured or estimated user load etc. There are 4 different topologies for the physical location of the edge nodes, as they are presented in Figure 6:

1. MEC and the local UPF collocated with the Base Station.
2. MEC collocated with a transmission node, possibly with a local UPF.
3. MEC and the local UPF collocated with a network aggregation point.
4. MEC collocated with the Core Network functions (i.e., in the same data center).

It's also worth reminding that 3GPP standards for 5G SA provide with ample flexibility to deploy, and even cascade the UPF, thus allowing for, in turn, flexibly deciding on the locations where Edge Computing centers may be located for hosting vertical applications, as depicted in Figure 7.

In 5G-INDUCE these topologies are analysed, and the final decision about the adopted topology for each ExFa will be described in WP5 deliverables.

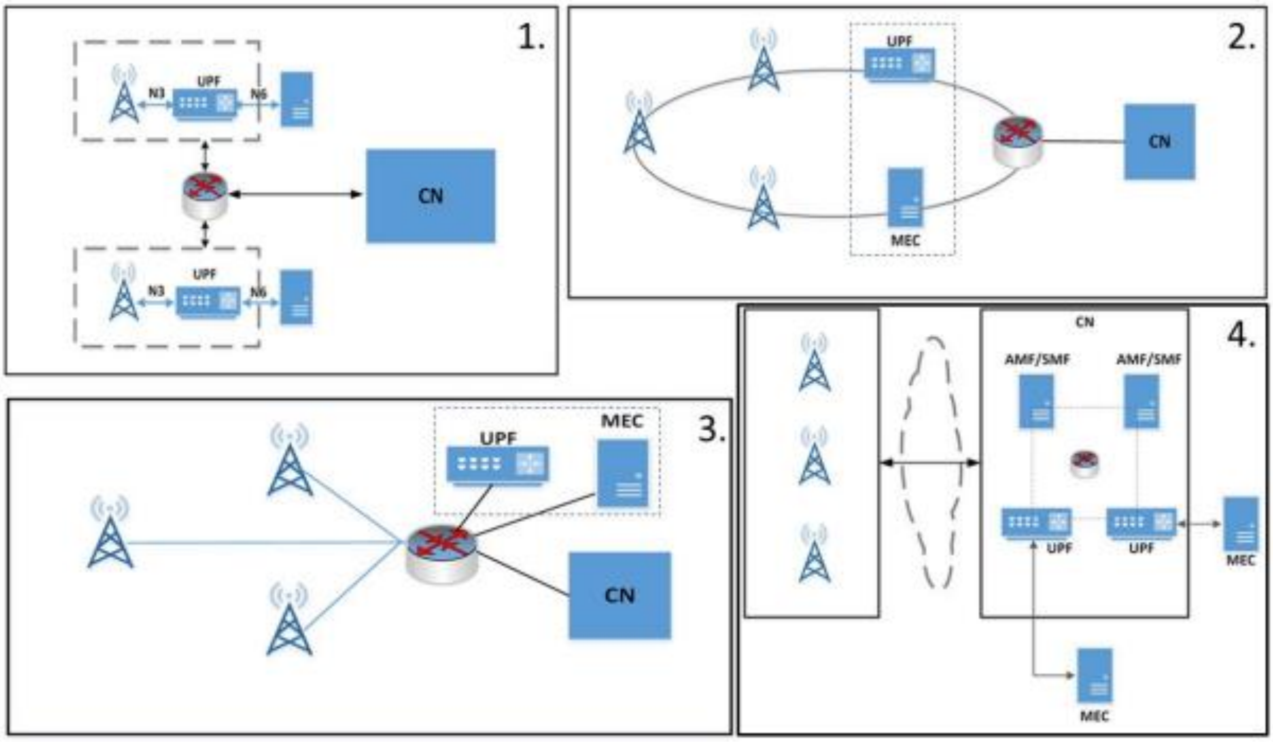

Figure 6. Physical location of the edge nodes.

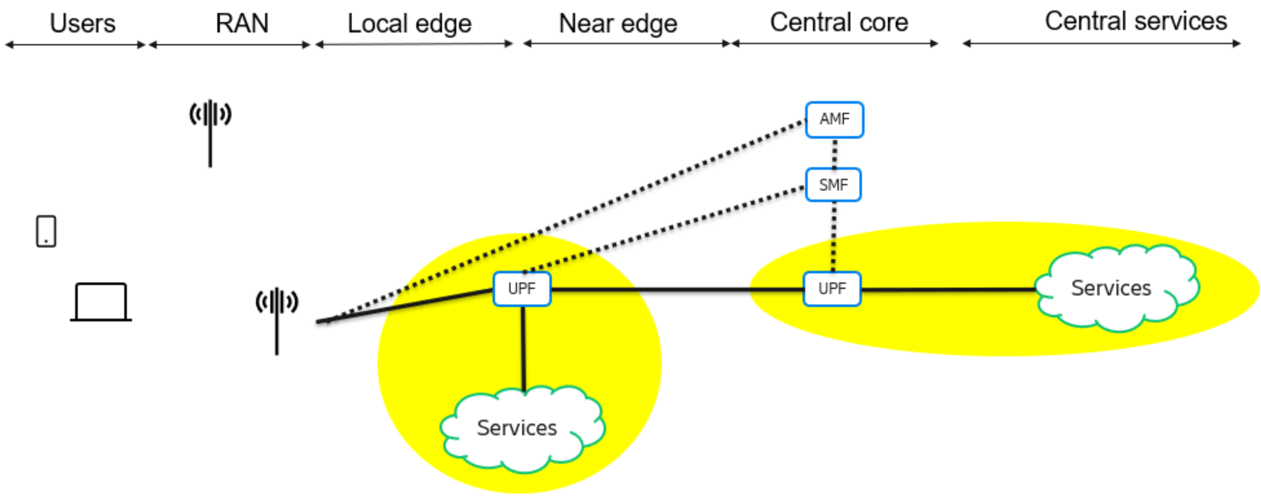

Figure 7. Simplified view of 3GPP Standard 5G SA model for User Plane & Services.

5 5G deployment at 5G-INDUCE: strategy and roadmap

This section provides the key deployment characteristics of the 5G-INDUCE platform over the targeted experimentation facilities (ExFas). It then proceeds in more detail with the adopted strategy and roadmap for each of the three ExFas in view of future deployments and needs.

5.1 The 5G-INDUCE platform design with respect to the underlying ExFas

For the needs of 5G-INDUCE use cases validation, three experimentation facilities are deployed, located in Spain, Italy and Greece. These facilities incorporate the 5G-INDUCE platform through which the NetApps are installed and managed, allowing the proposed services to be deployed and tested at each site. The generalised high-level architecture for the experimentation infrastructures is presented in Figure 8 and includes the 5G-INDUCE platform, the 5G testbeds and the vertical facilities where the use cases take place.

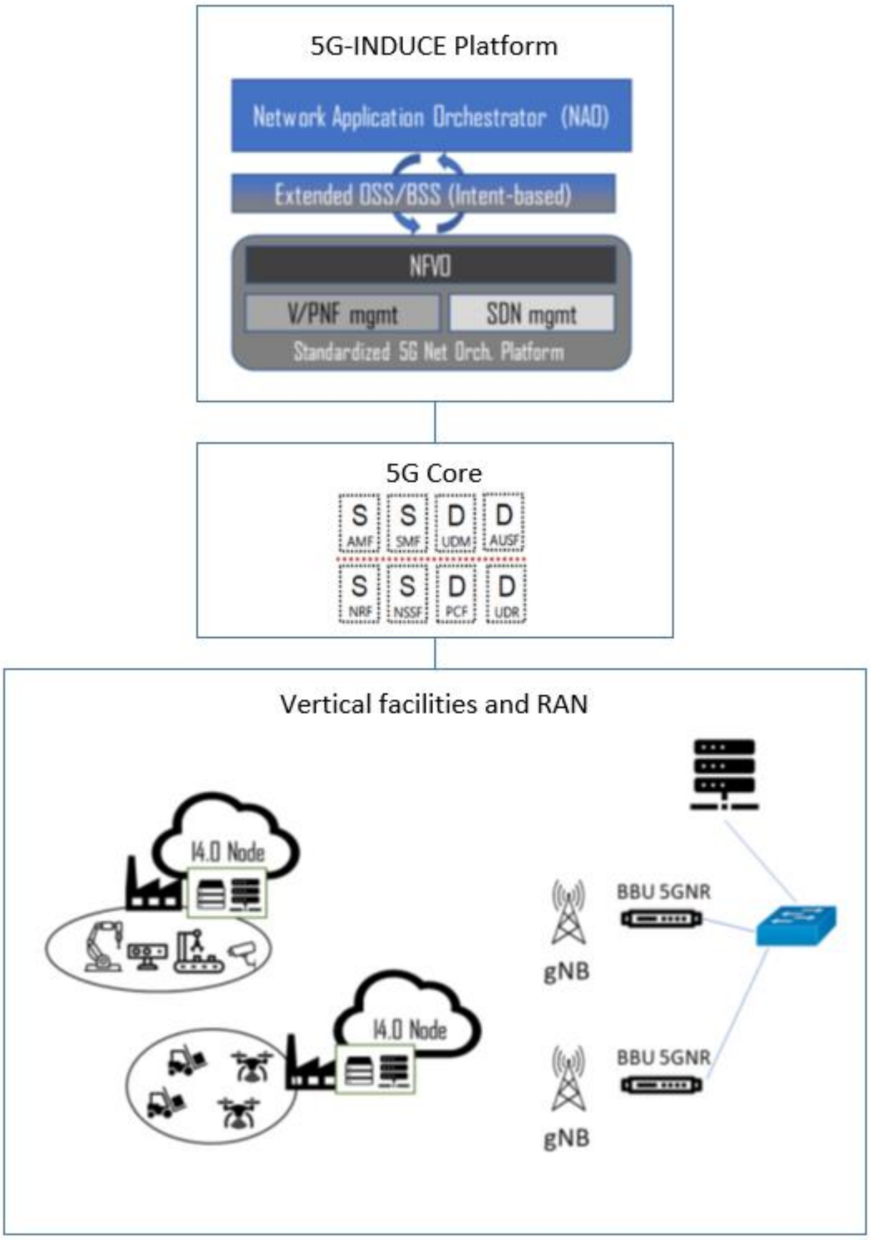

Figure 8. Common high-level architecture

The 5G-INDUCE platform provides the interface to the end users for the deployment and runtime management of the NetApps according to the requirements defined in [9]. The NetApps are deployed in the form of service graphs which are next translated into the appropriate slice requests through the slice manager part of the OSS, while taking into consideration the requested target location for the services and the operational resources required per NetApp component. After deployment, the runtime management of NetApps is achieved through the NetApp orchestrator and according to defined policies. In its northbound interface, the OSS interfaces with the supporting orchestration platform of the infrastructures by considering each testing infrastructure a different administrative domain, each of which is assigned with an instance of the southbound OSS. The administrative domains associated with ExFas are classified as:

- Fully programmable facilities, such as the DevOps testbed, where the full module stack of the OSS is enabled.
- Partially programmable facilities, which embed their own proprietary (black box) 5G management layer, but with a deeper programmability on edge computing resources and
- Nonprogrammable facilities, which are only manageable by their own proprietary control-management plane, and where only static configurations/resources will be assigned to 5G-INDUCE.

The adaptation of the platform to a variety of infrastructures is key to the 5G-INDUCE design and the creation of a valid roadmap towards actual deployments as the overall 5G infrastructure deployment at different sites progresses.

Detailed descriptions of the platform structure, the OSS functionalities and the southbound interfacing options with the experimentation facilities are provided in section 3 of [9] as well the initial platform development report in D3.4; (the latter is available only upon request).

5G-INDUCE testbeds with programmable features adopt Rel-15/Rel-16 standards providing several common functionalities. The infrastructures in these cases are implemented so that the NetApp deployment and management (through 5G-INDUCE platform) are seamlessly integrated and serve the vision and needs of the representative Industry 4.0 sites, as defined in 5G-INDUCE. At the same time each ExFa testbed will have the ability to support some common networking functions that are necessary. More specifically, the 5G-INDUCE testbeds will support:

- Slicing: multiple slices will be available, which will be selected and used fulfilling the needs of the UEs and the use cases.
- Monitoring: monitoring tools are planned to be used to provide network KPIs measurements such as: Throughput (User Date Rate), Latency, Reliability (packet loss), and Jitter.
- Orchestration: APIs will be available, in order to interconnect the 5G packet core with the orchestrator, allowing the slicing selection mechanism.

5.2 5G deployment strategy and roadmap in ExFa -ES

The Spanish 5G Experimentation Facility infrastructure is deployed with the goal to validate and showcase the developed network applications over a real industrial 5G environment. The main experimentation field is a large industrial facility, where Ford operates, located in Almussafes (Valencia, Spain). The experimentation facility includes three use cases, the *Autonomous indoor fleet management,* the *Smart AGV operation based on human gesture recognition* and the *VR immersion for AGV control.* These use cases imply indoor transport in Ford warehouses, coordinated with outdoor transportation in which the indoor AGV is replaced by the outdoor AGV. Figure 9 shows the AGV path in Ford premises.

Figure 9. AGV itinerary in Ford Factory.

Private 5G network deployment strategies in Spain

The infrastructure deployed must grant 5G coverage on this area, as well as the computing resources needed for running the use cases applications. This section details the actual implementation of such infrastructure, a solution that includes a distributed 5G network between 5TONIC lab in Madrid (Spain) and the already mentioned Ford factory in Almussafes, and is also connected to the CNIT premises in Genoa (Italy) for the applications orchestration. Figure 10 shows how the different components are distributed along Ford, 5TONIC and CNIT facilities.

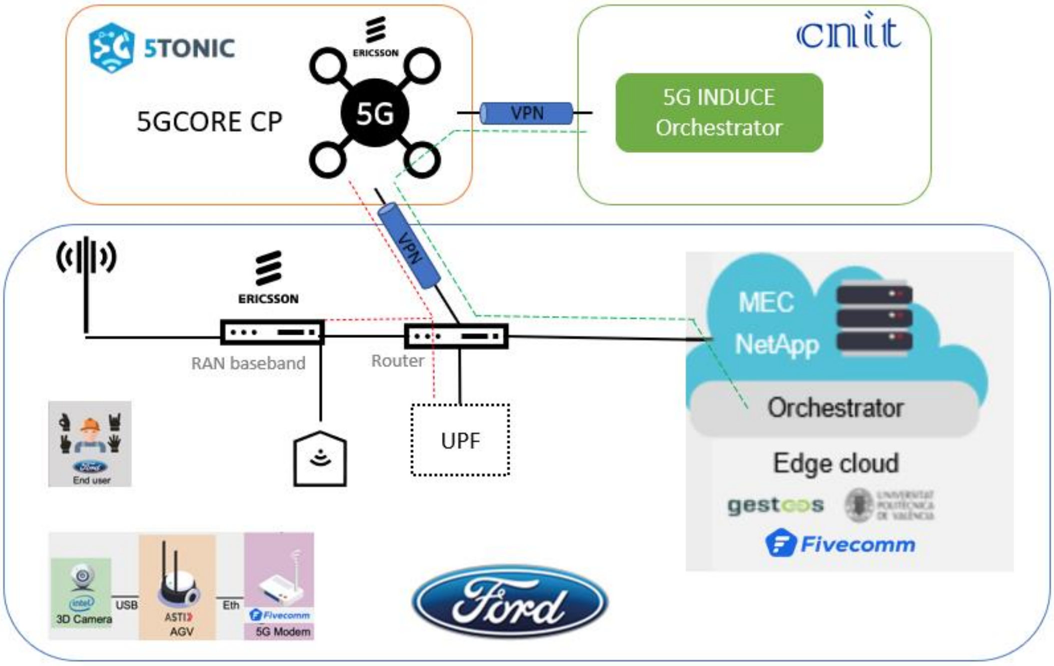

Figure 10. Valencia ExFa - Infrastructure distribution diagram.

The 5G-INDUCE NetApps software is deployed on dedicated compute servers located at Ford facilities. The orchestration of the NetApps is triggered from the central 5G-INDUCE Orchestrator at CNIT premises, connected to 5TONIC lab, which is in turn interconnected to Ford premises.

The selected architecture option is 5G SA, which is deployed in a distributed way. The RAN and the user plane function (UPF) are installed at Ford premises, while the rest of the 5G SA Core (control plane) is installed at 5TONIC. In this way, there is 5G coverage at Ford premises providing connectivity to the user end devices. The 5G RAN equipment splits the user plane traffic and the control traffic. The use cases traffic is directed towards the vertical applications executing also locally at Ford premises, so that it remains geographically close to the end user devices, keeping the latency very low. Complementarily, the control and management planes of the 5G equipment are done from a remote location (5TONIC lab in Madrid, 350 km away from Ford factory), as it does not require as low latency and high-speed levels as those of the local user plane.

Two areas of coverage are provided, one provided by all the 5G radio DOTs (Ericsson's antennas for indoor coverage) inside the factory, and one provided by the outdoor antenna, both operating on 3.5 GHz (50 MHz bandwidth). Five radio DOTs using Ethernet connection and the RADIO 4408 + Antenna 6524 (outdoor antenna) connected by optic fiber so as to cover the AGV itineraries (see Figure 11).

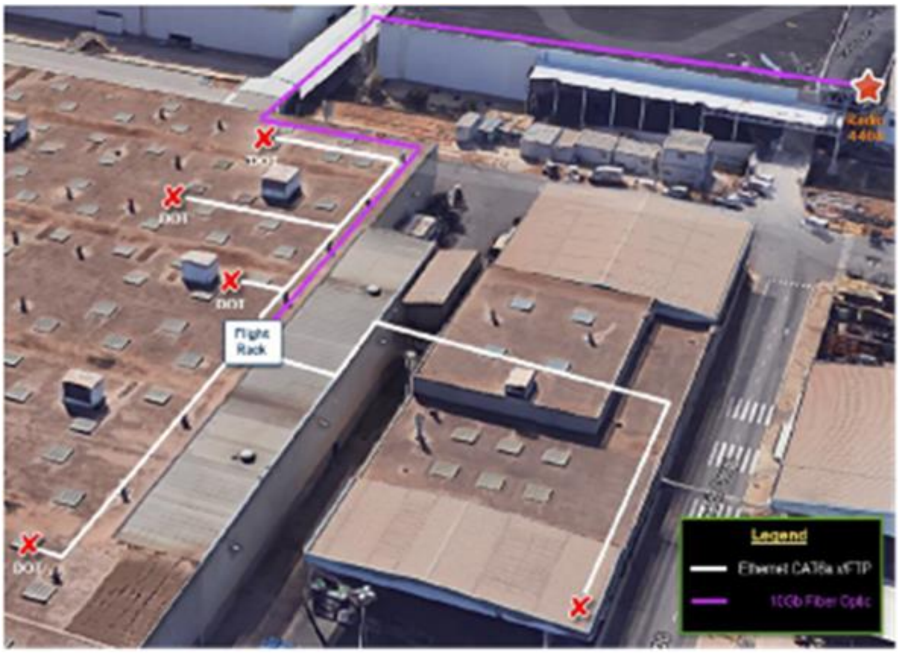

Figure 11. Ericsson antenna's location.

Figure 12 shows all 5G RAN equipment and the Dell Servers required for the UPF and for the applications installed at Ford Factory. 5G TDD requires a time and phase synchronization signal that is provided by a GPS antenna installed on the roof of the building. GPS synchronizes the router 6675 installed in the 5G SA flight rack and converts this equipment into a master clock that distributes the synchronization signal to all the other equipment in the flight rack in addition to providing regular data routing tasks. The router 6675 redistributes the synchronization signal to all the other equipment in addition to providing regular packet routing tasks.

The equipment introduced above (5G RAN + Dell Servers) is installed within a rack at Ford factory. The Ericsson RAN products are: a Router 6675, a 5G SA Baseband 6630 (outdoor cell), a 5G SA Baseband 6630 (indoor cell), a 5G Indoor Radio Unit (IRU) and a DPS850B-48-3 2.55 kW power source unit (PSU). Moreover, there are a Dell server for UPF and a Dell server for the NetApps.

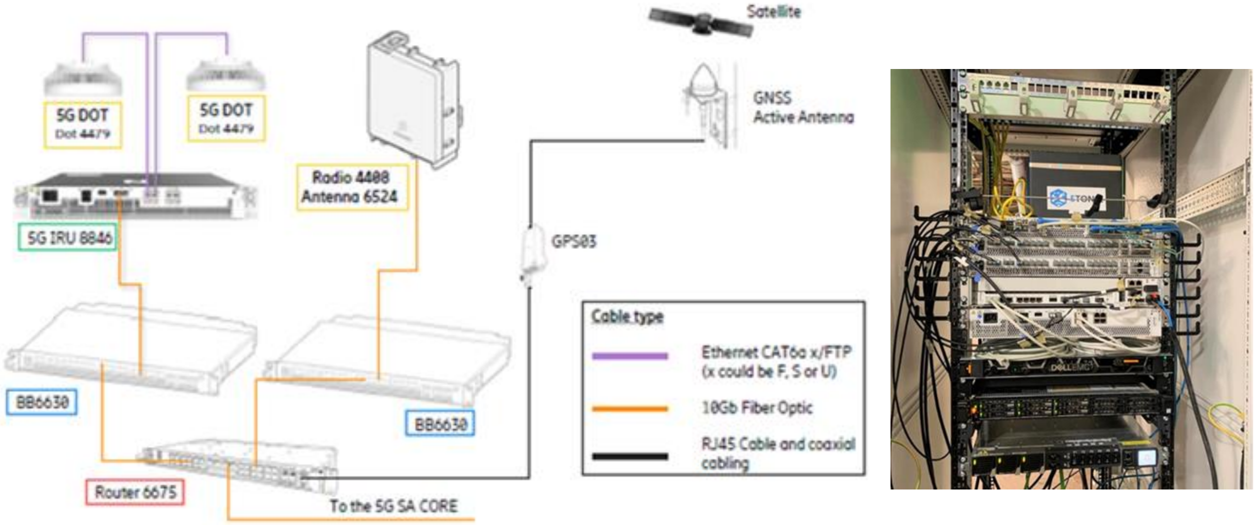

Figure 12. 5G RAN at Ford Factory - 5G Rack.

The DOTs are placed on the upper part of the columns of the Ford factory, as shown in Figure 13.

Figure 13. 5G DOTs antennas installation at Ford Factory.

Prior to the actual deployment of the base stations preliminary analysis were carried out using an iBwave design program, in order to determine and assure the needed coverage level to cover the AGV itinerary. Figure 14 shows the RSRP level serving by the radio DOTs and the Radio 4408 during the coverage tests.

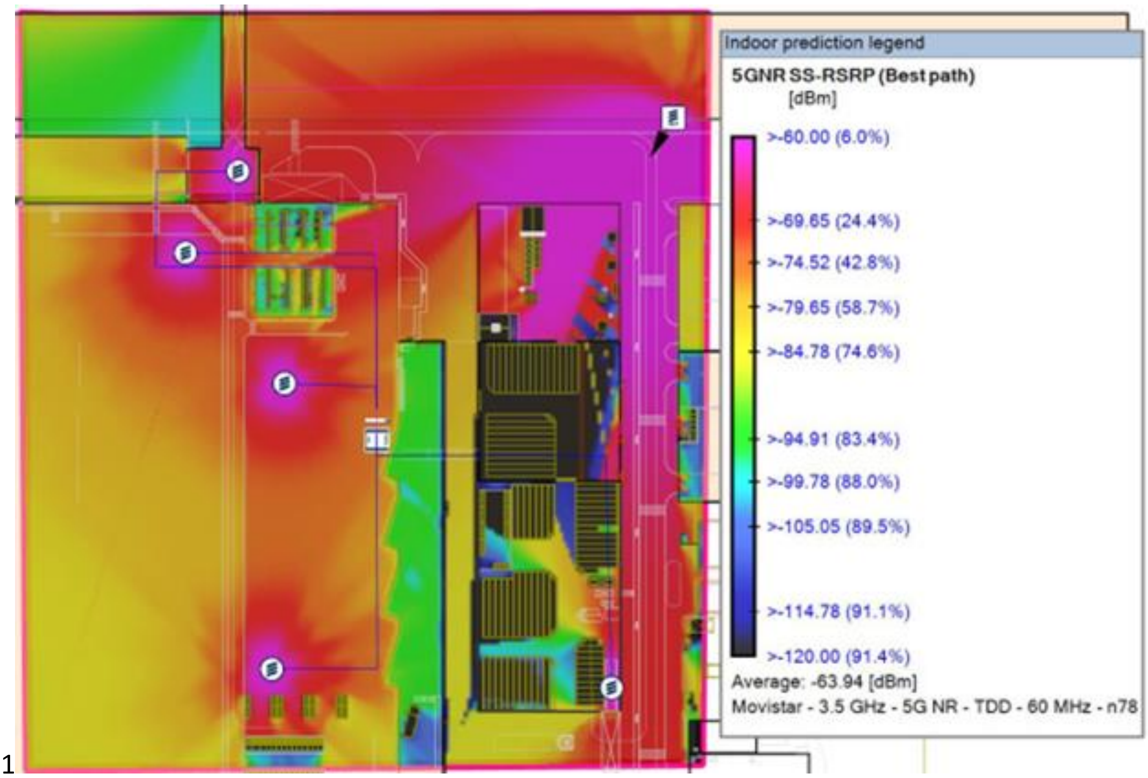

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Figure 14. 5G Coverage preliminary analysis.

Deployment roadmap for ExFa-ES in accordance with the overall strategy

The 5G deployment roadmap for the Spanish ExFa bases on three major milestones:

1. Q1 2022 – Deployment of 5G Rel 16 infra at 5TONIC lab, and integration and validation at 5TONIC lab of the portable unit including RAN and UPF to be deployed at Ford premises. That has allowed to test the 5G setup and configurations end-to-end, before actually distributing the components to the locations involved (Madrid and Valencia), and also to perform Use case integration and early validation in advance. The coverage in 5TONIC is based on radio dot units for indoor, operating on Sub-6 GHz n78 band, with 50 MHz bandwidth.
2. Q2 2022 – Deployment of 5G RAN and UPF at Ford premises in Valencia, along with establishing the interconnection and VPN between 5TONIC (Madrid) and Ford (Valencia). The deployment also includes the support for deployment of NetApps at Ford premises. The coverage in Ford is based on radio dot units for indoor, as well as on RADIO 4408 + Antenna 6524 for outdoor, all of them operating on Sub-6 GHz n78 band, with 50 MHz bandwidth.
3. Q4 2022 – The set-up described above might be complemented in two optional ways, depending on the needs and actual results of the validation of the use cases involved. On the one hand, in order to enable comparative tests, a mmWave kit could be also deployed and integrated in the ExFa. On the other hand, in order to validate flexible models for deployment, the NetApps –or some of them- could (alternatively to the current local deployment in the far edge) be deployed on near edge or central office options. Both options are open for further analysis and decision along the second half of 2022 and based on validation results and/or opportunities for innovation that could be identified, confirmed or discarded.

5.3 5G deployment strategy and roadmap ExFa-GR

The 5G testbed that will be deployed in Greece for the needs of 5G-INDUCE project will be in Athens. It includes network components based on the SA Rel. 16 architecture, the orchestration layer, the proper user equipment as well as the software and hardware that is required for the NetApps development.

The use cases that will be validated using the Greek testbed, will be in PPC premises in Glyka Nera, Athens, where the RAN will be deployed. The packet core as well as the rest of the required hardware and software (eg orchestrator, NetApps platform) will be located in OTE premises, in Marousi, Athens. The distance between the two sites is about 19km.

Private 5G network deployment strategies in Greece

The Athens 5G testbed is installed to support use cases 4, 5 and 6 validation tests. More specifically, the trials will take place in PPC premises where the RAN is installed. The area that should be covered includes outdoor and indoor parts of the PPC facilities. Therefore, the use of 4 indoor Radio Dots (Figure 15) and 1 outdoor ERS4408 (Figure 15). Additionally, a BBU and an IRU are installed on the trial site (Figure 16), connected via FO with the radio units.

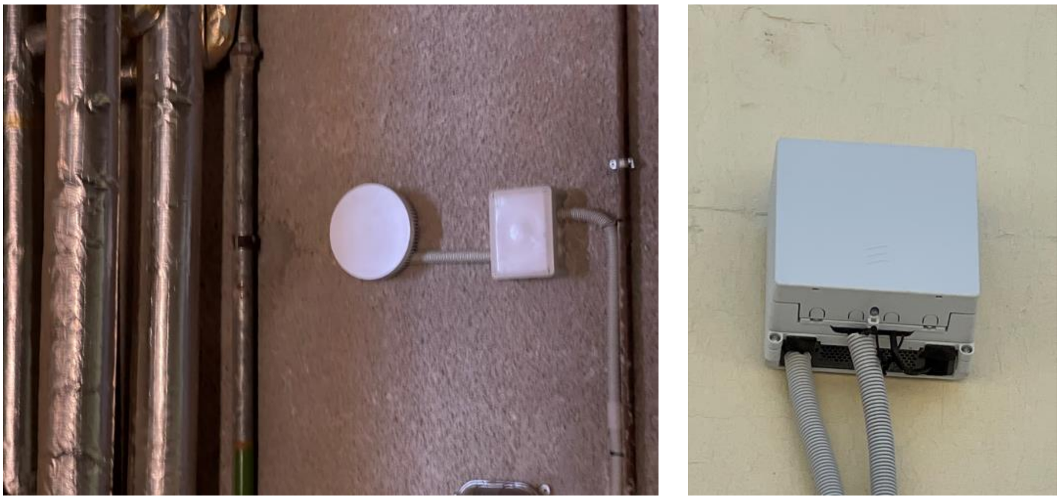

Figure 15. Indoor Radio Dot -Outdoor ERS4408.

Figure 16. BBU and an IRU on the trial site.

The packet core is located in OTE premises based on the 5G SA Rel. 16 architecture, using Athonet Griffone R2.0, which is an enhanced implementation of network functions.

Type	Manufacturer	Model	Information	Quantity
Radio Unit	Ericsson	ERS4408	4x4 MIMO, Carrier Aggregation and 256 QAM	1
Radio Unit	Ericsson	Radio Dots	4x4 MIMO, Carrier Aggregation and 256 QAM	4
Network Equipment	Ericsson	6630	Baseband Unit, 15 CPRI/9 eCPRI, LTE+NR with up to 12 CCs LTE and 12 CCs NR in dual mixed mode	1
Transport		IDU	FO Bridge	1

Table 11. RAN equipment features.

Deployment roadmap for ExFa-GR in accordance with the overall strategy

During Q1 and Q2 2022 the installation of the network components has been completed. The RAN equipment is installed in PPC premises, which includes one baseband unit and one indoor radio unit, four radio dots and one outdoor antenna. Packet core is installed in OTE premises, as well as the internal server, which includes three physical servers.

The testbed deployment will continue with the internal server configuration and the end-to-end integration, which is part of WP5 activities.

5.4 5G deployment strategy and roadmap in ExFa-IT

The 5G Experimentation facilities in Italy are deployed in order to demonstrate use of the developed network application providing 5G network. The experimentation facilities will be implemented in Cassinetta industrial site and the following use cases are considered: *Predictive maintenance for Thermoforming machine, AR assistance for maintenance, Crossroad control for safety, Network performance monitoring via drone and fix probe.* Deployment of 5G infrastructure and MEC are described in the following paragraphs.

Private 5G network deployment strategies in Italy

The use cases will be deployed in the commercial W3 network.

5G radio coverage is allowed with 5G antenna **VA138** that permits outdoor full coverage in TDD and FDD/DSS, while it permits indoor partial coverage in TDD and indoor full coverage in FDD/DSS.

The Non-Standalone core network according to Option 3.x is a virtualized infrastructure implementing Virtual Machines. The commercial network will be used for testing at Cassinetta site. The SGW and PGW network functions will be deployed at the edge site on the MEC, whereas the control plane functions such as the Mobility Management Entity (MME) and HSS are located at the W3 core network.

The local SGW selection is performed by the central MME according to the 3GPP standard DNS procedures and based on the Tracking Area Code (TAC) of the radio where the UE attaches to. This architecture allows offloading the traffic based on the APN. This deployment permits W3 to maintain total control over the MME, whereas the data plane flows through a separated network that does not impact any existing network nor business. Rel.15 is the current release deployed in CN.

Figure 17. 5G radio coverage in Cassinetta site.

A MEC server from Athonet will be implemented in W3 data center in Settimo Milanese. The first server will be configured as SGW/PGW in order to emulate a local core network, the second server will be locally connected to the first server and will contain the applications necessary for guaranteeing low latency at the edge. The MEC with SGW/PGW functionality will be equipped with 4x10Gbps Ethernet interfaces, 2x10GE-LR optical interfaces towards the W3 core network and 2x10GE-LR optical interfaces towards the W3 radio network. 2x10GE copper interfaces will be used for connecting to server dedicated to vApps. The Operating System installed will be Ubuntu server 18.04, the MEC application will be virtualized using Docker.

The MEC Server is implemented as described in the scheme of Figure 18.

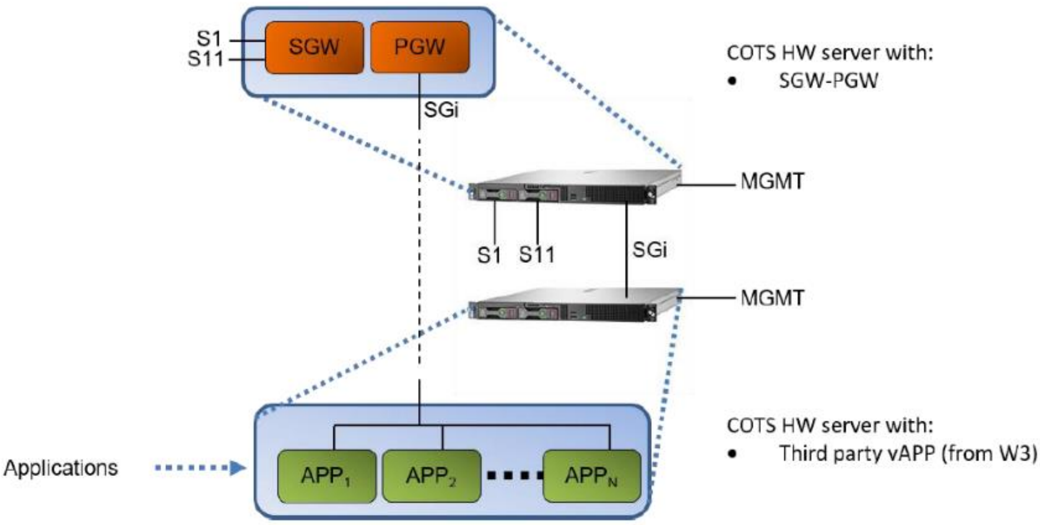

Figure 18. MEC server scheme.

The MEC server can have connectivity to an external server through a secure VPN in order to manage applications. A virtual firewall is configured to protect SGW/PGW by potential unauthorized access. A dedicated APN will be configured to allow data exchange only between 5G devices and MEC.

Deployment roadmap for ExFa-IT in accordance with the overall strategy

1. 1Q 2022 – Check about 5G radio coverage in Cassinetta site with positive result.
2. 2Q 2022 – Purchase request to vendor for installing and commissioning the MEC platform. Site survey required in Settimo Milanese data center. MEC server has been sent to Settimo Milanese data center.
3. 3Q 2022 – MEC server will be installed in W3 data center by Athonet vendor. W3 Eng. Dept will write projects that will be sent to W3 O&M Dept in order to implement MEC in the W3 Network. SIMs necessary for test will be ordered to our department (W3 requested to partner how many SIMs are needed).

5.5 5G deployment strategy and roadmap: general considerations

As a summary of the recommended 5G infrastructure for each ExFa, following the analysis of general and specific needs, priorities and technology fit of 5G for adapting to them, Table 12 indicates, for each ExFa, the standing key technology choices on 3GPP standards release compatibility and architecture options, frequency ranges to be used and bandwidth allocated, key parameters of access network configuration, deployment models for core network functions and for the NetApps to be hosted, the type and capabilities of UE devices and the KPI monitoring capabilities to be deployed.

ExFa	3GPP Rel.	3GPP Architecture Options	Spectrum	Operator/ Vendor	Access Network	Core Network	Edge Location (Apps)	End Devices	Monitored KPIs
GR	Rel 15 and Rel16	Option 2– SA	3.5 Ghz (100 MHz)	OTE	•TDD 7:3 •MIMO 4x4 •256QAM	5GC-Rel16 -Edge Deployment (OTE) -Central Office (OTE)	PPC		•RTT Latency •UL Data Rate •DL Data Rate •Reliability
IT	Rel 15	Option 3.x - NSA	TDD:3.7 GHz (60 MHz) FDD:1.8 GHz (20 MHz)	WindTre	•TDD 7:3 •mMIMO 32x32 •256QAM downlink •FDD •MIMO 2x2 •256QAM downlink	4GC-Rel15 -Data center (W3) -Edge Deployment (???)	W3 data center		•RTT Latency •UL Data Rate •DL Data Rate •Reliability
ES	Rel 15 and Rel16	Option 2 - SA	3.5 GHz-n78 (50 MHz)	Telefónica / Ericsson	•TDD 7:3 xº •MIMO 4x4 •256QAM (5TONIC + Ford)	5GC-Rel16 -Edge Deployment UP (Ford premises) -Central Office CP (5TONIC)	Ford Factory	CPE (Fivecomm) for mid bands CPE (WNC) for mid bands CPE (Askey) for mid bands and mmWave	•RTT Latency •UL Data Rate •DL Data Rate •Reliability

Table 12. Key 5G deployment aspects and choices.

Finally, Table 13 is an illustration of the timeline of key actions of deployment of 5G infrastructure items for year 2022, for each 5G-INDUCE facility.

ExFa	2022-Q1	2022-Q2	2022-Q3	2022-Q4
GR	- Installation of network components started	- RAN installed in PPC premises - Packet core and the internal servers installed in OTE premises	- Internal servers configuration - End-to-end integration	
IT	- 5G radio coverage granted in Cassinetta site	- Purchase request to vendor for installing and commissioning of MEC platform. - Site survey required in Settimo Milanese Data Center. - MEC server transported to Settimo Milanese Data Center	- MEC server will be installed in W3 Data Center and integrated in W3 Network. - SIMs necessary for test will be acquired	
ES	- Deployment of 5G Rel 16 infra at 5TONIC lab. - Integration of 5G SA portable kit for Valencia for coverage, UPF and EC support.	- Deployment of 5G RAN and UPF at Ford premises in Valencia. - Interconnection between 5TONIC (PN) and Ford (NPN) established. - Full integration and first validation of 5G Rel 16 infra, with 5G-INDUCE UCs in 5TONIC.	- Both indoor and outdoor coverage on Sub 6 GHz is deployed at Ford premises in Valencia and used for validation purposes. - Iterative integration and validation activities over the PN-NPN interconnected facility, with both UPF and Net Apps deployed at Ford premises.	- Deployment of mmW coverage for extended validation of use cases (optional, if needed). - Applications and UPF alternative deployment in near Edge location for extended validation of uses cases (optional, if needed).

Table 13. 5G Deployment timeline.

With the approaches and deployment roadmaps just summarized, 5G-INDUCE project plans to address not only the specific needs of the use cases in its scope, at each ExFa, but also to create a solid platform that can be incrementally enhanced and evolved to cater for the evolved needs of these use cases over time and also to attract new I4.0 use cases of the vertical stakeholders of the project, enabled by the same technology choices on 5G, justified in this document.

6 Conclusions

The scope of this deliverable is to report the identified key technologies of 5G-INDUCE, which enable various strategic sectors in I4.0 to offer increased benefits in terms of performance, productivity, safety, and security. The deliverable outcome will feed the Market Analysis, Exploitation, and Business Planning work activities in T7.3 which carries out the evaluation of the identified markets for all 3 business actors: I4.0 players, network operators and NetApp developers.

In more detail, the deliverable provided:

- State of the art, on 5G technology and its application to I4.0 use cases:
- An overview of the current landscape of both I4.0 and 5G has been reported. For I4.0, this deliverable provided a description of general concepts, state of the art and major trends while for 5G we described the standards and solutions that are applicable to I4.0. Additionally, synergies between 5G and I4.0 have been identified as well as opportunities and challenges.
- Analysis of requirements of 5G-INDUCE vertical stakeholders:
- A survey regarding the views of vertical stakeholders on I4.0 and the role of 5G has been presented as well. An analysis of common requirements has been additionally provided. The stakeholders that participated on this survey are PPC, Whirlpool, Ford and ASTI.
- Identification of key 5G features supported by 5G-INDUCE:
- A detailed report about all the key 5G features that includes access, core and edge capabilities of 5G infrastructure to be deployed for the demonstration 5G-INDUCE use cases was provided.
- 5G Deployment within 5G-INDUCE: strategy and roadmap:
- A description of the three experimentation facilities that will be deployed in Spain, Italy and Greece for use cases validation and their deployment strategy, was also provided.

References

[1] "5G-INDUCE D2.2 - Targeted use cases and NetApp related requirements," [Online]. Available: https://www.5g-induce.eu/index.php/outcomes/.

[2] ACATECH, "Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Final report of the Industrie 4.0 Working Group," 2013. [Online]. Available: https://en.acatech.de/publication/recommendations-for-implementing-the-strategic-initiative-industrie-4-0-final-report-of-the-industrie-4-0-working-group/.

[3] 5G-PPP, "5G and the Factories of the Future," 2015. [Online]. Available: https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Factories-of-the-Future-Vertical-Sector.pdf.

[4] M. Hermann, T. Pentek and B. Otto, "Design Principles for Industrie 4.0 Scenarios," *2016 49th Hawaii International Conference on System Sciences (HICSS),* no. doi: 10.1109/HICSS.2016.488., pp. 3928-3937, 2016.

[5] ITU-R M.2083-0, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond," September 2015.

[6] J. Ordonez-Lucena, J. F. Chavarria, L. M. Contreras and A. Pastor, "The use of 5G Non-Public Networks to support Industry 4.0 scenarios," *2019 IEEE Conference on Standards for Communications and Networking (CSCN),* vol. doi: 10.1109/CSCN.2019.8931325., pp. 1-7, 2019.

[7] GSA, "Private-Mobile-Networks June 2022 Summary report," [Online], June 2022.

[8] Ericsson, "5G spectrum for local industrial networks," [Online], April 2022.

[9] "5G-INDUCE D2.1 - 5G platform design and requirements in support of Industrial sector NetApps," [Online]. Available: https://www.5g-induce.eu/index.php/outcomes/.

[10] 3GPP Release 15, [Online]. Available: https://www.3gpp.org/release-15.

[11] 3GPP Release 16, [Online]. Available: https://www.3gpp.org/release-16.

[12] 5G-PPP, "Understanding the Numbers – Contextualization and Impact Factors of 5G Performance Results," 2021. [Online]. Available: https://5g-ppp.eu/wp-content/uploads/2021/08/TMV-Results-Explanation-White-Paper-V1.0.pdf.

[13] 5G-ACIA, "5G Non-Public Networks for Industrial Scenarios," 2019. [Online]. Available: https://5g-acia.org/wp-content/uploads/2021/04/WP_5G_NPN_2019_01.pdf.

[14] ITU-R M.2083-0, ""IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond"," September 2015.

Annex I: Survey on I4.0 and 5G to 5G-INDUCE Vertical Stakeholders – Questionnaire

Survey on I4.0 and 5G
to 5G-INDUCE Vertical Stakeholders
–
Questionnaire

INSTRUCTIONS

PLEASE READ CAREFULLY

You are invited to fill out this Questionnaire as you have been identified as the appropriate person within your H2020/5GPPP project to provide relevant feedback on I4.0 Trends enabled by 5G.

This Questionnaire comprises 11 questions. To answer each question, please, refer to the following instructions:

For all questions, contributors are encouraged to include illustrative diagrams, drawings, pictures, etc.

Question 1: What are the main competitive advantages that a company may achieve by adopting Industry 4.0 with 5G?

[ ] Production time reduction

[ ] Optimization of resources

[ ] Cost savings

[ ] Security

[ ] Efficient data flow

[ ] Maintenance through VR integration

[ ] Others… ____

Question 2: What kind of specific applications and use cases are enabled by Industry 4.0 with 5G that previously were not feasible?

(Suggested min: 700 characters)

Question 3: In what areas of the industrial process do you embrace Industry 4.0 with 5G?

INDUSTRIAL PROCESS	ALREADY IN USE	PLAN TO USE	UNDER EVALUATION
FACTORY AUTOMATION			
SUPPLY CHAIN			
QUALITY CONTROL			
CUSTOMIZATION			
MAINTENANCE			
PLANNING			
OTHERS (Please specify)			

Please add any details that you may consider relevant:

Question 4: When will Industry 4.0 with 5G have been mostly adopted by your industrial sector?

[ ] 2022-2024

[ ] 2025-2029

[ ] 2030-2040

Please share on relevant milestones that you foresee in the adoption of Industry 4.0:

(Suggested min.: 700 characters)

Question 5: What technologies do you consider critical for the Industry 4.0 transformation?

Indicate your answer from 1 (not relevant) to 5 (most relevant).

COMMUNICATION TECHNOLOGIES	1-5
EDGE COMPUTING	
HYBRID CLOUD	
PUBLIC CLOUD	
5G eMBB	
5G mMTC	
5G URLLC	
IOT/IIOT	
WIFI	
NETWORK SLICING	
NETWORK EXPOSURE	
COMPLEMENTARY TECHNOLOGIES	**1-5**
TSN AND DETNET STANDARS	
AR/VR/XR	
BLOCK CHAIN	
QUANTUM COMPUTING	
COMPUTER VISION	
MOBILE ROBOTICS	
MACHINE LEARNING	
TACTILE INTERNET	
3D PRINTING	
OTHERS (Please specify)	

Question 6: Could you please introduce any Industry 4.0 with 5G initiative out of your company that you consider relevant for the industry overall?

Initiative 1:

Initiative 2:

Initiative 3:

Question 7: The relationship between machine and human work effort is variable. What benefits can a company get by having human resources and machines cooperating with one another?

Indicate your answer from 1 (not relevant) to 5 (most relevant).

BENEFITS	1-5
REDUCE THE NUMBER OF EMPLOYEE HOURS DEDICATED TO THE MANAGEMENT OF REPETITIVE PROCESSES	
INCREASE AUTOMATION OF THE PRODUCTION PROCESS	
INCREASE PRODUCTION CAPACITY	
INCREASE FLEXIBILITY	
MULTIPLY PRODUCT QUALITY	
INCORPORATE CUSTOMIZATION CAPABILITIES	
DEDICATE THE WORK EFFORT OF HUMAN RESOURCES TO ACTIVITIES WITH GREATER ADDED VALUE	
RAISE THE CAPACITY TO INNOVATE IN PRODUCTS AND SERVICES	
HEALTH AND SAFETY	

Question 8: If you are considering to engage in Industry 4.0 with 5G projects, what investment model would you consider?

Indicate your answer from 1 (not considered) to 5 (preferred option).

INVESTMENT MODEL	1-5
OWN INVESTMENT	
CO-INVESTMENT (WITH TECHNOLOGY AND BUSINESS PARTNERS)	
PUBLIC FUNDING PROGRAMS	
INVESTING IN EXTERNAL VENTURES	

Question 9: What options do you consider for vertical application deployment in the context of Industry 4.0 with 5G?

More than one option can be selected.

[ ] Local data center (on-prem)

[ ] Near Edge

[ ] Central office (Telco)

[ ] Hyperscaler

For what scenarios would you choose the selected options?

(Suggested min: 700 characters)

Question 10: What are your key requirements and expectations on non-public networks for Industry 4.0 and 5G projects?

[ ] Network performance

[ ] Optimize network resource utilization

[ ] Customization and flexibility

[ ] Security and privacy

Please add any details that you may consider relevant:

(Suggested min: 700 characters)

Question 11: What are your key requirements for additional security and privacy mechanisms for Industry 4.0 and 5G? What is your current approach and plans in this subject?

(Suggested min: 700 characters)

Annex II: Survey on I4.0 and 5G to 5G-INDUCE Vertical Stakeholders - Tabulated Answers Summary

Survey on I4.0 and 5G
to 5G-INDUCE Vertical Stakeholders
–
Tabulated Answers Summary

Question 1: What are the main competitive advantages that a company may achieve by adopting Industry 4.0 with 5G?

Q1: ADVANTAGES ADOPTING INDUSTRY 4.0	POSITIVE ANSWERS
OPTIMIZATION OF RESOURCES	100.0%
COST SAVINGS	75.0%
SECURITY	75.0%
EFFICIENT DATA FLOW	75.0%
MAINTENANCE THROUGH VR INTEGRATION	75.0%
PRODUCTION TIME REDUCTION	50.0%
OTHERS	

Question 3: In what areas of the industrial process do you embrace Industry 4.0 with 5G?

Q3: INDUSTRIAL PROCESS	Plan to use - PA	Under evaluation -PA
SUPPLY CHAIN	100.0%	50.0%
MAINTENANCE	100.0%	50.0%
FACTORY AUTOMATION	75.0%	75.0%
QUALITY CONTROL	50.0%	50.0%
CUSTOMIZATION	25.0%	75.0%
PLANNING	25.0%	50.0%
OTHERS		

Question 4: When will Industry 4.0 with 5G have been mostly adopted by your industrial sector?

Q4: ADOPTION BY YOUR INDUSTRIAL SECTOR	POSITIVE ANSWERS
2025-2029	100.0%
2030-2040	25.0%
2022-2024	0.0%

Question 5: What technologies do you consider critical for the Industry 4.0 transformation?

Q5: CRITICAL TECHNOLOGIES	% MINOR	%SIGNIFICANT	%CRITICAL	%SIGNIFICANT + %CRITICAL
EDGE COMPUTING	0.0%	25.0%	75.0%	100.0%
5G mMTC	0.0%	50.0%	50.0%	100.0%
IOT/IIOT	0.0%	50.0%	50.0%	100.0%
COMPUTER VISION	0.0%	50.0%	50.0%	100.0%
MACHINE LEARNING	0.0%	0.0%	100.0%	100.0%
5G eMBB	25.0%	50.0%	25.0%	75.0%
5G URLLC	25.0%	25.0%	50.0%	75.0%
MOBILE ROBOTICS	25.0%	25.0%	50.0%	75.0%
3D PRINTING	25.0%	50.0%	25.0%	75.0%
HYBRID CLOUD	50.0%	25.0%	25.0%	50.0%
WIFI	50.0%	0.0%	50.0%	50.0%
TSN AND DETNET STANDARDS	50.0%	50.0%	0.0%	50.0%
AR/VR/XR	50.0%	50.0%	0.0%	50.0%
BLOCK CHAIN	50.0%	25.0%	25.0%	50.0%
NETWORK SLICING	75.0%	0.0%	25.0%	25.0%
NETWORK EXPOSURE	75.0%	0.0%	25.0%	25.0%
TACTILE INTERNET	75.0%	25.0%	0.0%	25.0%
PUBLIC CLOUD	100.0%	0.0%	0.0%	0.0%
QUANTUM COMPUTING	100.0%	0.0%	0.0%	0.0%
OTHERS				

Question 7: The relationship between machine and human work effort is variable. What benefits can a company get by having human resources and machines cooperating with one another?

Q7: BENEFITS	% MINOR	%SIGNIFICANT	%CRITICAL	%SIGNIFICANT + %CRITICAL
INCREASE AUTOMATION OF THE PRODUCTION PROCESS	0.0%	75.0%	25.0%	100.0%
REDUCE THE NUMBER OF EMPLOYEE HOURS DEDICATED TO THE MANAGEMENT OF REPETITIVE PROCESSES	25.0%	50.0%	25.0%	75.0%
INCREASE PRODUCTION CAPACITY	25.0%	25.0%	50.0%	75.0%
DEDICATE THE WORK EFFORT OF HUMAN RESOURCES TO ACTIVITIES WITH GREATER ADDED VALUE	25.0%	0.0%	75.0%	75.0%
RAISE THE CAPACITY TO INNOVATE IN PRODUCTS AND SERVICES	25.0%	50.0%	25.0%	75.0%
HEALTH AND SAFETY	25.0%	50.0%	25.0%	75.0%
MULTIPLY PRODUCT QUALITY	50.0%	0.0%	50.0%	50.0%
INCREASE FLEXIBILITY	75.0%	25.0%	0.0%	25.0%
INCORPORATE CUSTOMIZATION CAPABILITIES	100.0%	0.0%	0.0%	0.0%

Question 8: If you are considering to engage in Industry 4.0 with 5G projects, what investment model would you consider?

Q8: INVESTMENT MODEL	% MINOR	%SIGNIFICANT	%CRITICAL	%SIGNIFICANT + %CRITICAL
CO INVESTMENT	0.0%	100.0%	0.0%	100.0%
PUBLIC FUNDING	50.0%	0.0%	50.0%	50.0%
OWN INVESTMENT	75.0%	0.0%	25.0%	25.0%
INVESTING IN EXTERNAL VENTURES	100.0%	0.0%	0.0%	0.0%

Question 9: What options do you consider for vertical application deployment in the context of Industry 4.0 with 5G?

Q9: DEPLOYMENT OPTIONS	POSITIVE ANSWERS
NEAR EDGE	100.0%
CENTRAL OFFICE (TELCO)	100.0%
LOCAL DATA CENTER (ON-PREM)	75.0%
HYPERSCALER	75.0%

Question 10: What are your key requirements and expectations on non-public networks for Industry 4.0 and 5G projects?

Q10: REQUIREMENTS ON NPN	POSITIVE ANSWERS
NETWORK PERFORMANCE	100.0%
OPTIMIZE NETWORK RESOURCE UTILIZATION	100.0%
CUSTOMIZATION AND FLEXIBILITY	75.0%
SECURITY AND PRIVACY	75.0%