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D1.2. Requirements and needs of scientific communities from ICT-based Research Infrastructures

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Scientific Large-scale Infrastructure for Computing Communication Experimental Studies **Design Study**

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Executive Summary

Digital Infrastructures and the Internet technologies lie at the heart of the digital transformation of our society. SLICES aspires to design, deploy and operate a heterogeneous fully programmable and virtualized, remotely accessible, European-wide research infrastructure, providing advanced computing, storage and network components, interconnected by dedicated high-speed links. It will be a flexible platform designed to support large-scale, experimental research focused on networking protocols, radio technologies, and services as well as data collection, distributed control and various edge-based computing architectures.

As the research in the sector covers simultaneously different fields, the principles need to be identified and prioritized, based on the requirements that have been identified by the respective community. In this document we detail our analysis and requirements for the current need for experimentation from the ICT research community. Different tools have been employed for collecting the technical and operational requirements from the scientific community, gathering inputs from participants with diverse backgrounds but working on research in the ICT sector. The results denote that the need for the deployment of the RI is evident, with the involvement of the industry of paramount importance for the definition of target use cases that will be executed on top.

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Acronyms

AAL	Active and Assisted Living
AI	Artificial Intelligence
AR	Augmented Reality
CN	Core Network
CPS	Cyber Physical System
C-V2X	Cellular Vehicle to everything
DI	Digital Infrastructure
EDIH	European Digital Innovation Hub
FIRE	Future Internet Research and Experimentation
FUHD	Full Ultra High Definition
GAFA	Google, Amazon, Facebook, Apple
HPC	High Performance Computing
IaaS	Infrastructure as a Service
ICT	Information Communication Technology
IoT	Internet of Things
LPWAN	Low-Power WAN
ML	Machine Learning
NFV	Network Functions Virtualization
NGI	Next Generation Internet
NGO	Non-governmental Organization
NR	New Radio (5G)
OAI	OpenAirInterface
RF	Radio Frequency
RI	Research Infrastructure
RPA	Robotic Process Automation
SDN	Software Defined Networking
SLA	Service Level Agreement
SME	Small or Medium-sized Enterprise
UAV	Unmanned Aerial Vehicle
VR	Virtual Reality
WAN	Wide Area Network

1 Introduction

Digital Infrastructures and the Internet technologies lie at the heart of the digital transformation of our society. The recent global crisis caused by the COVID-19 pandemic pinpoints the important role of the Digital Infrastructures, and outlines how they should be reinforced for the coming years. SLICES aspires to design, deploy and operate a heterogeneous highly distributed infrastructure, that will drive experimentally-driven research over real, scalable Digital Infrastructures. Nevertheless, as the research in the sector covers simultaneously different fields, the principles need to be identified and prioritized, based on the requirements that have been identified by the respective community.

This report summarizes the analysis of the current need for experimentation from the ICT research community. The analysis has been performed by the SLICES consortium, fostering inputs from different institutes at a global level, consolidated as the requirements for experimentation in the SLICES research infrastructure. Different tools have been employed for collecting the technical and operational requirements from the scientific community, gathering inputs from participants with diverse backgrounds but working on research in the ICT sector. Two main tools were used and are reported in this document: 1) A survey study, conducted by the SLICES consortium, and 2) a workshop organized by SLICES.

2 User Survey

2.1 User Survey Methodology

A user survey was conducted during December 2020 and January 2021, targeting in gathering inputs from potential SLICES users from the research community. The survey was distributed among the research community to identify the technological domains, the use cases, the requirements and other expectations from the future users of the SLICES research infrastructure. The consultation of the research community permits to know the real demand for ICT research infrastructure. The results of the survey are presented and analysed in this section.

The partners of the SLICES-DS project have proposed numerous questions in the initial phase of the survey conception. After the common review of the survey draft, including the selection of the most relevant questions, Mandat International created the survey on the LimeSurvey server managed in the IoT Lab testbed. The survey was distributed through mailing lists related to ICT research in Europe. For instance, the mailing lists of the Fed4FIRE+ project were used for the survey distribution, and other mailing lists were used by several partners to distribute the survey.

At the end, **226 people took part in the survey**, with 67 of them answering all the questions of the SLICES-DS survey.

2.2 User Background Results

The initial survey questions targeted at getting the background information from the participants, and location.

The first question was: *Would you consider yourself as:*

- *Academic/student;*
- *SME/industry;*
- *Public administration;*
- *Other.*

The following figure displays the received results:

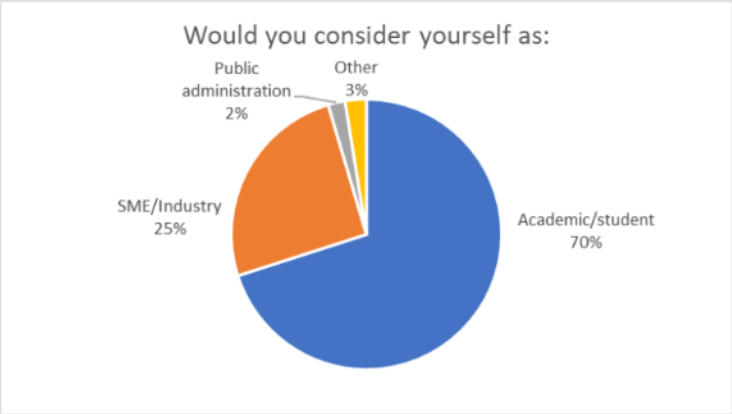

Figure 1 – Organisations

The main participants categories are 70% academia (including students) and 25% SME/Industry. This is in line with what we observe in our current ICT testbeds and with our objective for SLICES RI where we target academia and 20% usage from industry. Thus, it is representative of our targeted users categories.

The category "Other" encompasses NGOs and public-private foundations.

The second question of the survey permits to locate the responders: *Where do you live?*

The available possibilities are listed as follows:

- Europe;
- Asia and Pacific;
- North America;
- Latin America and Caribbean;
- Africa;
- Middle-East.

To simplify the visualisation of the results, all the parts of the world outside Europe were grouped in the category "Other":

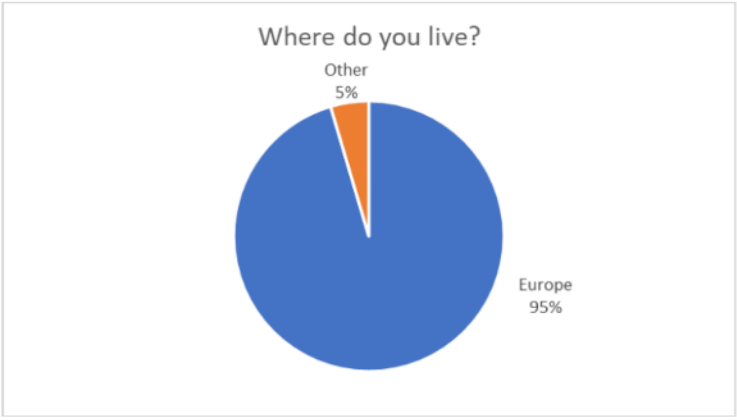

Figure 2 – Locations

The participants are mostly European as 95% of the responders are based in Europe. If we compare this result, we are not in line with our pre-existing testbeds where 50% of users are non-European, but this is more in line with the target of SLICES to increase the percentage of European users to 70% still keeping a high level of internationalization. Thus the needs that we will identify from the users will be focused mostly on the European demand, which is good to understand the European need that we will have to answer within ESFRI, and which is also good to attract new European users as it is our objective. Moreover, we think, from experience in our testbeds, that the international demand is quite similar to the European demand, but we have to keep in mind for future steps to also reach out and understand the demand from users outside Europe to fit our objective of 30% of international users.

2.2.1 Key Topics and Challenges

The exact question was: *What are the key topics and challenges to be researched in the coming years for supporting digital transformation and/or Network - Cloud - Edge - Internet of Things integration?*

The answers to this open question are illustrated in the following figure:

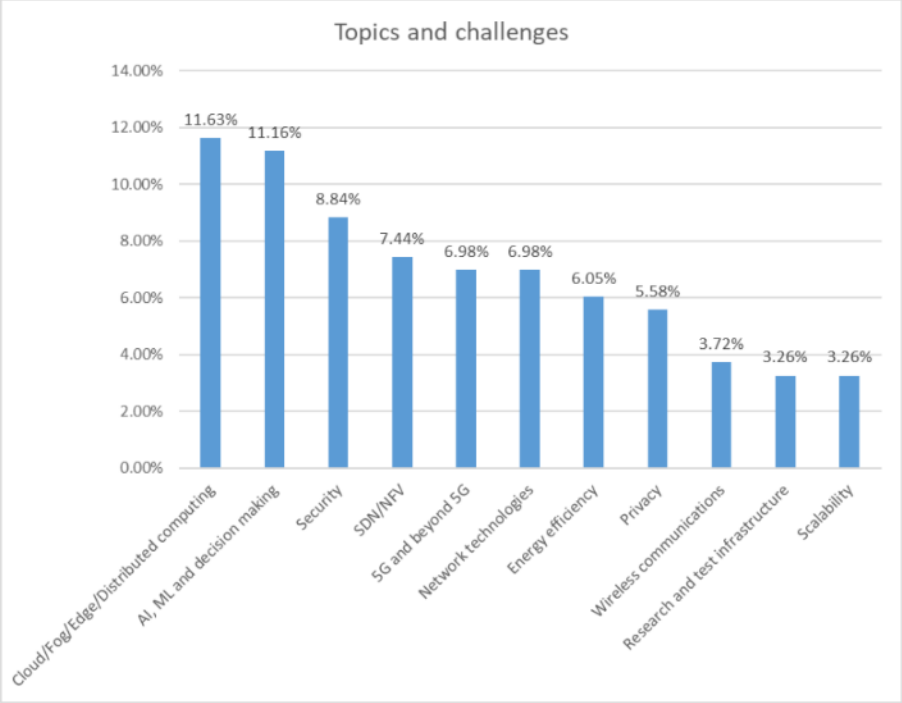

Figure 3 – Key topics and challenges

The most relevant responses are shown in the figure above and the challenges to be addressed by the research community are mainly:

- **The distribution of the computing in the different formats: cloud, fog, edge and distributed.** The architecture of the computing infrastructure is yet under study. The interactions between the cloud, the fog and the edge should be defined at the same time. The interoperability between the data generated in the context of the Internet of Things should be improved; indeed, the increasing number of data sources provided by the cloud, the fog and the edge make interoperability harder;

- **Artificial Intelligence (AI) and Machine Learning (ML):** The main challenge of this topic is how to use AI and ML to optimise the management of the network and the data flows transmitted at high rate;
- **Security:** The security by design is clearly a must-have. Testing the implementation of the security at large scale is also a challenge;
- **SDN/NFV:** The programmability brought by SDN and NFV technologies should be explored more, as they allow a complete automated management of the network, linked to the new developments of AI and ML;
- **5G and beyond 5G:** The 5G and the planned 6G should be developed at the European level;
- **Network technologies:** They should be more investigated to permit the realisation of use cases demanding high performance, low latency, etc.;
- **Energy efficiency:** The computing should be environment-friendly and so, a limited energy consumption is sought through research;
- **Privacy:** The data protection is very important and it should be correctly addressed during the development of new technologies;
- **Wireless communications:** The latency should be reduced and the throughput should be increased in the context of wireless communications, like Wi-Fi, but also for the related radio technologies;
- **Research and test infrastructures:** The availability of Research Infrastructures (RIs) is instrumental to support our research agenda. Better research infrastructures are needed to experiment with new use cases coming from the new technologies;
- **Scalability:** The lack of dedicated research and test infrastructures permitting the evaluation of the scalability is evident for a share of the responders.

Other challenges and topics to be addressed by the research are enumerated below:

- Interoperability, in particular for IoT;
- IoT in general;
- IoT integration, associated with the communication protocols used by the IoT devices;
- Autonomous vehicles: drones, cars;
- Blockchain and cryptocurrency;
- New applications or services;
- Remote working, including remote meetings: new tools to be developed to ensure better productivity at home. Probably a consequence of the COVID-19 situation;
- Sustainability: How to ensure the sustainability of the new solutions to be developed in the research infrastructure?;
- Big data: The realisation of experiments related to big data is currently difficult for a minority of the responders;
- Data analytics: New tools for data analytics should be provided by the research infrastructures;
- Hardware: The development of the hardware should continue, notably for IoT sensors and microprocessors;
- Quantum computing;
- Standardisation, in particular to ensure interoperability;
- Storage capacity: More memory space needed to realise experiments. A higher volume of data is expected to be used in the future experiments to measure the scalability for instance;
- AAL (Active and Assisted Living);
- AR (Augmented Reality);
- Cost reduction. Experiments are needed to estimate the possible reductions of costs;
- CPS (Cyber-Physical System);

- European services: Cloud services provided by European organisations to avoid the dependence on American services;
- Food production;
- High Performance Computing (HPC);
- RPA (Robotic Process Automation).

2.2.2 Functionalities

The question asked was: *What capabilities or functionalities are currently missing in terms of ICT research infrastructure?*

This open question brings a lot of answers which are related to the topics and challenges mentioned in the previous questions. The principal results are shown here:

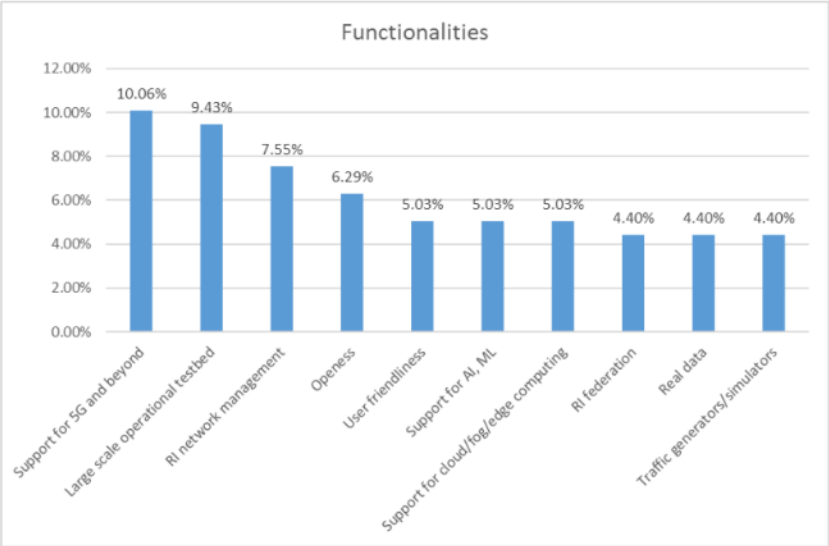

Figure 4 – Functionalities

The main functionalities proposed by the responders are the following:

- **Support for 5G and beyond 5G:** It should be possible to create experiments linked to 5G in the research infrastructures;
- **Large scale operational testbed:** It should be very similar to real deployments in the industry;
- **RI network management:** The experimenters should be able to manage the network used for their experiments.;
- **Openness**;
- **Support for AI and ML:** More experiments associated to AI and ML should be realised in research infrastructures;
- **Support for cloud, fog and edge computing;**
- **RI federation:** Mainly to ensure the scalability required for some tests;
- **Real data:** The research infrastructure should provide a catalogue of real data sets to be used in the experiments;
- **Traffic generators and simulators:** Several responders point out the lack of traffic generators and simulators in the current research infrastructures.

So, the ideal research infrastructure is dedicated to experiment all the interactions between the cloud, the fog and the edge in a real environment, using the latest communication technologies like 5G and 6G. The research infrastructure should be sufficiently large and similar to real industrial deployments to conduct very realistic tests. The experimenters should be able to manage the network provided by the research infrastructure. The access to the research infrastructure is completely open. The RI permits also to use AI and ML for all kinds of experiments, in particular for the interactions with the cloud, the fog, the edge and the network. The scalability is an important point to develop through RI federation. Real data sets should be provided also by the research infrastructure as well as the traffic generators.

Other functionalities suggested by the survey are:

- Support for RF, RAN and RFID: The experiments about radio technologies are high in demand by the responders;
- Energy monitoring: The research infrastructure should provide tools to measure the energy consumption and should be itself energy efficient;
- Devices provided by the RIs: computers, robots, UAVs, IoT;
- HPC resources;
- Support for SDN/NFV;
- Support for connected vehicles;
- Support for Low Power WANs (LPWANs);
- Replication of experiments.
- Storage capacities;
- Qualified technicians;
- Cybersecurity;
- Big data analytics;
- Collaborative tools;
- Integration of 3rd party tools;
- Transparency;
- Support for streaming;
- Quantum computing;
- European services: to avoid GAFA (Google, Amazon, Facebook and Apple);
- Aerial, space, maritime networks: The RI should have access to such networks;
- Non-technical tests: The research infrastructure should provide tools to evaluate the experiments under the point of view of the users. For example, does the proposed solution tested in the RI bring any advantages for the users like comfort, cost reduction?;
- Tutorial and courses;
- List of RIs and related Terms and Conditions (T&C);
- Support for AR;
- Support for Industry 4.0;
- Support for smart agriculture.

2.2.3 Use Cases

The exact open question was: *Could you suggest an example of ICT research (use case) that would like to run on a European research infrastructure?*

The responders provided different use cases to be realised in a research infrastructure. The use cases are focused on the following subjects:

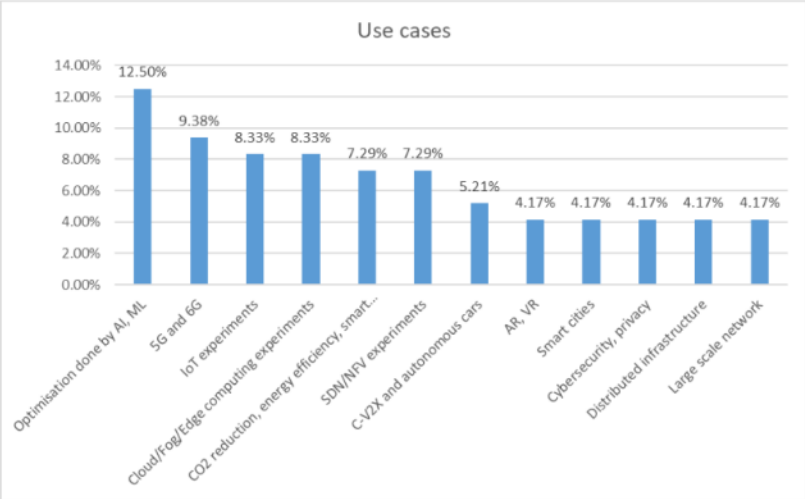

Figure 5 – Use cases

In order of relevance, the proposed use cases concern:

- Optimisation done by AI and ML: The dedicated experiments should demonstrate how the AI and ML can optimise the decision making;
- 5G and 6G;
- IoT experiments;
- Cloud, fog, edge computing experiments;
- CO2 reduction, energy efficiency, smart grid;
- SDN/NFV experiments;
- C-V2X and autonomous cars;
- AR and VR;
- Smart cities;
- Cybersecurity and privacy;
- Distributed infrastructure: How to handle a distributed infrastructure? Real experiments are to be set to have a clear vision for the future distributed infrastructure management;
- Large scale network.

Other use cases were also suggested, but by a limited number of people:

- UAVs and autonomous vehicles for smart agriculture;
- Industry 4.0;
- Optimisation of the mobility;
- Prototyping of applications;
- Real traffic injected in a network;
- Validation of new solutions;
- RFID for security in the art;
- Artificial brain;
- Space wireless experiments;
- Management of education certificates;
- Blockchain;
- Data integration;
- Big data processing;
- Human assistance.

Some **use cases** are described below:

- Mobility is changing as people connected with devices can make better choices on modes and vehicles (also interconnected) depending on the time of the day and evolving conditions. This can be simulated and optimized if tested in a realistic infrastructure;
- Generate a realistic dataset to be used in ML solutions to address many network-related problems. The dataset will be structured to obtain the performance metrics of a network using multiple topologies, network configurations and traffic matrices. The dataset can be used to train a GNN model which can later be incorporated in a SDN control panel to make fast and optimal decisions;
- A framework allowing to test the same applications in different cities. The infrastructure should provide means to integrate data that can be gathered by various data sources in the city (IoT data, legacy platforms, cloud sourcing, open data platforms, etc.). The infrastructure can provide a common repository of applications, which can be filled up by experimental apps developed by the community. The participant cities could decide which application to test based on the current challenges they have in their city;
- Agriculture enhanced with autonomous vehicles for crop and yield management as well as physical security systems with alarms, also enhanced with unmanned operations;
- An example of a use case that could use such a research infrastructure would be a new in-car 8K video communications services for enhanced safe fully autonomous vehicles. This use case has the ambition to create a life-saving innovative system empowered by the new EU research infrastructure, to reduce car accidents in the cars of the future, by focusing on the instrumentations of the interior of a car to perform highly detailed human behaviour analytics based on video information. A test vehicle can be equipped with 4 FUHD 8K video cameras to allow FUHD to enable super accurate human analytics when on-road. While, on the one hand, it is important to ensure real-time uplink video transmission so that driver status data reaches the analysis system in time, on the other hand, the processing of such data and the transmission of warning signals back should be fast enough to warn drivers and give them time to perceive, process and react to those events. This will impose a significant challenge where the network, at the same time, should provide ultra-high bandwidth, ultra-low latency and ultra-high reliability. The system requires to face a massive amount of data to be streamed and processed with an estimated 191 Gbps per car (7680 width × 4320 height * 60 FPS * 3 colour channels * 4 cameras * 8 bits of depth). This amount of processing capabilities for this use case requires the usage of both off-loading of computational capabilities to the 6G compatible research infrastructure and usage of advanced video codec that will reduce throughput to an estimated 1-2 Gbps per car which clearly cannot be supported by the existing 5G networks at scale.

The analysis of the use cases proposed by the research community shows that there are in fact two categories of use cases. The first category is the core network which is the common layer where the research should be focused to provide new technological solutions to improve the communications and the data exchange between the connected resources through the core network. The second category of use cases is more focused on the different verticals encountered in the ICT domains. Typically, specific research areas are the connected vehicles, the smart grid and smart cities; every vertical has its own requirements and needs based on its use cases. This should be taken into account when designing a solution dedicated to a specific vertical.

2.2.4 Perceived Benefits

The question asked in the survey was: *How would you assess the usefulness of developing a European large-scale research infrastructure to support research and innovation in the Network - Cloud - Edge - Internet of Things domains?*

The provided responses have generated the following figure:

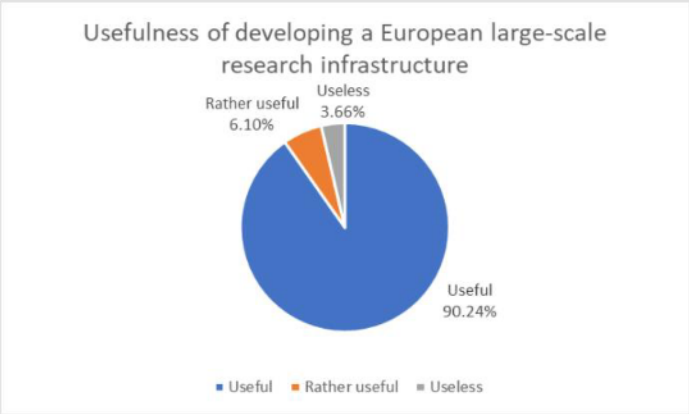

Figure 6 – Usefulness

The creation of a large-scale research infrastructure in Europe is considered as useful by a large majority of the responders (90.24%).

Moreover, a second question was asked on the perceived benefits of the infrastructure to industry and SMEs. The question was formulated like this: *Do you think that a European large scale ICT research infrastructure would benefit to the industry and SMEs?*

The responses were positive indeed:

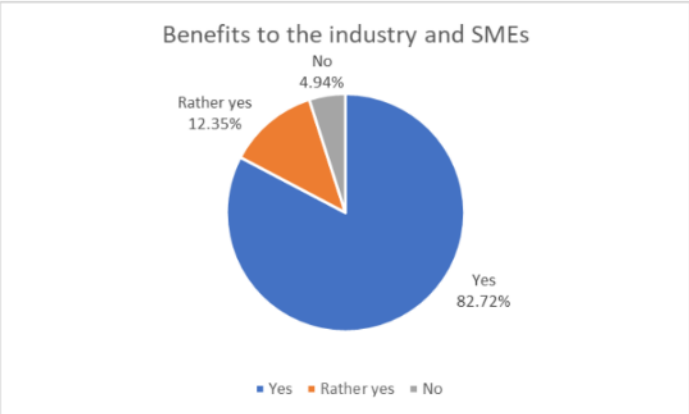

Figure 7 – Benefits

A very large portion of the responders (82.72%) have positive feedback concerning the benefits brought by the research infrastructure to the European industry and the SMEs.

2.2.5 Liaison with Industry and International Alliances

The question was: *Do you think the European industry should be involved in building and operating the research infrastructures and why?*

The following chart shows how many responders agree or not to the involvement of the European industry in the research infrastructures:

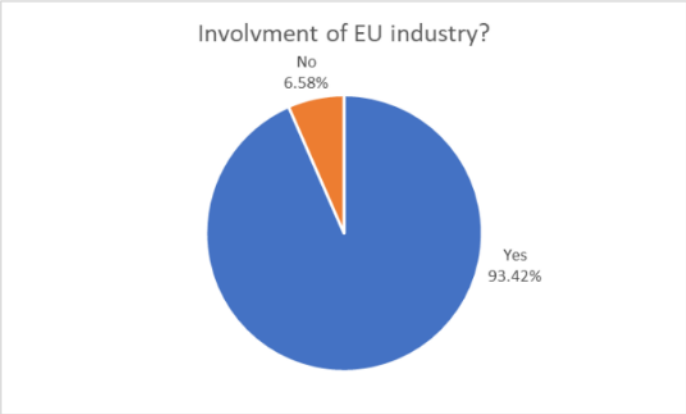

Figure 8 – Involvement of the EU industry

The survey shows that a large majority of the responders (93.42%) supports the involvement of the industry in the building and operation of new RIs.

Based on the previous results, the reasons to involve the European industry are detailed below:

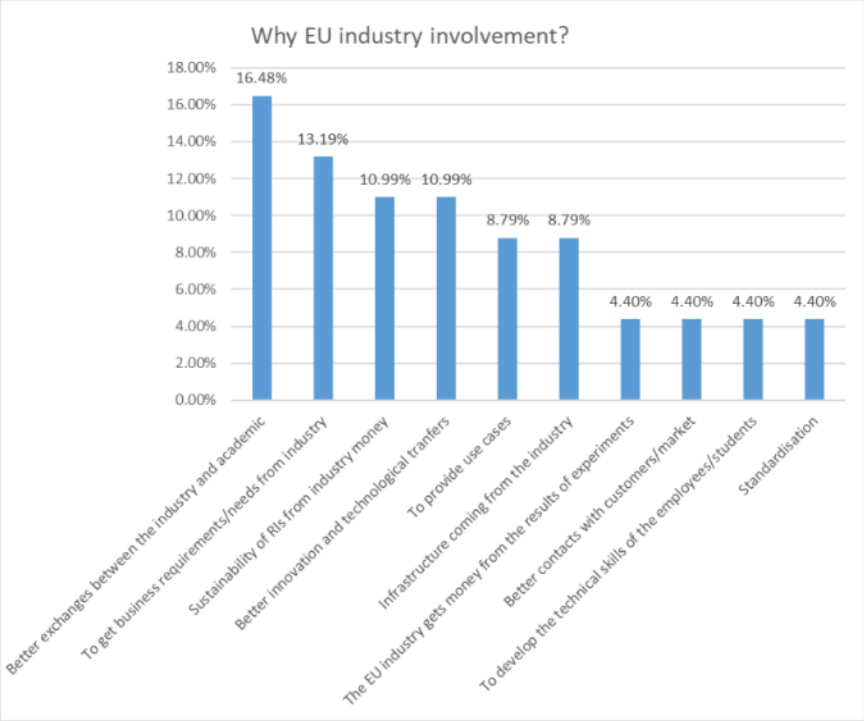

Figure 9 – Reasons to involve the EU industry

The reasons given in the survey are:

- Better exchanges between the industry and the academic world;
- To get business requirements and needs from the EU industry;
- To ensure the sustainability of the research infrastructures from the money given by the European industry;
- Better innovations and technological transfers;
- To obtain use cases from the EU industry;
- The infrastructure is built by the industry;
- The European industry gets money from the results of the experiments;
- Better contacts with customers and the market through the European industry;
- To develop the technical skills of the employees and students;
- The standardisation.

Other reasons were also indicated by few responders:

- The deployment of the applications in the industry;
- To accelerate the commercialisation;
- The alignment of the research infrastructures with the industrial infrastructures;
- GDPR issues to be tackled by the industry;
- To ease the access to the research infrastructures;
- To ensure the independence from GAFA.

A second question was asked on the alliances that each participant is involved in. The question was: *What are according to you the main alliances and fora active in digital transformation and/or Network - Cloud - Edge - Internet of Things domain in Europe?*

This open question brought a lot of different answers compiled in this figure, because the question was general in fact:

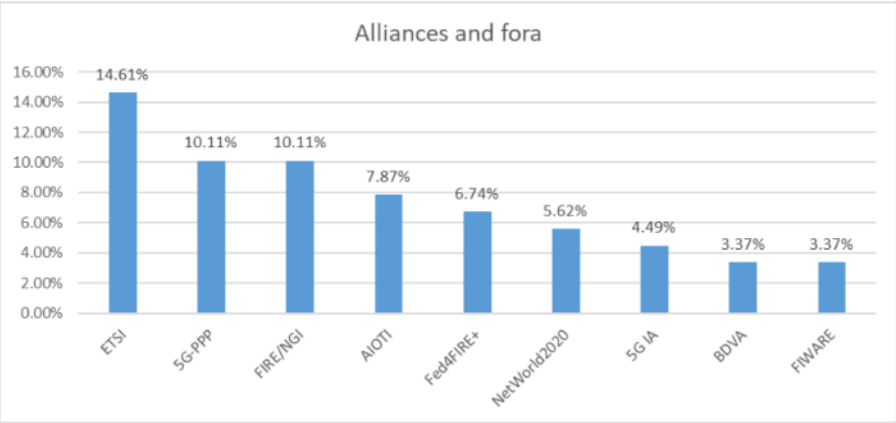

Figure 10 – Alliances and fora in EU

Following the responders, the main alliances and fora active in Europe are:

- ETSI;
- 5G-PPP;
- FIRE/NGI;
- AIOTI;
- Fed4FIRE+;
- NetWorld2020;
- 5G IA;
- BDVA;
- FIWARE;

Other responses encompass the following alliances and fora:

- 3GPP;
- 5TONIC;
- EDIH (European Digital Innovation Hubs);
- GEANT;
- ISO/IEC;
- 5G-ACIA;
- EECC (European Edge Computing Consortium);
- EIP-SCC;
- ENISA;
- ENoLL;
- Europrivacy;
- ERNCIP (European Reference Network for Critical Infrastructure Protection);
- European Partnership for smart networks and services;
- EuroXR, the European network for Virtual Reality, Augmented Reality and Mixed Reality;
- Horizon EU;
- IEEE EU;
- IoT Forum;
- ITU;
- LoRa Alliance;
- NESSI, the Networked European Software and Services Initiative;
- OAI Alliance (OAI = OpenAirInterface);
- OSM (Open-Source MANO);
- PRACE (Partnership for Advanced Computing in Europe);
- SAE;
- UTA (Urban Technology Alliance);

Then the same open question was asked for outside Europe: *What are according to you the main alliances and fora active in digital transformation and/or Network - Cloud - Edge - Internet of Things domain outside Europe?*

Plenty of answers were received as the question is general and not focused on RI specifically:

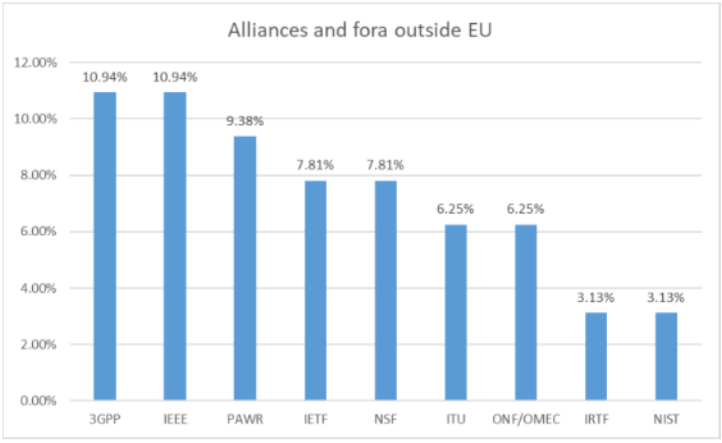

Figure 11 – Alliances and fora outside EU

The most relevant alliances and fora outside Europe are:

- 3GPP;
- IEEE.
- PAWR (Platforms for Advanced Wireless Research);
- IETF;
- NSF (National Science Foundation);
- ITU;
- ONF/OMEC (Open Networking Foundation/Open Mobile Evolved Core);
- IRTF;
- NIST.

Other organisations, alliances and fora were cited:

- 5G-ACIA;
- ANSI;
- CENI, the Chinese equivalent of GENI and Fed4FIRE;
- Edge Computing Association;
- GENI;
- GSMA;
- IGF (Internet Governance Forum);
- INATBA (International Association for Trusted Blockchain Applications);
- Industrial Internet Consortium;
- ISF (Information Security Forum);
- ISO/IEC;
- ISOC, the Internet Society;
- Kaggle, the largest data science community in the world;
- LoRa Alliance;
- O-RAN Alliance;
- PlanetLab;
- TM Forum;
- UTA (Urban Technology Alliance);
- WBA (Wireless Broadband Alliance);
- Wi-Fi Alliance;
- Zindi Africa, a data science competition platform in Africa.

Regarding standardization efforts, the open question posed was: *What should be the priority standardization effort to support digital transformation and/or Cloud - Edge - IoT integration? What is missing in terms of standards for digital transformation and Cloud – Edge – IoT integration?*

The received responses were varying as follows in the Figure:

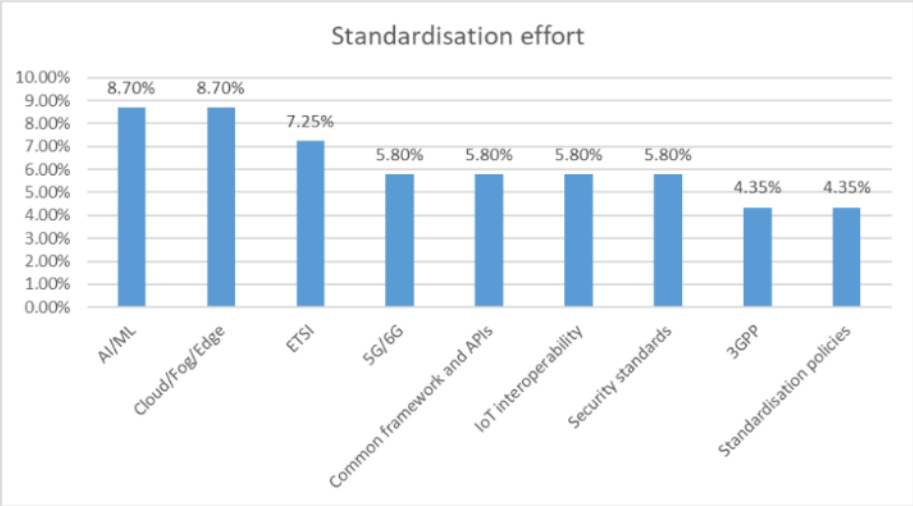

Figure 12 – Standardisation effort

Some details on the answers are provided below:

- **AI/ML:** Some standards are actually missing in this area;
- **Cloud/Fog/Edge**: More standardisation is required, following the responders;
- **ETSI:** It is the principal SDO where the standardisation should happen;
- **5G/6G:** An absolute need for Europe to be present in the standardisation of 5G and 6G;
- **Common framework and APIs:** Standardised APIs used in the research infrastructure can facilitate the development of new technical solutions;
- **IoT interoperability**, in particular for the communication protocols and data models;
- **Security standards**: More standards are requested, also for the organisational aspect of the security;
- **3GPP**;
- **Standardisation policies:** How to reduce the work in the process of standardisation? Less bureaucracy in the different phases of standardisation.

Other suggestions and recommendations concerning the standardisation efforts to be done in the future are listed below:

- Benchmarking: Standardisation of procedures for benchmarking;
- Data models to be standardised;
- Hardware test procedures;
- IaaS standardisation;
- IETF;
- IoT scalability test procedures;
- oneM2M, in particular for the IoT interoperability;
- Privacy standards;
- SDN/NFV interoperability;

- Standardisation about 3D.
- Certification.
- Communication protocols to be standardised.
- Full control of the user on the infrastructure: Some work on standardisation to be done.
- Standardisation on gestures.
- ITU.
- NGSI-LD.
- RI federation.
- SLA: The goal is to have common SLAs across testbeds/RIs.
- Time to market faster: How the standardisation can help to speed up the time to market of products or services?
- Trustworthiness.
- Standardisation of the voice in the context of the control of devices.

2.2.6 Importance and need for the RI from verticals

The basic question was: *How would you assess the importance of the following requirements for the research infrastructure?*

The proposed requirements are the following:

- Scalability of the research infrastructure;
- User-friendliness of the user interface;
- Data analytics tools and functions;
- Diversity of the communication protocols supported;
- Security and confidentiality of the experiment;
- Remotely accessible.

The question about the requirement on the scalability of the research infrastructure provided the following results:

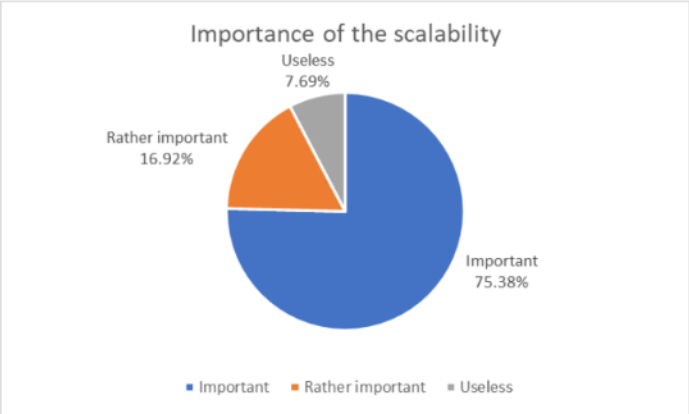

Figure 13 – Importance of the scalability of the RI

75.38% of the responders estimate that the scalability of the research infrastructure is an important requirement.

The results of the question about the user-friendliness of the user interface are shown below:

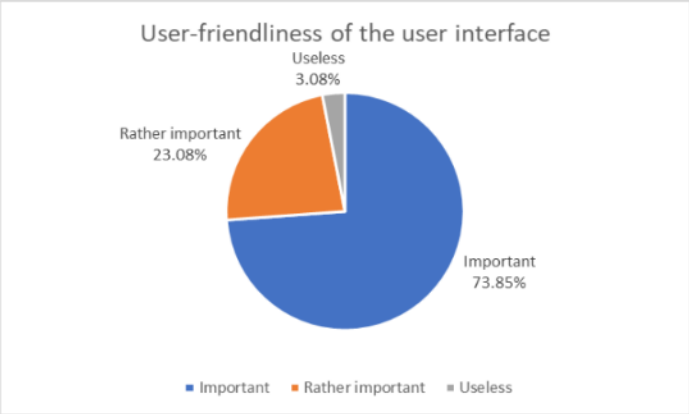

Figure 14 – Importance of the user-friendliness

The majority of the responders (73.85%) thinks that the user-friendliness is important for a RI.

The importance of the data analytics tools and functions is illustrated below:

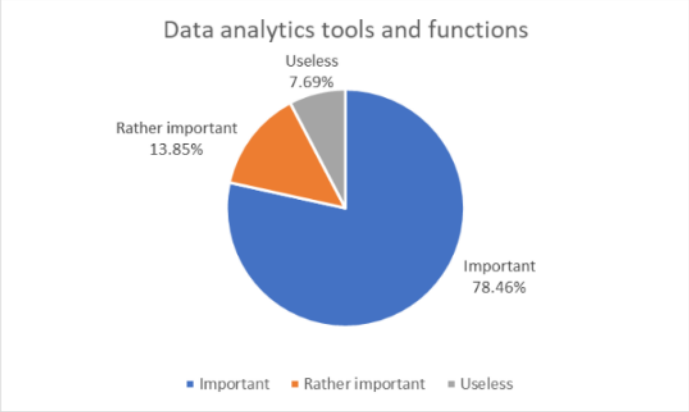

Figure 15 – Data analytics tools

The data analytics tools and functions are important to be used in the research infrastructure for 78.46% of the responders.

The results concerning the importance of the diversity of communication protocols are displayed below:

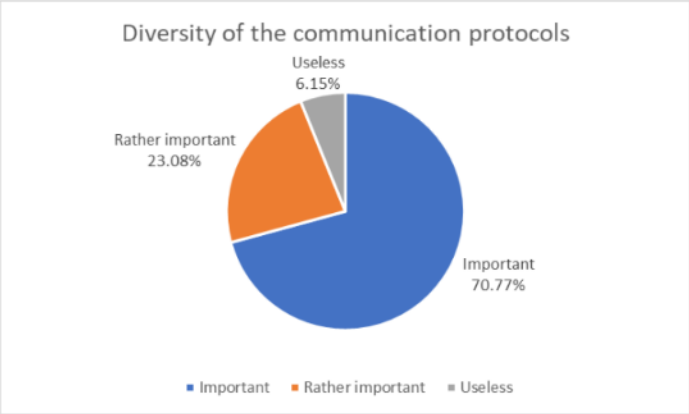

Figure 16 – Diversity of the communication protocols

70.77% of the responders think that the diversity of the communication protocols supported by the research infrastructure are important.

The security and the confidentiality of the experiment is an important requirement as shown in the following figure:

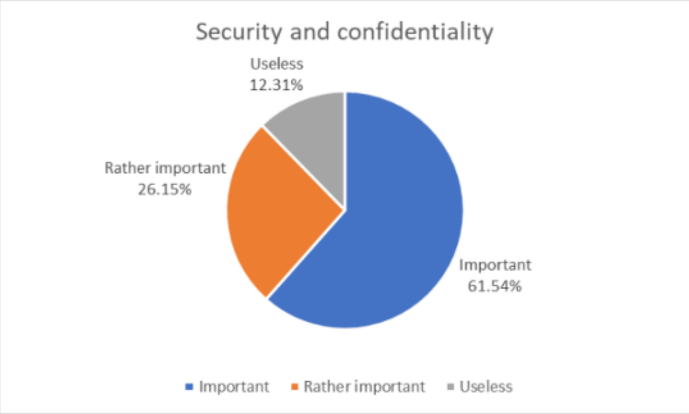

Figure 17 – Security and confidentiality

The requirement on the security and confidentiality inside the research infrastructure must be fulfilled as an important topic for 61.54% of the responders.

The following chart illustrates the importance of a research infrastructure remotely accessible:

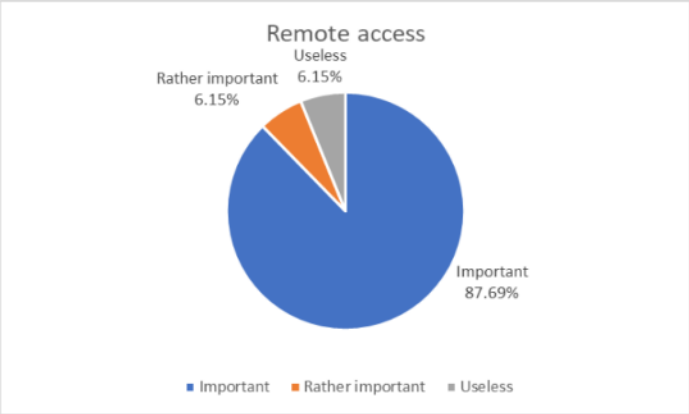

Figure 18 – Remote access to RI

87.69% of the responders estimate that the remote access to research infrastructure is important.

The following table illustrates the requirements in function of their importance:

Table 1 – Importance of the requirements

Requirements	Important [%]
Remote access	87.69
Data analytics tools and functions	78.46
Scalability	75.38
User-friendliness	73.85
Diversity of communication protocols	70.77
Security and confidentiality	61.54

The next question in the survey was: *How would you assess the importance of the following areas of research in the coming years?*

The suggested areas of research are defined as follows:

- Internet of Things;
- Edge computing;
- Artificial Intelligence;
- Cellular networks;
- Cloud computing;
- Future network architecture;
- Blockchain and distributed ledger;
- Green and energy efficient ICT;
- Data analytics.

The results given by the research community will permit to identify the best use cases for SLICES.

The importance of the research on IoT is displayed below. The Internet of Things encompasses for example the e-health, the smart cities, etc.

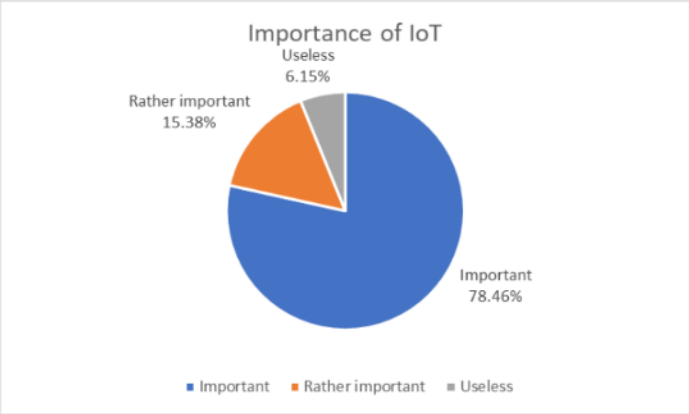

Figure 19 – Internet of Things

The responders have given the following importance concerning the research on the edge computing:

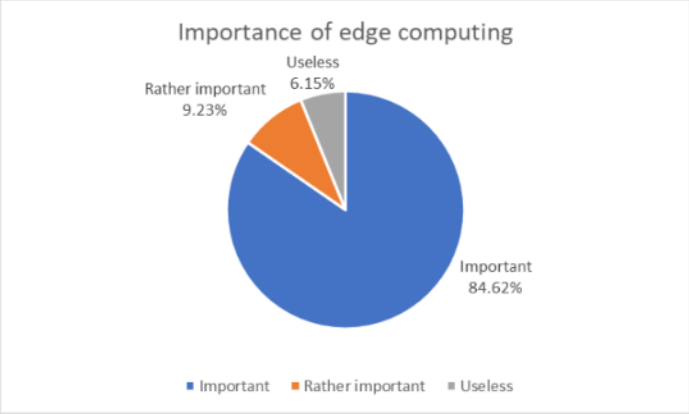

Figure 20 – Edge computing

The importance of the research on the Artificial Intelligence (AI) is noted by the responders as follows:

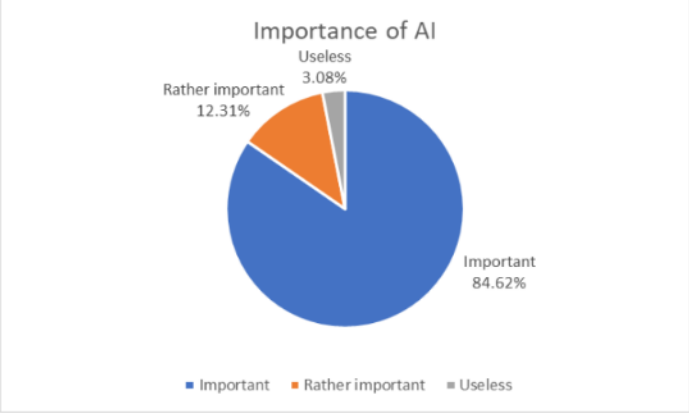

Figure 21 – Artificial Intelligence

This question concerns the importance of the research on cellular networks. 5G, 6G and NB-IoT are typical research topics addressed in the cellular networks.

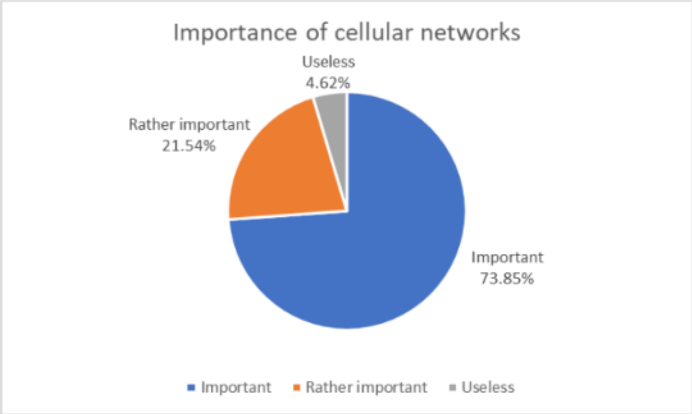

Figure 22 – Cellular networks

The answers for the importance of the research on the cloud computing are shown below:

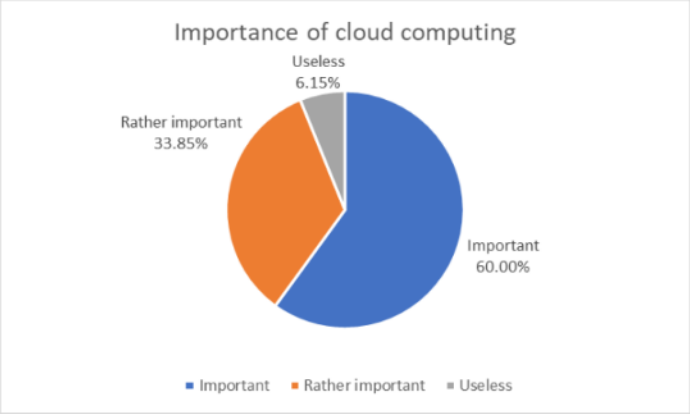

Figure 23 – Cloud computing

The importance of the research on the future network architecture is evaluated in this question. The technologies used in this context are the virtualisation, in particular SDN and NFV, and also the network slicing. The results are displayed here:

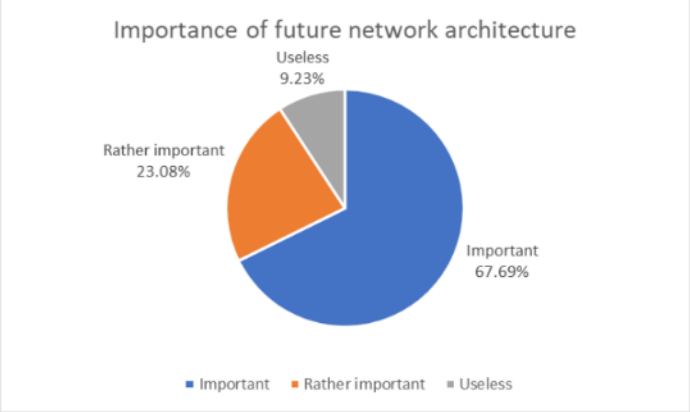

Figure 24 – Future network architecture

This question is related to the importance of the research on the blockchain and on the distributed ledger. The corresponding chart gives these results:

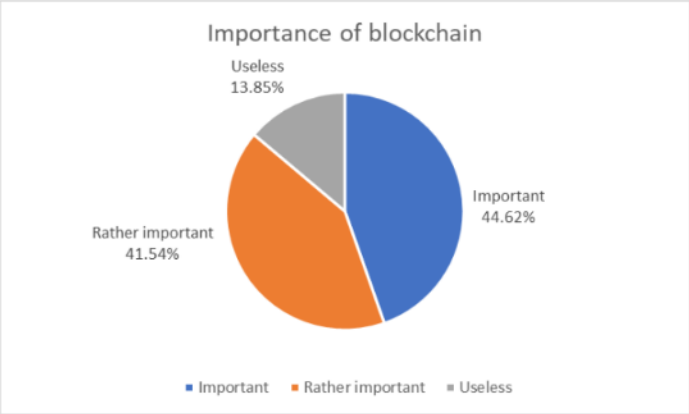

Figure 25 – Blockchain and distributed ledger

This question is addressing the importance of the research on the green and energy efficient ICT. The answers are illustrated below:

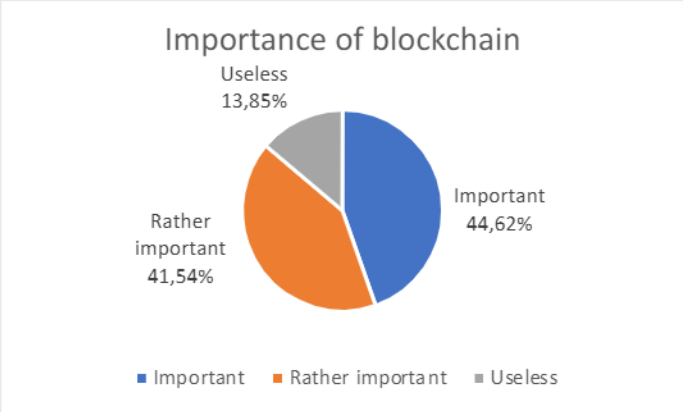

Figure 26 – Green and energy efficient ICT

The evaluation of the importance of the research on the data analytics is done through this question and the corresponding results are displayed here:

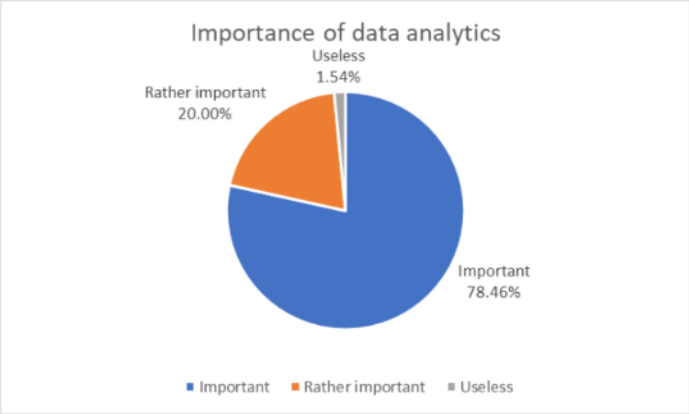

Figure 27 – Data analytics

The following table shows the areas of research based on their importance:

Table 2 – Importance of the research areas

Area of research	Important [%]
Artificial Intelligence	84.62
Edge computing	84.62
Data analytics	78.46
Internet of Things	78.46
Cellular networks	73.85
Future network architecture	67.69
Cloud computing	60.00
Green and energy efficient ICT	44.62
Blockchain	44.62

The figure below illustrates which are the most important areas of research for the responders:

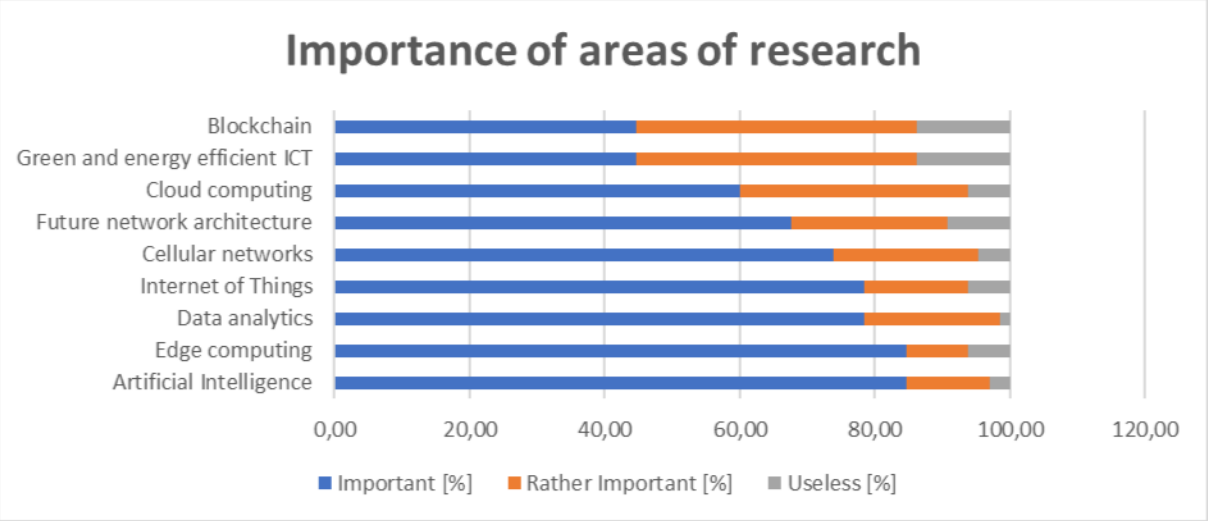

Figure 28 – Importance of areas of research

The last question on the survey was: *How do you assess the usefulness and need of research infrastructure to support?*

The support provided by the research infrastructure concerns each of these topics:

- Smart farming.
- e-health.
- Clean and sustainable energy.
- Mobility and connected vehicles.

- Smart manufacturing and supply chains.
- Telecommunication and network technology.
- Artificial Intelligence.
- Nanotechnology and electronic components.
- Cybersecurity.
- Privacy and data protection.

The results of each topic are presented in this section and allow the identification of use cases for verticals and core network.

The question was related to the usefulness and need of research infrastructure for the smart farming/agriculture domain. The results are displayed in this graph:

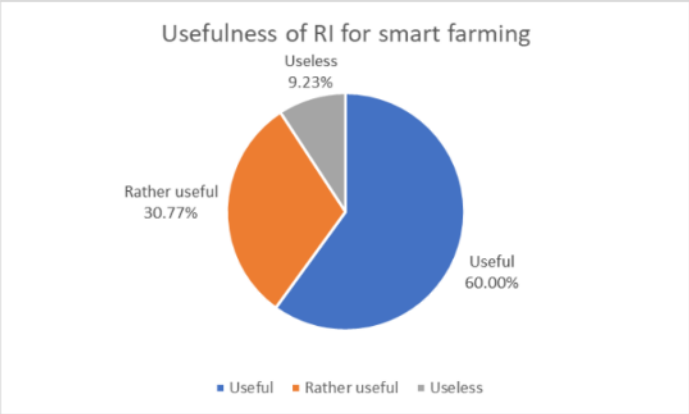

Figure 29 – Usefulness of RI for smart farming

The results concerning the usefulness and the need of research infrastructure for the e-health domain are illustrated below:

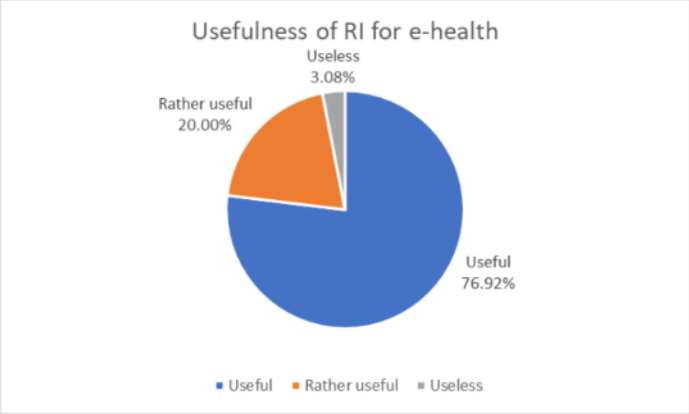

Figure 30 – Usefulness of RI for e-health

The following question is related to the usefulness and the need of research infrastructure for the research about the clean and sustainable energy. The corresponding results are shown in this chart:

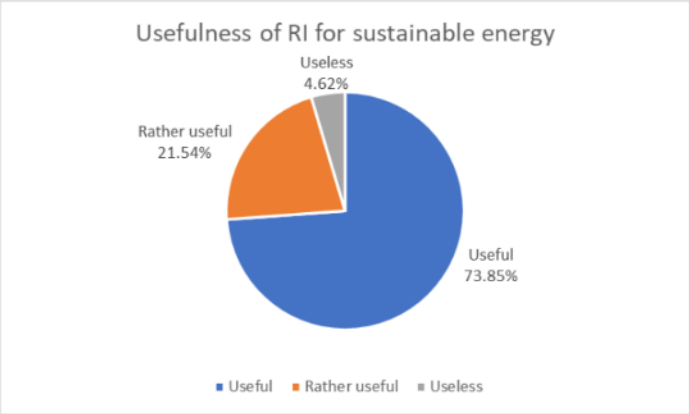

Figure 31 – Usefulness of RI for clean and sustainable energy

This question is addressing the usefulness and the need of RI for the research on the mobility and connected vehicles. The related answers are displayed here:

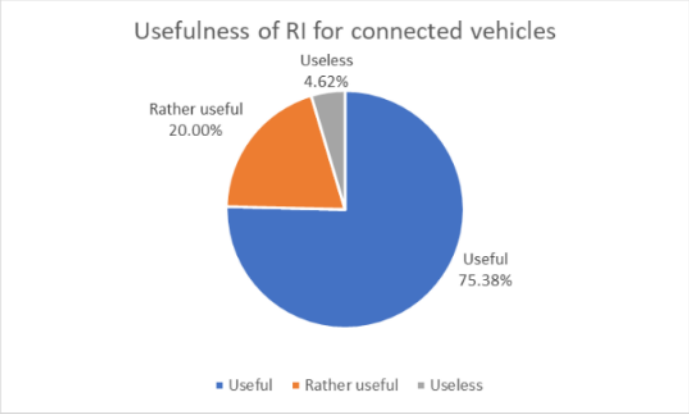

Figure 32 – Usefulness of RI for mobility and connected vehicles

The usefulness and the need of research infrastructure for the research linked to the smart manufacturing and the supply chains were evaluated through this question. The results are shown below:

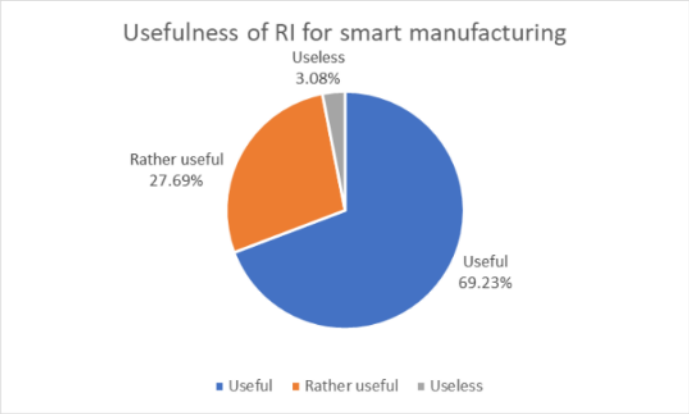

Figure 33 – Usefulness of RI for smart manufacturing and supply chains

The following question concerns the usefulness and need of RI for the research concerning the telecommunication and the network technology. The results are available in this graph:

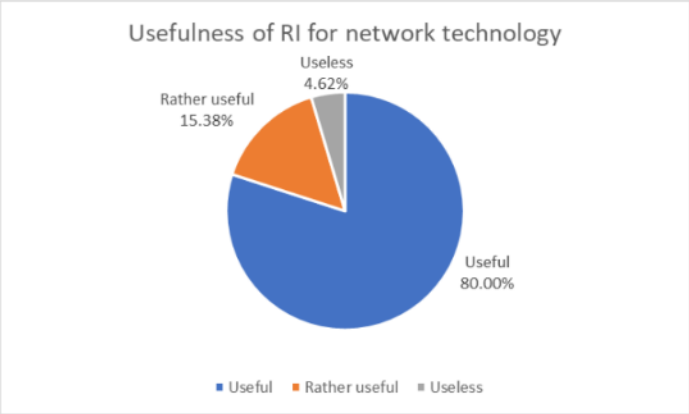

Figure 34 – Usefulness of RI for telecommunication and network technology

The question is addressing the usefulness and the need of research infrastructure dedicated to the research on Artificial Intelligence. The answers obtained are illustrated here:

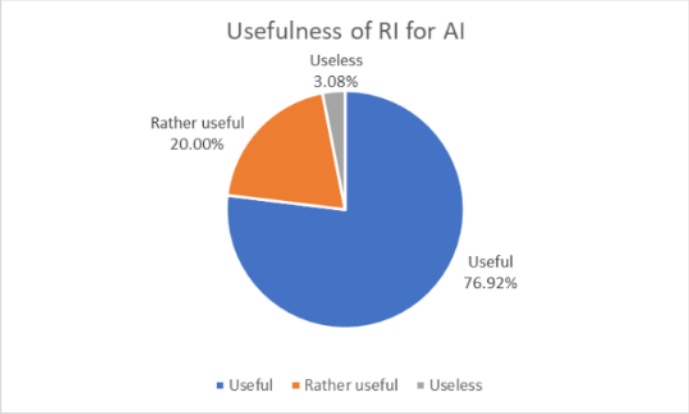

Figure 35 – Usefulness of RI for AI

The question was related to the usefulness and need of research infrastructure concerning the research on nanotechnology and electronic components. The following graph is illustrating the answers:

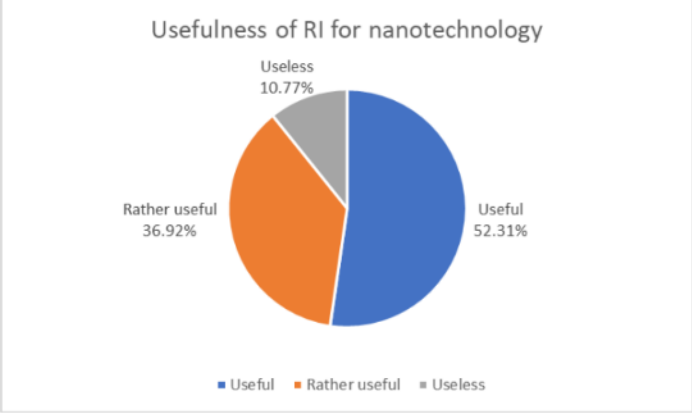

Figure 36 – Usefulness of RI for nanotechnology

The usefulness and the need of RI for the research on cybersecurity were evaluated in this question. The results are shown in the following chart:

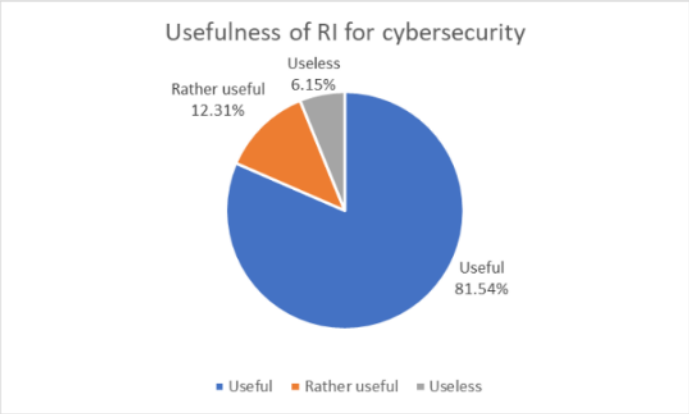

Figure 37 – Usefulness of RI for cybersecurity

This final question is addressing the usefulness and need of research infrastructure for the research concerning the privacy and data protection. The corresponding results are displayed below:

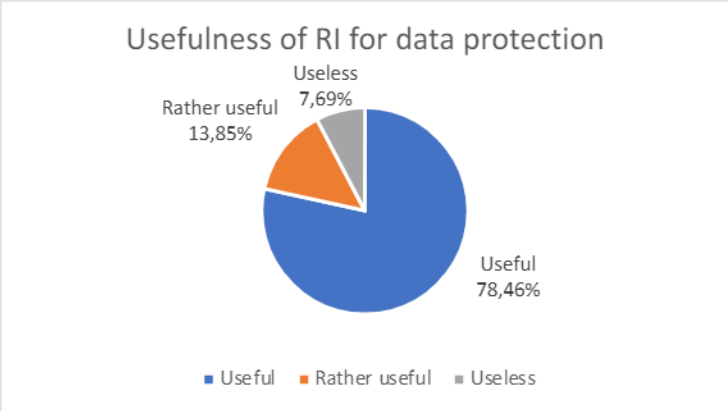

Figure 38 – Usefulness of RI for privacy and data protection

The following table presents the usefulness and need of research infrastructure in function of the topic to be supported by the research infrastructure:

Table 3 – Usefulness and need of RI

Topic to be supported by RI	Useful [%]
Cybersecurity	81.54
Telecommunication and network technology	80.00
Privacy and data protection	78.46
Artificial Intelligence	76.92

E-health	76.92
Mobility and connected vehicles	75.38
Clean and sustainable energy	73.85
Smart manufacturing and supply chains	69.23
Smart farming	60.00
Nanotechnology and electronic components	52.31

The following figure shows the importance of topics which should be supported by the new SLICES research infrastructure:

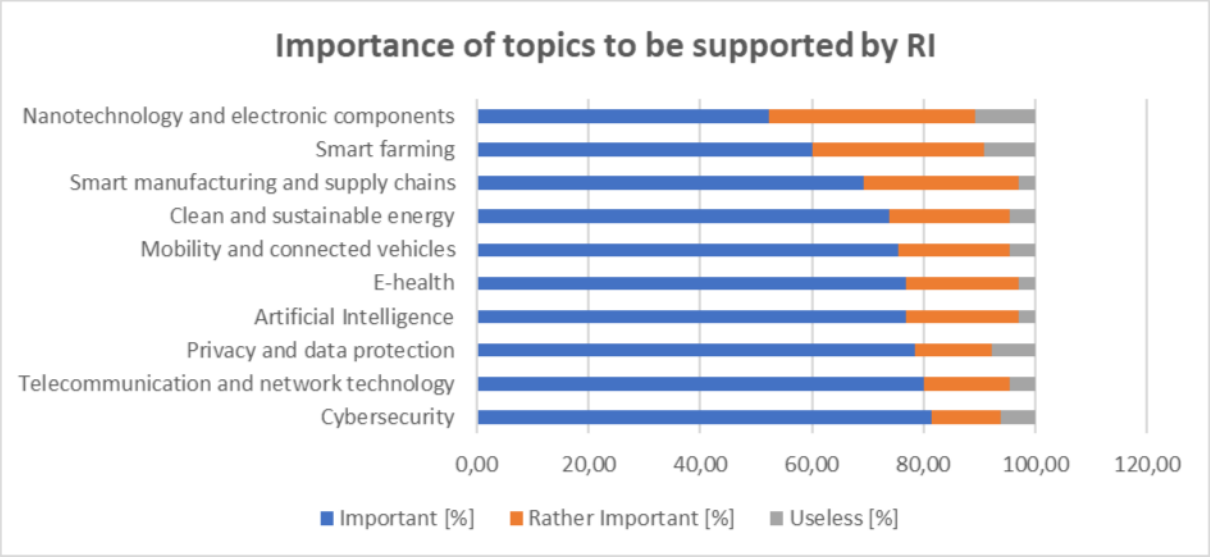

Figure 39 – Importance of topics to be supported by RI

3 The 1st SLICES Workshop: Next Generation ICT Research Infrastructures

3.3 Workshop Methodology

The SLICES consortium organized a two-day virtual-presence workshop in March 2021, focusing on the research challenges driving the evolution of Research Infrastructures to support scientists and researchers in the following fields:

- Advanced wireless networking;
- New Digital Infrastructures and hyper-converged infrastructures (Fog/Edge/Cloud);
- Artificial Intelligence;
- High Performance Computing.

The goal of this workshop was to explore the needs and requirements for future ICT research infrastructures that will support the research community with beyond state-of-the-art experimental facilities and guarantee high quality contributions to development of future ICT technologies. The workshop brought together decision and policy makers, Research Infrastructure stakeholders, industry representatives and research communities from Europe and outside with broad expertise in areas related to the discussion to establish better alignment and understanding of potential benefits to users from new ICT Research Infrastructures. The specific objectives of the workshop were the following:

- To provide a venue for researchers to share experiences and expectations for experimental research in the ICT field;
- To identify key research directions for future Internet design and development and determine required functionality and features of new ICT Research Infrastructures;
- To discuss and to address technological aspects in building future European digital Research Infrastructures;
- To promote collaboration and research at the European level

The expected outcomes of the workshop were the following:

- To accomplish a better understanding of current limitations of existing research infrastructures;
- To align research roadmaps and identifying critical challenges and needs for new ICT Research Infrastructures;
- To accomplish effective sharing of knowledge and practices in support of the implementation of the new pan-European ICT Research Infrastructure.

3.4 Workshop Agenda

3.4.1 Day 1 - Wednesday 3 March 2021 (CET)

2:00 PM	Introduction	Serge Fdida, Sorbonne Université
2:15 PM	**Keynote**	Chair: Andrea Passarella, IIT-CNR, Italy
	Federation, Generalisation, Heterogeneity or Edge v. In-Network compute?	Jon Crowcroft, University of Cambridge
3:00 PM	BREAK	
3:10 PM	**International RIs**	Chair: Serge Fdida, Sorbonne Université
3:15 PM	*6G Ultimate Customizability Driven by Democratization*	Aki Nakao, University of Tokyo
3:30 PM	*Q&A*	
3:45 PM	*The Road Ahead: An approach to Building an ecosystem for Beyond 5G to 6G Research*	Manu Gosain, PAWR Office
4:00 PM	*Q&A*	
4:15 PM	*Towards 6G, the European agenda*	Bernard Barani, DG CONNECT
4:30 PM	*Q&A*	
4:45 AM	*Presentation*	David Fraboulet, French Ministry of Education, Research & Innovation
5:00 PM	*Q&A*	
5:15 AM	Conclusion of day 1 / Wrap up	Peter Van Daele, iMEC
5:20 PM	*End of day 1*	

3.4.2 Day 2 - Thursday 4 March 2021 (CET)

9:00 AM	**Scientific challenges**	Chair: Andrea Passarella, IIT-CNR, Italy
9:05 AM	*On the road to 6G*	Ari Pouttu, University of Oulu
9:20 AM	*Trusted data sharing and the responsible Internet*	Paola Grosso, Institute for Informatics at the University of Amsterdam
9:35 AM	*On Scaling Testbeds and Sharing Insights*	Joerg Ott, Technische Universität München
9:50 AM	*Autonomous Driving Slices: what SLICES can bring to Network AI research*	Dario Rossi, Huawei
10:05 AM	Q&A	
10:20 AM	BREAK	
10:30 AM	**Socio Industrial perspectives**	Chair: Sebastien Ziegler, Mandat International
10:35 AM	*Future business opportunities with Data and AI – what are the needs from perspective of the manufacturing industries?*	Thomas Hahn, Siemens AG
10:50 AM	Presentation	Vania Conan, Thales Group
11:05 AM	*Twinning Networks: On the Use and Challenges of Network Digital Twins*	Diego Lopez, Telefónica
11:20 AM	Q&A	
11:35 AM	BREAK	
11:50 AM	**INFRA, EOSC and ESFRI as potential catalysts for SLICES**	Chair: Arturo Azcorra, IMDEA Networks
11:50 AM	*The evolving landscape of ESFRI, eInfras and EOSC*	Liina Munari, Deputy Head of Unit - European Commission - DG CONNECT - CNECT.C1 Open Science and Digital Modelling
12:10 PM	Q&A	
12:45 PM	Conclusion	Bartosz Belter, PSNC
12:45 PM	*End of day 2*	

3.5 Workshop attendance and video recording

The figures of workshop registration, attendance and participation are very good and above our expectations with:

- 215 registrants
- 152 attendees
- 154 messages
- 43 questions

The video recording of the full event (3h30) is available at:

https://youtu.be/eIKwxROK0uE

3.6 Workshop Results

The workshop discussions highlighted the need for a new ICT-based Research Infrastructure. It was emphasized, that our society gets Digital and everything gets connected, always connected and everybody is connected. Digital Society is on the agenda at all levels of public authority in Europe and worldwide. Such (r)evolution requires dedicated tools and instruments to develop, test and validate new solutions for Digital Society.

The new Research Infrastructure must: i) serve the community and ii) support Digital Transformation. This can be realized only by offering low threshold access to a top-quality / vendor neutral Research Infrastructure for a broad spectrum of activities in the IT domain covering a wide range of technologies and supporting application across multi-technology.

The following recommendations from the speakers have been captured as the workshop outcomes:

- Repeatability and reproducibility of experimental results is highly desired;
- Experimental data needs to be captured with high granularity, stored and processed for further analysis;
- Industrial users can provide use cases and new business models for further validation in RIs:
    - Blue-Sky Research vs Applied Science.
- Research Infrastructures should not only offer technology components, but should be also capable of providing data from on-going and past experiments:
    - Consider the “Experimental Data as a Service” approach.

3.6.1 Importance of the Infrastructure

From the discussions that took place during the workshop, it is evident that although some important work has been done on these topics, the stringent need for a scientific instrument, a test platform to support the research in the digital infrastructures’ domain is an urgent concern. SLICES ambitions to provide a European-wide test-platform, providing advanced compute, storage and network components, interconnected by dedicated highspeed links.

This will be the main experimental collaborative instrument for researchers at the European level, to explore and push further, the envelope of the future Internet. A strong, although fragmented expertise, exists in Europe and could be leveraged to build it. SLICES is answering to this need. It is ambitious, practical but overall timely and necessary. Although this RI is centred on the research related to Digital Infrastructures, it has a strong potential for interdisciplinarity. Indeed, on the one hand, lessons learned could be advantageously exploited in other RIs where such infrastructure might

be relevant in the near future. On the other hand, the digital transformation of various application domains opens an avenue for research in verticals such as smart grid, smart agriculture, autonomous vehicle, connected health etc.

3.6.2 Key Challenges to be addressed

The main fields highlighted by the SLICES workshop were in-line with the SLICES vision on research areas that the project shall focus on. The overall conclusion was that SLICES needs to allow researcher and industry to question scientific challenges regarding the future technologies and services. They need to be based on a technology roadmap that will be consolidated on the basis of the analysis of several inputs provided by the community as for instance developed by the EU EMPOWER project regarding the wireless technology advances, that are pertinent to the evolution of new radio (NR) and core network (CN) over the next decade 2020-2030. It is important to note that the competition at the international level is already in place with ambitious projects similar to the mission defined in SLICES, in the US (NSF PAWR 2017-2022 100M$, NSF FABRIC 2019-2024 20M€) and China (CENI 018-2022 190M€), and efforts also developing in Japan. A non-exhaustive list of research directions needs to be enabled by using SLICES is provided below:

- **Advanced wireless networking**, including research on new waveforms, including higher frequencies up to THz, spectrum and ultra-dense wireless network management, integrated sensing and communication and multiple heterogeneous radio technology management;
- **Smart/intelligent infrastructure operation and management,** specific to advanced protocols and architecture, including recent trends of virtualization and containerization of network functions, extended network softwarization and programmability, AI applied to infrastructure operation and optimization at all layers, generation of data to train algorithms and distribution of intelligence into the Edge of the network;
- **Design and validation of new Edge/Fog infrastructures**, including software and components deployment, distributed resource management, geo-distributed data management, Federated deep-learning, and the creation of cloud-to-things resource continuums;
- **Advanced functionalities**, including power consumption and energy efficiency, security and privacy, new security issues and challenges that arise from the verticals and the ubiquitous network, interoperability, composable infrastructure services on-demand (RI as a Service) and seamless user experiences across technologies and domains.

4 Conclusion

In this report, a summary of the methods and their results for conducting a requirements analysis for the SLICES RI was presented. The two methods for conducting the requirements analysis were a user survey, focussing on the needs of the users, and a two-day SLICES workshop, open to the community with decision and policy makers, Research Infrastructure stakeholders, industry representatives and research communities from Europe and outside with broad expertise. The produced results are very useful for extracting the requirements analysis for the infrastructure.

In detail, the consultation of the research community through the user survey allowed the consortium to capture a first assessment of the demand for an ICT research infrastructure. First, the audience reached by the user survey is relatively broad as more than 200 people have answered to the survey, 67 of them having responded to all the questions. 95% of responders are European, the continent which is the target of the new SLICES research infrastructure. 70% of the responders are coming from the academic world and 25% from the industry or SMEs. So, the panel for the user survey is representative of the current situation in Europe in terms of RI.

Concerning the key topics and challenges to be investigated by the new SLICES infrastructure, the results of the survey show a variety of answers, but the main subjects are linked together. Indeed, the future ICT research infrastructure should be able to handle at the same time the distribution of computing (cloud, fog, edge) and the processes running on top of computing, which should be optimised thanks to Artificial Intelligence and Machine Learning. AI and ML will also play an important role to manage the underlying layers, in particular to improve the performance and the energy efficiency of the wireless and network technologies (SDN/NFV) in the context of 5G networks and beyond. The security, privacy and scalability are very important features to be implemented by the research infrastructure with the possibility to assess them directly in the RI. Another important challenge to be addressed by the future RI is the possibility given to the researchers to configure for themselves the network used in the different kinds of experiments.

The functionalities recommended by the research community through the survey allow a preliminary description of the new SLICES research infrastructure. The research infrastructure should use the latest communication technologies such as 5G and beyond 5G, in a real environment including components deployed at the cloud, at the fog and at the edge. More realism in the RI is also required by the researchers to ensure experiments closer to the industry; this means that the scalability should be improved compared to the current testbeds. The open access and the configuration of the research infrastructure are very important for the research community. New tools should be incorporated in the new RI like traffic generators and real datasets. These tools should at the end help the development of AI and ML in the experimentations.

The use cases proposed by the responders are various, but can be separated in two categories: core network and verticals. The core network encompasses the communications technologies and how the interactions between the components interconnected through these technologies can be realized in an efficient way. Use cases associated to verticals (connected vehicles, smart grid, etc.) should be also supported by the research infrastructure, although it is well understood that the requirements put on the RI are different (a stable operation is necessary). It means that the new SLICES RI will focus first on the core technologies but will be able to support their applications in the different ICT domains, taking into account the specific requirements and needs of each use case. The most relevant use cases can be combined. For example, AI and ML are applied in the context of IoT and 5G to optimize the collection and the analysis of data. The network layer can also be better managed using AI and ML in the SDN/NFV deployments. Some use cases described in the survey are horizontal and concern the energy efficiency, the scalability, the cybersecurity, and the privacy.

The usefulness of new European ICT research infrastructure and the involvement of the European industry is without doubts to the research community. Many benefits were invocated in the survey, showing that the collaboration between the RI and the industry will lead to a win-win situation. The exchanges and the technological transfers will be improved, including the technical skills of the personnel. In parallel, the needs and requirements of the industry will be taken into account in the research infrastructure. More realistic use cases can be run in the experiments made in the RI, with a close relation with the market and the customers reached out by the industry. The industry should also provide the components of the research infrastructure to guarantee an alignment of the RI with the real industrial deployments. The sustainability of the research infrastructure could also partly benefit from the industry because the benefits of the experiments organized in the RI are shared to the industry. Indeed, the new ICT research infrastructure is considered as an innovation powerhouse for the industry and the SMEs based in Europe.

The suggestions made during the consultation with the European research community are multiple and enable us to find new features and requirements for the new SLICES research infrastructure. In particular, a special focus should be given by the research infrastructure to the industry, start-ups and SMEs. The access to the RI should be easy and open for the researchers. The utilisation of the RI resources should be facilitated for the experimenters. Notably, the network used for the experiments should be configurable by the experimenters. The future RI should support 5G and 6G experiments with SDN/NFV, but also contain a cluster of GPU and FPGA available. The received suggestions and recommendations can be combined: for instance, the close involvement of the industry and the RI openness can be applied with the utilisation of open-source solutions already used by the industry, like ONAP (Open Network Automation Platform) and OAI (Open Air Interface) in the context of 5G.

Concerning the standardisation, the research community consulted through the survey mentions the lack of standardisation in different areas such as AI, ML, cloud, fog, edge computing, and security. The research infrastructure can be used to realise the work linked to the standardisation and so, to contribute to main SDOs like ETSI.

The European research community has also evaluated the importance of several requirements to be implemented in the SLICES research infrastructure. The remote access, the data analytics tools and the scalability are the most important requirements, followed by the user-friendliness, the diversity of communication protocols and finally, the security and the confidentiality. All these requirements will be taken into account during the elaboration of the SLICES research infrastructure, notably during the design of the architecture.

The research community has given its opinion about the importance of the research areas to be undertaken in the research infrastructure. The most important topics of research are Artificial Intelligence and edge computing. So, the RI should prioritize both. They are followed by data analytics and Internet of Things, representing the second order of priority. Cellular networks, future network architecture and cloud computing follow data analytics and IoT. Finally, the green and energy efficient ICT and blockchain are the lowest priority topics with a score under 50%, but we will also address them as we want to have a broad offer, and as SLICES ambitions to become an impactful RI in Digital Sciences including concerns regarding energy consumption and the implementation of the green deal.

Responding to the usefulness and need of the RI from the research community, the results permit to identify use cases for core network and verticals in function of the usefulness estimated by the researchers. So, the cybersecurity, the telecommunications and network technologies, the privacy and the data protection are the topics the most useful for the responders in the frame of a dedicated research infrastructure. The new research infrastructure should prioritise these topics and then, take

care of the following ones, namely the Artificial Intelligence, the e-Health, the mobility and the connected vehicles, the clean and sustainable energy. At the end, the responders estimate that the need of RI for domains like smart manufacturing and supply chains, smart farming, nanotechnology and electronic components is relatively less evident.

The results obtained from the SLICES workshop denote that the participants -from the community at large with decision and policy makers, Research Infrastructure stakeholders, industry representatives and research communities from Europe and outside with broad expertise - share the same view on the requirements and need for SLICES-RI as the survey user community. The workshop results highlight the need for repeatability and reproducibility of results across different testbeds, so as to better validate the research contributions. Results shall be made publicly available as data, provided ideally as an Experimental Data as a Service, so as the research community can be a critical role in this domain. SLICES is primarily focusing on advanced research, however, liaison with industry already exists and will be developed. The RI shall be harmonized with existing industry standards and approaches for reaching experimental results, minimizing the gap in the approaches in the general research community and the industrial users.


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