Innovation Management in 6G research: the case of Hexa-X project

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***Abstract*— Very often in the past, innovations from research communities have been disconnected from industry adoption, leading to a lack of exploitation of research projects. To overcome this issue, in the view of future 6G systems, the Hexa-X project is putting in place an Innovation Management (IM) process, aiming to facilitate and promote innovation opportunities based on project outcomes and ensure that all the ideas emerging from the project are captured and tracked, not "lost". Focus of IM is on supporting the project to promptly identify innovations and engage with emerging innovation needs in the sector, for identifying gaps and potentials with strategic value. This paper presents the IM approach in Hexa-X and selected innovations (some of which also awarded by the EC Innovation Radar), with particular emphasis on the technical aspects of these findings coupled with their identified strategic value for future 6G market exploitation.**

Keywords*— 6G, innovation management, market exploitation, technology readiness level, service innovation and creation.

1 Introduction

The continuously growing traffic demand [1] confirms that the society is moving towards a data driven world, and it is also a natural driver for communication network evolution (especially mobile networks). This market demand translates into many technical requirements to be addressed by communication networks, a situation which obliges the entire ecosystem, from e.g., Mobile Network Operators (MNOs), to technology and service providers, to continuously introduce elements of innovation in the network infrastructure and terminals, for the evolution toward future systems. At the same time, it is worth noticing that the usage of new networks will be mainly influenced and determined by the introduction of new terminals to the market. In this perspective, it is worth highlighting that this phenomenon is true since the era of smartphones, where the actual usage of new and performing devices acted as a catalyzer to stimulate the creation and consumption of new services, thus as a further enabler for data traffic demand (which is again driving a further cycle of network evolution).

In summary, as we have seen in the past, also for the evolution toward B5G systems, we may rely again on the typical cycle of innovation (Figure 1), where the involvement of both networks and terminals is driven by traffic demand but also acts as a driver for the same market evolution, encouraging an increased data consumption. By quoting Brian Krzanich (former Intel's CEO), "Data is the new oil" [3]. With this scenario in mind, the creation of new market opportunities will start from the creation of new network technologies. In this context a proper innovation management is key to ensure industrial impact of technical research and development.

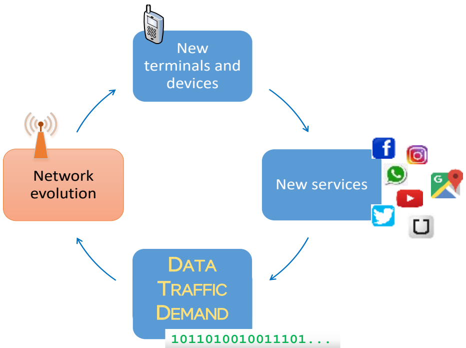

Fig. 1. Typical Innovation cycle in communications [2]

2 Innovation Management toward 6G

At the time of writing this paper, 5G network deployments are still ongoing. However, the industry is already preparing the field for its evolution toward 6G systems. Apart from standardization efforts (which are still focused on 5G-Advanced), many communities and 6G projects are influencing the innovation cycle with their findings. However, the research community is full of examples where in the past generation many promising and valuable innovations coming from research projects were disconnected from industry and real market adoption, leading to a lack of exploitation of those research projects. Moreover, while 5G (introduced in an age of network virtualisation) is gradually transforming the mobile industry, a clear trend for the evolution toward 6G systems is the need for the dynamic cross-layered resourcing and reconfigurability of functions and services in operation [14]. In future systems, digital service chains are becoming more distributed and advanced, requiring abstracted 6G network capabilities built on resources provided "as-a-service". Also, from a business point of view, 6G networks will be designed, deployed, managed, and put on the market not only by the traditional mobile network operators but new stakeholders like local operators, cloud operators, and resource brokers. Moreover, while technology advancements toward 5G were so far focused on separate protocol-layered technology innovations of focal firms, now the need is to shift toward a more dynamic multi-level innovation in platforms and ecosystems [14], with novel business models and collaboration among various stakeholders (e.g. MNOs and vertical market segments) that enable the creation and capture of value with 6G services and profiting from 6G innovations.

Consequently, also innovation management previously applied to 5G research should evolve coherently with this new trend and technology evolution, by fostering collaboration at various levels, between business, IT, and telecommunication. The risk otherwise is to have research findings disconnected from this changing business environment. To overcome these issues, in the view of future 6G systems, the Hexa-X project is putting in place an Innovation Management (IM) process, with the aim to facilitate and promote innovation opportunities based on project outcomes and ensure that all the ideas emerging from the project are properly captured and analysed. Focus of IM is on supporting the project to promptly identify innovations and best engage with emerging innovation needs in the sector, for identifying gaps and potentials that have strategic and commercial value in Hexa-X. The IM goal in Hexa-X is to continuously analyze the technical progress of the project by monitoring the state of the art in the market, being responsible for identifying missing gaps that have strategic and commercial value in Hexa-X. A possible outcome of IM is also the identification of promising areas for new business creation, collaborations with start-ups and emerging initiatives, also possibly by stimulating the creation of spin-offs and/or new ventures. The Hexa-X methodology for IM is thus comprising 1) brainstorming meetings along the project lifetime by establishing an Innovation Management Committee (IMC), composed by scientists and managers, so that not only technological advances are pursued, but also commercial opportunities, and 2) a recurrent series of internal Call-for-Ideas (CFI), issued by the IMC every 6 months, where innovators in the projects could submit (on a voluntary basis) their ideas. The IMC (led by an Innovation Manager reporting to the project PMT, Project Management Team) is thus coordinating this 6-month innovation cycle, where at each CFI round the innovations are analyzed from both technical and business point of view, in order to identify innovation potentials, market opportunities and make recommendations to the PMT and innovators on possible exploitation steps. At each CFI stage, an analysis is conducted both as a self-assessment from innovators and as analysis from the IMC members (see Table II in section 5).

This IM process led also to an award of some Hexa-X innovations by the EC in the framework of EU Innovation Radar [4], and will likely lead to further opportunities for innovators, e.g. wider networking, business creation, thus amplifying the impact of Hexa-X innovations even after project end. Additionally, we expect that this IM process in Hexa-X will bring more impact to innovations toward their roll-out/implementation in 6G systems (wrt previous generations), where not only more efficient and autonomous networks can be introduced, but also novel stakeholders can be attracted, e.g. related to local networks, cloud, AI/ML technologies, thus expanding the market outside of traditional MNO business model view from past generations.

3 HEXA-X INNOVATIONS

All Hexa-X innovations captured by the IMC innovation management process are described here below. At each CFI cycle they evolved and new innovations came to IMC, so this live process was indeed capturing a natural evolution of the innovations through the end of project lifetime (note: at the time of writing this paper, when Hexa-X is heading to its very final stage, thus authors can provide already a well consolidated view).

3.1 *Federated Learning of Explainable Artificial Intelligence Models (FED-XAI)*

Trustworthiness of Artificial Intelligence (AI) has become paramount for both users and government entities. In 6G systems, AI-based approaches must i) preserve the privacy of data produced by the users and involved in the Federated Learning (FL) process, and ii) provide details about their own functioning, in order to make the latter transparent and understandable by a human. On one hand, FL has been proposed as a privacy-preserving paradigm for collaboratively training AI models. On the other hand, inherently explainable AI models can be considered to improve trustworthiness, such as decision trees or rule-based models. Within Hexa-X, we propose to merge the above concepts to achieve FL of eXplainable AI (XAI) models (FED-XAI) [5]. In particular, we apply such approach to predict the Quality of Experience (QoE) of video streaming in automotive applications, such as see-through or tele-operated driving. In fact, the large volume of data produced by multiple road users that are running such applications can be leveraged to collaboratively train a local AI model at the UE side and share it with a FED-XAI aggregator in the core of the network, according to the FL paradigm, as shown in Fig. 2.

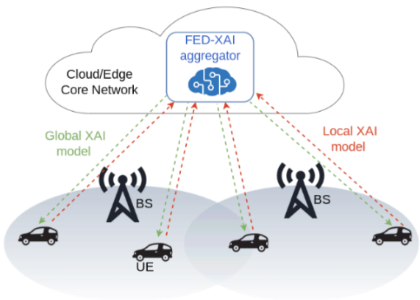

Fig. 2. FED-XAI approach.

Designing the FL process so that the obtained model is explainable-by-design will contribute to increase the trust of car manufacturers, MNOs and final users in AI, and in turn will accelerate the adoption of AI-based services in the automotive sector. This aspect is also very important from an IM point of view, as with this FED-XAI innovation MNOs can provide a more explainable set of 6G functionalities (e.g., FL agents enabling QoE predictions) and expose to their customers (including car OEMs, but also application developers and system integrators), while on the other hand, OEMs can also benefit from more information on network predictions, exploitable to improve the automated driving features offered to their end-customers (i.e. the actual drivers). In a nutshell, FED-XAI impact will be to improve the understanding and mutual trust between stakeholders in the 6G ecosystem (in this example MNOs and OEMs).

3.2 *Resilient manufacturing through 6G (handling unexpected situations in industrial scenarios)*

To ensure dependability and robustness in robotic-powered industrial scenarios, key parameters are monitored (throughput, latency, application layer indicators, etc.) and in case of a problem/faults in the network, robotic devices or functionality, specific mitigation actions must be triggered. An anomaly detection algorithm and diagnosis system for an industrial is involved, with the intention of handling unexpected situations like faults and errors in the network, the devices or functionality. The infrastructure consists of a set of robots, cooperating on a task (regular operation). In case of an unexpected situation, the functionality is redistributed to other robots in the vicinity, in an orchestrated manner. For this reason, a Functionality Allocation Mixed Integer Programming (MIP)-based Algorithm is designed and used, which takes into consideration power consumption and computational costs, as well as network related aspects, such as end-to-end (E2E) latency. At the same time, a human-robot interface based on VR and Digital Twin (DT) technology is available for conducting teleoperation and remote repair of the impaired components. Key challenges comprise robot cooperation, massive DT of industrial scenarios, handling impairments, via automated redistribution of functions, and finally enabling remote users to supervise and make repairs with the use of DT applications.

From an IM point of view, this innovation brings a high-added value for various stakeholders: 1) manufacturing companies can benefit greatly via improved and sustainable production processes, reducing downtime, improving product quality and reducing costs; 2) MNOs can offer new services to their customers for supporting these scenarios thanks to resilient 6G systems; 3) OEMs and service providers can offer tailored manufacturing process anomaly detection algorithms, VR/XR and DT-enabled technologies and interfaces to their customers and generate new revenue streams.

3.3 Zero-Energy Devices (ZED)

In Hexa-X project vision [13], Zero Energy Devices (ZED) are self-powered devices connected to the 6G network. They harvest solar, vibratory and/or RF energy to power themselves. They use ultra-low power communication techniques such as backscattering to communicate with the 6G network. Various types of ZEDs are designed to cope with various use cases. The most complex ZED is the ZED sensor device. The simplest ZED is the 6G passive radio frequency (RF) tag, that is similar to a Radio Frequency Identification (RFID) tag. One could envisage a sustainable development of services based on an Internet-of-Tags, thanks to 6G tags that would be detectable by 6G base stations and 6G devices.

In terms of concrete recent achievements by the Hexa-X project, the first use case of ZED which has been successfully tested experimentally, on the field, is the "Asset Tracking out-of-thin air" service thanks to prototypes of "Crowd-detectable zero-energy-devices" (CD-ZED) [6]. A CD-ZED is a tag that backscatters signals from the base station to be detected by a customer smartphone close by. It also, simultaneously backscatters signals from a smartphone, and can also be detected by a base station. In [6], an object bearing a prototype of CD-ZED has been tracked in various challenging environments (in outdoor dense urban scenarios, in deep indoor environment and even on board of a fast-moving car on the highway). The object was tracked without generating additional waves (by re-using ambient waves) or additional energy (by harvesting solar energy), or any need to deploy RFID portals and readers (hence, almost "out-of-thin-air"). The study has also shown that the CD-ZED prototype could reach an "infinite" autonomy, with an appropriate setting of communication parameters such as messages periodicity.

From an IM point of view, this innovation for IoT tracking will attract the 6G markets of logistic companies and individuals, thanks to its cost, coverage and sustainability.

3.4 Device-Edge-Cloud Continuum Orchestration

A major challenge for the upcoming B5G/6G networks is to integrate the extreme-edge domain in the management and orchestration (M&O) workflows, due to the high heterogeneity of devices that the extreme edge will have to deal with. These devices are typically volatile, support a diversity of technologies, have limited computing/storage resources, a random behavior and can be also massive in scale. This need is the driver for this innovation in the infrastructure manager and in the interfaces with the orchestrator, where AI/ML techniques can be used to process big amount of data coming from diverse extreme-edge devices, and trigger actions based on results from data analysis.

This innovation expects to impact positively on MNOs as well as verticals deploying their private networks, proposing a common M&O framework able to efficiently deploy & manage network slices (NSs) on a wide distributed computing platform, integrating both heterogeneous network domains (considering not only the MNO public resources but also 3rd party nodes, some of them forming non-public networks) and extreme-edge domains (i.e. those end-user devices beyond the MNO access network, and consequently not under strictly controlled conditions, thus not necessarily under regular maintenance, or unexpectedly moved or even switched off/on). Besides, continuum M&O is also about enabling the atomic network functions composing network services in such a way they could be efficiently moved among the different domains in a very agile way. M&O systems for 6G are envisaged to span across the multiple domains, extending the traditional M&O of cloud & edge resources towards the extreme-edge, where UE devices are equipped with computing/storage resources that can be allocated dynamically to run part of service components.

From an IM point of view, as intelligent IoT devices take on critical analytics and decision-making tasks, opportunities for innovation and new forms of on-site service delivery are opening up, driving the digital transformation of industries.

3.5 AI Management and Orchestration (AI MANO)

B5G/6G networks are already becoming increasingly difficult to manage due to the growing heterogeneity and complexity of the network and the multiplicity of parameters that can be configured in an attempt to achieve optimality. For this reason, they are expected to have cognitive capabilities and abilities in terms of autonomous operation, optimization of operation, and prediction of future network states. In this context, undertaking an efficient data management strategy becomes substantial to facilitate all data-driven processes conducted in the network.

This innovation [7] performs data-driven processes utilizing the data originated at multiple network levels (slice, service, infrastructure) and defining mechanisms for cross-layer monitoring to optimize slicing. The operations related to dynamic optimization of NSs include four aspects: 1) Slice-related data collection from all layers of the system and pre-processing; 2) Extraction of relevant features for optimization; 3) Performance of slice self-optimization algorithms to optimize resource consumption while keeping slice KPIs at the required level, fulfilling SLAs; 4) Performance of slice self-healing and self-configuration actions in a fully automated manner, enabling an efficient scaling of the solution with the increasing number of concurrent NSs, and removing the need of the human intervention to operate them.

The overall resource allocation scheme keeps slices isolated from each other, in the sense that congestion in one slice cause minimal (if not zero) impact on other slices. This innovation is expected to benefit MNOs very significantly in terms of operational costs reduction by minimizing the human intervention needed for network configuration and maintenance, while improving customer experience. Besides, it lowers barriers for industry verticals access to B5G communication services.

From an IM point of view, this innovation leads to a reduction of IT costs in the networking industry and a reorientation towards more strategic, higher-value tasks.

3.6 Simulation and modelling framework for Radio Frequency impairments (SIM-RF)

Modeling radio frequency components and their impairments is an essential task before and during wireless communication standard development. The first simulations before the first standard draft set cornerstones for standardization work, and thus validity and reasonable accuracy of the first radio component simulation models will significantly impact new radio system development.

This innovation proposes a simulation framework that combines different modeling-level design blocks into one simulation structure based on work done in Hexa-X [8]. The system level simulation requires strong knowledge of the hardware implementations and impairments and interactions. The needed abstraction levels of RF components' mathematical models depend on modeled impairments and the research problem to which the information is applied. The 6G system and link-level research can use the inventive simulation framework and analyze radio parameters of future 6G networks with more accurate simulation parameters as studies shown for 6G link level [9] or localization analysis [10]. The inventive framework can model different levels of detail: power level analysis, complex number additive non-idealities, and waveform sample analysis, respectively. The physical-level models can be based on circuit simulations, electromagnetic simulations, or look-up tables based on measurement results. The simulation framework can be utilized by radio system engineering, algorithm design, waveform analysis, and development or any 6G research and development disciplines working on advanced physical radio circuits. The framework supports a concurrent engineering approach where both simulation results or measured hardware properties can be added and upgraded into the simulation framework as hardware in between (HIB) by replacing one or more physical models with measurement-based models. As an example, the first level a simple third order linearity model in link-level simulation can be replaced with measurement-based compression curve of 290 GHz low noise amplifier [11].

From an IM point of view, this innovation brings benefits in 6G radio network and RF implementation co-simulations which are essential ensuring E2E radio performance.

3.7 Goal-oriented communications design for AI-native 6G (AI6GOAL)

The concept of "connecting intelligence", introduced by this Hexa-X activity, implies enabling different agents to exchange (i.e., transmit) and process data (i.e., reason) in real-time, to operate cooperative tasks with energy frugality, latency, accuracy, and trustworthiness targets. This calls for a new paradigm shift from data-oriented to *goal-oriented* communications, to design new transmission strategies that do not necessarily aim at the correct reception of the original information, but rather focus on the effect of the (possibly not error free) decoded information on higher layer performance. The idea is then to adapt communication KPIs (e.g., Packet Error Rate), by measuring the effect of such adaptation on the actual application performance (and not, e.g., on physical layer performance), as the tolerance of information distortion is dynamically defined with respect to the task being performed by the agents. As such, a clear definition of the goal is needed, including: i) the goal-effectiveness, i.e. an appropriate metric to determine goal accomplishment, and ii) the goal cost, i.e., the price to pay (e.g., in terms of resource utilization) to accomplish the goal.

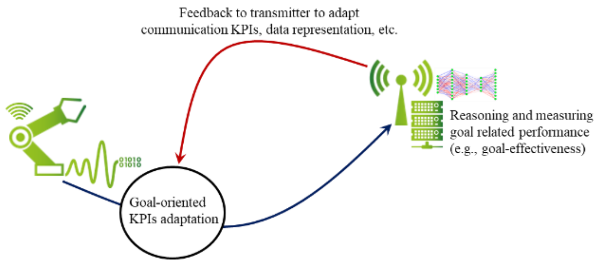

Fig. 3. Goal-oriented communication for real-time processing.

An example of use case is shown in Fig. 3, in which a controlled system transmits data to an edge cloud server, which process them through an ML model. The edge server is also capable of measuring goal related parameters, including goal-effectiveness, thus being able to estimate the needed information quality (e.g., the tolerable level of distortion) to achieve the goal. This measured information is exploited to adapt communication KPIs, data representation, and computing resources to the actual goal, rather than with a conventional pure communication perspective. In [12] this paradigm is applied to an edge inference use case, with both standalone and ensemble inference, to explore the trade-off between energy saving, inference timeliness and accuracy. Ongoing investigations relate to the coexistence of goal-oriented and classical data-oriented systems with mutual interference.

From an IM point of view, the efficient utilization of resources brought by this innovation opens the possibility of reducing costs and footprints for MNOs, with a tighter interaction with service providers.

3.8 Information reliability measures as a service

Communication, sensing and localization services provided by 6G systems will be used by many different services, ranging from regular data-communication to low-latency, high reliability communication in safety critical systems. Similarly, location and sensing information will be used in applications ranging from simple pedestrian navigation to highly reliable digital twins in industrial applications. The different applications, require a different reliability of the information/service provided by 6G networks, and knowledge of the reliability. This opens up for new services provided by 6G networks: localization and sensing with reliability information. If the network can offer localization and sensing information to network users, with associated reliability information, then devices not only can request a certain reliability level, but also can subscribe to or pay for reliability information.

Looking at industrial applications, such digital twining for example, wrong or inaccurate information e.g., wrong position of a robot, can potentially result in many different failure modes. Introducing (sensor-) redundancy is a typical method to cope with potentially inaccurate information. However, if reliability information of sensing and localization information can be provided as part of the data, failure modes can be handled more efficiently. For example, position/orientation information could be coupled with the following information: 1) exact timestamp; 2) max error per dimension; 3) error variance. Similar metrics can be derived for sensing. It is important to note that the idea is not promoting 6G as being part of a safety critical system, but that it can deliver input to safety critical systems in a meaningful way. In a wider sense, reliability measures of sensing information can be provided as a service; in that perspective, from an IM point of view, this innovation will enable MNOs to widen their offering and support new applications.

3.9 Automated orchestration of distributed AI functions for intelligent network management.

The management of mobile networks can be efficiently automated adopting AI/ML techniques that complement the traditional network control logic, taking intelligent decisions for optimizing resource utilization and network performance. The AI/ML algorithms can be implemented in cloud-native applications to be provisioned and configured as virtual functions of the management system, following the Service Based Architecture (SBA) pattern. Moreover, when specialized and tailored to particular categories of service requirements, the AI/ML functions can be orchestrated as part of the various NSs, delivering custom AI logics following the "as-a-Service" paradigm. In the context of future 6G networks, the management and orchestration layer will need to consistently deploy and coordinate the runtime of these AI components in distributed infrastructures, adapting their allocation in edge and core resources depending on their specific functionalities. Examples of AI/ML functions include collection and processing of multi-source and multi-layer data (at network and service level), training and re-training of ML models, storage and exchange of trained models in distributed environments for edge AI, runtime inference decisions and continuous model validation, to automatically trigger re-training actions. These functions are orchestrated during the E2E Network Slice management, optimizing AI service composition, and automating its deployment, configuration and runtime operation. It's worth noting that some AI functions can be shared based on service intents, multi-tenancy policies and slices characteristics.

The orchestration should jointly coordinate the management of ML and monitoring functions, to guarantee the proper feeding of data during the various phases of ML training and runtime inference. Programmability becomes a fundamental enabler for this dynamicity. Open interfaces, e.g. RESTful APIs, should allow a dynamic configuration of heterogeneous data sources or probes for network, infrastructure or service monitoring, as well as proper handling of actions for ML training pipeline or ML models selection. Finally, the various virtual functions should be dynamically provisioned and migrated at runtime across the continuum of resources in extreme edge, edge, cloud. As consequence, orchestration must be able to operate over several domains, including extreme edge nodes which may be characterized by their own mobility and volatile resources and, as such, would require mechanisms for dynamic discovery and registration.

From an IM point of view, this innovation brings additional values for MNOs, enabling more automated and efficient operations of AI functions as integrated part of 6G network management. The AI orchestrator is key to exploit edge resources, optimize placement and data steering, also considering energy efficiency in ML pipelines' deployment. Moreover, its potential adoption in MLOps procedures makes it particularly suitable for software developers of AI/ML solutions to simplify and speed up the delivery of new algorithms and related ML models.

4 HEXA-X INNOVATION POTENTIAL TOWARD 6G MARKETS

According to the above described Innovation Management process in Hexa-X, incoming innovations are tracked by the IMC by identifying first of all the main characteristics and information related to these activities (Table I): each innovation includes its respective TRL (Technology Readiness Level)[1], both current and targeted values (at the project end), but also their potential (e.g. about 1-3 years after the project end). Also, in this tracking process all innovations are requested to specify their target use cases and the category of related beneficiaries of these use cases, once implemented in the market (note: this information is also helping to identify envisaged business models, e.g. B2B, B2C, B2B2C, …).

TABLE I. TRACKING OF HEXA-X INNOVATIONS

Innovation identifiers	e.g. Submission ID#, Title of the Idea, Lead innovator, members and their roles
Relevance to Hexa-X	e.g., Task 4.1-3, Task 5.1-2-4
TRL (Technology Readiness Level) [1-9]	Baseline TRL (at project start), e.g., 2
	Hexa-targeted TRL (at project end), e.g., 4
	Potential TRL (1-3y after project), e.g. 9
Use cases	e.g. AIaaS, CaaS, AI-assisted V2X
Use cases Beneficiary (stakeholder categories)	e.g., End-user, MNOs, Vertical (e.g.V2X), OEMs, Vertical, SME, Research, Govn/SmartCities/Citizen…

Then, as a very important step, innovators have to identify the targeted Key Performance Indicators (KPI) of their ideas, since a serious performance evaluation should be based on the comparison between KPI values from State of The Art (SoTA), *target* gains (i.e. those achievable during the project lifetime) and also *potential* gains (i.e., those gains obtained by mature/hypothetical products after the Hexa-X project lifetime). Talking about 6G innovations (and thus still not existing products), the definition itself of the relevant KPIs is often not a trivial task for innovators, and needs to be refined over time, together with the technical progress of the innovations; that's why this tracking process is maintaining over the project lifetime and updated at each 6-month innovation cycle). Moreover, the evaluation of the potential gain is often very delicate, and should be done carefully, on a case-by-case basis. As an example, reasonable performance assessments of the potential gains of a certain solution or device/component (e.g., RF power amplifiers in base stations) could be done by defining first the appropriate KPI (e.g. defining energy efficiency metrics of the PA) and via

[1] TRL levels are defined by the EC for the Horizon 2020 programme, here: https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/2018-2020/annexes/h2020-wp1820-annex-g-trl_en.pdf

projections based on the annual improvement of average products (e.g., average per-year 8% improvement for the parameters of the base station power models). Then, these projections can provide useful targets/estimations that may help innovators in better understanding the current level of maturity of their solutions (and the target gains by Hexa-X project end) against the market potential (after project end).

Innovations are then assessed by considering multiple aspects on their possible market exploitation after project end:

- **Path toward the potential**: scenarios envisaged to unlock the potential of the innovations (e.g., MNOs expanding collaboration with other sectors, or new industrial sectors being created, need for new terminals to stimulate customer needs, or again creation of new ventures/startups/spinoff envisaged to move faster);
- **Technology impact**: technological innovation areas in Hexa-X that can be impacted by the idea, in terms of generating high technological impact for innovators and Hexa-X companies (or in the market as whole);
- **Market impact**: areas of expected impact in the market, by identifying a targeted beneficiary of the idea; in fact, the innovation should provide a benefit to a specific pain that the beneficiary is experimenting or a gain over existing products; examples include impacts at various levels of the organizations (production, marketing, technological, financial, research, etc.);
- **Unlocked 6G potential**: opportunities that the innovation can unlock, in terms of enabling new services in the 6G era, for the organization (or in the ecosystem): examples here relate to providing better performance for existing services, or enabling innovative 6G services, expanding the Total Addressable Market (TAM) or even expanding its market share (SAM - Serviceable Addressable Market) [15].

TABLE II. OVERVIEW OF HEXA-X INNOVATIONS SUBMITTED TO IMC

Innovation # (nickname)	TRL[2] [1-9]	KPIs	Market impact	
			beneficiary	main benefits
HI #1 (FED-XAI)	(2,4,9)	Inferencing accuracy, Interpretability level	MNO, vertical segment (Car OEM)	MNOs expose more explainable 6G funct., to their customers
HI #2 (Resilient manufact. through 6G)	(3,5,6)	Round-Trip Time, Data rate	Network Vendor	Manufact. companies improve processes, product quality and reduce costs
HI #3 (ZED)	(2,3,5)	Energy autonomy, backscattering detection range / QoS	All sectors (End User, Network Vendor, MNO, vertical)	IoT tracking will attract the 6G markets of logistic companies and individuals
HI #4 (DEC CONOR)	(2,3,5)	Latency, Storage Cap, Proc Cap, Availability, Reliability, Resiliency	MNOs will manage their network more efficiently	Stimulate new forms of on-site service delivery, driving the digital transformation of industries
HI #5 (AI MANO)	(3,4,5)	AI/ML models training time. Creation time, automation	MNOs will manage their network more efficiently	reduction of IT costs in the networking industry will help more sustainable biz.
HI #6 (SIM-RF)	(2,3,4)	Maximum per-user data rate, minimum data rate	Network Vendor	6G radio network and RF implementation co-simulations are essential ensuring E2E radio performance
HI #7 (AI6GOAL)	(1,3,5)	Goal energy efficiency, End-to-end (E2E) delay, Goal effectiveness	MNO, Research	reduce costs and footprints for MNOs, with tighter interaction with service providers
HI #8 (Info Reliability)	(1,2,2)	Information Accuracy, Latency, Availability	End User, MNO	reliability measures of sensing info provided "as a service"
HI #9 (AI-aaS Orchestr.)	(2,4,7)	Data transferred, Computational load, E2E network slice provisioning time	MNO, SME	enable more automated and efficient operations of AI functions

[2] format: (x; y; z) = (Baseline TRL (at project start); Hexa-targeted TRL (at project end); Potential TRL (after project end e.g. 1-3 years))

Finally, for internal purposes only, innovations are assessed within the project, by considering multiple evaluation criteria and KPIs/KVIs, such as KPI gains and their targets against the respective potentials, but also project-internal ranking based on TR, impact and potential. These elements are used by IMC to provide recommendations at PMT and to innovators, on possible exploitation steps.

While Table II summarizes some aspects of the analysis conducted in the framework of Hexa-X Innovation Management, according to the current status of innovations, the process revealed a set of preliminary considerations (technical and business-oriented):

- the tracked innovations cover almost all the Hexa-X technology areas in the project [13], with a various maturity of their own KPI definitions and related performance assessment in the respective areas;
- in terms of path toward 6G potential, all innovations foresee the need for MNOs to expand their collaborations with other sectors (e.g., verticals); this is expected to be a turning point for 6G service providers;
- all solutions will likely enable innovative 6G services, where the main market beneficiaries are MNOs and OEMs, in few cases also SMEs and vendors (meaning network, device and test equipment vendors);
- majority of innovations help expanding stakeholders' SAM (market share), while still only a part of them (33%) has clear how to enable TAM expansion (this will likely be a decision from MNOs, in collaboration with verticals).

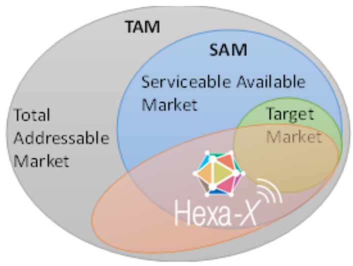

Fig. 4. Outlook of Hexa-X innovations on possible 6G market expansion.

In summary, many valid technologies are being implemented in the framework of Hexa-X. A key aspect for their actual deployment in future 6G systems will be a joint success of technical implementation and benefits for targeted users (e.g., performance improvement of existing use cases and/or enablement of new services), but also proper business decisions from stakeholders (e.g., MNO and verticals), also in terms of possible 6G market expansions (Fig. 5).

CONCLUSION

This paper presented the Innovation Management approach in Hexa-X and selected innovations (some of them also awarded by the EC Innovation Radar), with particular emphasis on the technical aspects of these findings coupled with their identified strategic value for future 6G market exploitation. Future work may include further exploring targeted market opportunities, as suggested exploitation steps for the Hexa-X project innovators.

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