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"Towards Enhanced EU-US ICT Pre-competitive Collaboration"

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Abstract:

The *PICASSO Opportunity Reports*, which were originally published in March 2017, describe the major results that were obtained by the PICASSO Expert Groups during the PICASSO project in the technology sectors Internet of Things (IoT) / cyber-physical systems (CPS), Big Data, and 5G, and on ICT policy relating to these sectors. The major contributions of the PICASSO Opportunity Reports are technology themes and collaboration mechanisms that have been identified as being promising for EU-US collaboration, which were synthesized based on comprehensive analyses of the technological EU and US research and innovation priorities in these sectors, the EU-US funding and collaboration landscape, the major barriers for EU-US collaboration, and the current EU and US policy environment. The sections in these report are based on in-depth discussions with a large network of international experts, analytical research by the Expert Groups, preliminary PICASSO results and other feedback collection mechanisms such as interactive webinars and public consultations.

This document contains the final revisions of the PICASSO Opportunity Reports that have been updated to reflect new insights that were generated by the Expert Groups since March 2017. The key proposals for the fostering of EU-US collaboration of the PICASSO Expert Groups that were published in the report "Strategic Initiatives Proposals and Recommendations" were derived from the results described in the PICASSO Opportunity Reports, which provide background information and more detailed and extensive summaries on collaboration opportunities and potential mechanisms.

All elements of the *IoT/CPS Opportunity Report* (pages 4 - 61 of this document), including the analysis and comparison of drivers, needs, enabling technologies, EU and US R&I priorities, and application sectors, the overview of the funding and collaboration environment, the barriers to collaboration, and collaboration opportunities and mechanisms were updated significantly to reflect insights generated by the activities of the IoT/CPS Expert Group. In addition, the technology themes defined in chapter 3 were prioritized. *Autonomy* currently has the highest priority and should be in the focus on EU-US collaboration. Two other themes are currently of high importance as well according to our discussions, *model-based systems engineering* and *trust and cyber security*.

The revised version of the *Big Data Opportunity Report* (pages 62 - 108 of this document) contains significant updates on EU-US collaboration opportunities specifically on newly defined topics such as Big Data for Smart Cities, Environment, Food, Energy-Water and Health. Moreover, an updated version of potential collaboration mechanisms has been provided including updated information both from EU and US stakeholders.

The revised version of the *5G Opportunity Report* (pages 109 - 150 of this document) contains significant updates on technology themes and recommendations for EU-US collaboration in the 5G network domain based on discussion carried out inside the PICASSO 5G Expert Group. In addition, as an EU-US mirror call on the 5G networks domain was opened during the PICASSO project period, the 5G Expert Group analysed the collaboration opportunities by providing insights on perspective challenges and opportunities for achieving the expected impact and success.

The *Policy Opportunity Report* (pages 151 - 181 of this document) was updated to reflect recent insights of the Policy Expert Group. In addition, conclusions, an outlook, and an executive summary were added.

Keywords:

Internet of Things (IoT), Cyber-physical Systems (CPS), Big Data, 5G, ICT/NIT Policy, Research and Innovation Priorities, Technology Themes for EU-US Collaboration, Opportunities and Mechanisms for EU-US Collaboration, EU-US Funding Environment, EU-US Collaboration Environment

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Opportunity Report

"Towards Enhanced EU-US ICT Pre-competitive Collaboration"

Internet of Things / Cyber-physical Systems

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Executive Summary

This report describes the major results that were obtained by the PICASSO Expert Group on the Internet of Things (IoT) and cyber-physical systems (CPS) in the PICASSO project.

The major contributions of this report are:

- **Technology themes** (chapter 3) and **collaboration opportunities and mechanisms** (section 4.3) that have been identified as being promising for EU-US collaboration, synthesized based on comprehensive analyses of:
- The **EU and US research and innovation priorities** in the technology sectors and related application domains (chapter 2),
- The **EU-US funding and collaboration landscape** (section 4.1), and
- **Barriers for EU-US collaboration** (section 4.2).

In chapter 3 of this report, the PICASSO Expert Group on IoT/CPS (www.picasso-project.eu/iotcps-expert-group) has defined technology themes that are promising for EU-US collaboration:

- Closing the Loop in IoT-enabled Cyber-physical Systems
- Model-based Systems Engineering
- Trust, (Cyber-)security, Robustness, Resilience, and Safety
- Integration, Interoperability, Flexibility, and Reconfiguration
- Autonomy and Humans in the Loop
- Situational Awareness, Diagnostics, and Prognostics

Collaboration opportunities and mechanisms are defined in section 4.3 of this report. The IoT/CPS Expert Group has found that lightweight collaboration measures currently have the best chance of success, and that the EC should aim for the establishment of such measures with both, federal US agencies and US industry and industry-led associations. Measures should aim to establish roadmaps and benefit assessment for EU-US collaboration, the set-up of suitable matchmaking initatives, and lightweight joint research and innovation with agencies and industry.

This report is mainly addressed to academic and industrial experts, academic institutions, companies and industry-led associations, and policy makers willing to enhance trans-Atlantic collaboration by building on top of common IoT/CPS opportunities, needs, and challenges, both technological and societal.

The contents of this report are based on in-depth discussions with a large network of international experts, analytical research by the Expert Group, preliminary PICASSO results (i.e. the reports (1), (2), and (3)) and other feedback collection mechanisms such as a public consultation on the PICASSO website.

The IoT/CPS opportunity report was circulated widely for feedback collection to leading individual researchers and practitioners in the EU and the US, to the expert networks of the projects and initiatives *AIOTI*, *CPS Summit*, *BILAT USA 4.0*, *TAMS4CPS*, *CPSoS*, *Road2CPS*, *oCPS*, and *CPSE Labs*, and to the industry associations *ARTEMIS-IA*, *Industrial Internet Consortium* (*IIC*), and *SafeTRANS*. Furthermore, the report contents were presented and discussed in detail with an international audience in an interactive webinar that was held by the PICASSO IoT/CPS Expert Group on February 2, 2017[1], and in-depth 30-minute personal interviews were subsequently conducted with senior representatives from the US government agencies *NSF* (*National Science Foundation*) and *NIST* (*National Institute of Standards and Technology*), the IoT and CPS units of the European Commission, the *ERA-*

[1] More information and a summary is available at: http://www.picasso-project.eu/newsevents/project-events/iot-cps-webinar-feb2017.

NET instrument, the industry-led associations *Industrial Internet Consortium* (*IIC*), *Smart Manufacturing Leadership Coalition* (*SMLC*), and *ARTEMIS-IA*, the *University of California*, the *Intelligent Manufacturing Systems* (*IMS*) global research and business innovation program, and the *National Council of University Research Administrators* (*NCURA Global*).

Since its previous revision V1.0.1 that was published on March 19, 2017, the report has been updated to reflect the results of the activities of the IoT/CPS Expert Group since then. In particular, the following sections were updated:

- Minor updates and corrections were made in all of the subsections of chapter 2 to reflect the results of EG-internal discussions of the report.
- The technology themes defined in chapter 3 were prioritized in discussions within the EG and with external stakeholders, and this prioritization has been added below. **Autonomy and Humans in the Loop** currently has the highest priority and should be in the focus on EU-US collaboration. Two other themes are currently of high importance as well according to our discussions, **Model-based Systems Engineering** and **Trust and Cyber Security**.
- The description of the barriers to EU-US collaboration in section 4.2 was updated to reflect internal EG discussion results.
- The concrete collaboration opportunities in section 4.3 were refined and revised based on the results of the activities of the EG since the publication of the previous version of this report.

The strategic initiative proposals that are described in the PICASSO report D3.2 were developed based on the insights and investigations described in the opportunity report. Thus, the opportunity report provides a common view on priorities and future cooperation opportunities between the EU and the US and is a strong basis and guideline for concrete EU-US collaboration actions of the PICASSO project.

The PICASSO Project

The aim of the 30-months PICASSO project is (1) to reinforce EU-US collaboration in ICT research and innovation focusing on the pre-competitive research in key enabling technologies related to societal challenges - 5G Networks, Big Data, Internet of Things and Cyber Physical Systems, and (2) to support the EU-US ICT policy dialogue by contributions related to e.g. privacy, security, internet governance, interoperability, ethics.

PICASSO is oriented to industrial needs, provides a forum for ICT communities and involves 24 EU and US prominent specialists in the three technology-oriented ICT Expert Groups - 5G, Big Data, and IoT/CPS - and an ICT Policy Expert Group, working closely together to identify policy gaps in the technology domains and to take measures to stimulate the policy dialogue in these areas. A synergy between experts in ICT policies and in ICT technologies is a unique feature of PICASSO.

A number of analyses will be accomplished, as well as related publications, that will for a major part be made public and contribute to the project's outreach. Dedicated communication and dissemination material will be prepared that should support the operational work and widespread dissemination though different channels (website, social media, publications …). The outreach campaign will also include 30+ events, success stories, factsheets, info sessions, and webinars.

List of Figures

List of Acronyms

3GPP	3rd Generation Partnership Program
4G	4th Generation
5G	5th Generation
AI	Artificial Intelligence
AIOTI	Alliance of IoT Innovation
AV	Autonomous Vehicle
AWS	Amazon Web Services
B2B	Business-to-business
B2C	Business-to-customer
BBI	Bio-based Industries
BD	Big Data
BDVA	Big Data Value Association
BDVPPP	Big Data Value Public Private Partnership
CEDR	Conference of European Directors of Roads
CERN	Conseil Européen pour la Recherche Nucléaire
CPS	Cyber-physical System
CPSoS	Cyber-physical System of Systems
CPS-VO	CPS Virtual Organization
CPU	Central Processing Unit
CS	Clean Sky
CSAAC	Cyber Situational Awareness Analytical Capabilities
D2D	Device-to-Device
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DISA	Defense Information Systems Agency
DoC	Department of Commerce
DoD	Department of Defense
DoDIN	DoD Information Networks
DoE	Department of Energy
DoS	Department of State
DoT	Department of Transportation
DSL	Digital Subscriber Line
DSM	Digital Single Market
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EeB	Energy-efficient Buildings
EG	Expert Group
EPI	European Platform Initiative
ERA	European Research Area
EU	European Union
FBMC	Filter-Bank Multi-Carrier
FCC	Federal Communications Commission
FCH	Fuel Cells and Hydrogen
FET	Future and Emerging Technologies
FIRE	Future Internet Research & Experimentation
FoF	Factories of the Future
FP7	Framework Programme 7

FY	Financial Year
Gbps	Gigabit per second
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GENI	Global Environment for Networking Innovations
GFDM	Generalized Frequency-Division Multiplexing
GHz	Gigahertz
H2020	Horizon 2020
H2M	Human-to-machine
HD	High-definition
HMI	Human Machine Interface
HPC	High Performance Computing
HPUE	High Performance User Equipment
IA	Industry Association
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IERC	IoT European Research Cluster
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IM	Innovative Medicine
IMS	Intelligent Manufacturing Systems
INCOSE	International Council on Systems Engineering
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Rights
ISM	Industrial, Scientific, Medical
ITER	International Thermonuclear Experimental Reactor
ITS	Intelligent Traffic System
ITU	International Telecommunication Union
JTI	Joint Technology Initiative
JU	Joint Undertaking
LTE	Long Term Evolution
M2M	Machine-to-Machine
M&S	Modeling and Simulation
MEC	Mobile Edge Computing
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MoU	Memorandum of Understanding
ms	Millisecond
NACFAM	National Coalition for Advanced Manufacturing
NB-IoT	Narrowband IoT
NCP	National Contact Point
NCURA	National Council of University Research Administrators
NFV	Network Function Virtualization
NGI	Next Generation Internet
NGMN	Next Generation Mobile Networks
NIH	National Institutes of Health
NIPRNet	Nonsecure Internet Protocol Router Network
NISD	Network and Information Security Directive

NIST	National Institute of Standards and Technology
NIT	Networking and Information Technology
NITRD	Networking and Information Technology Research and Development
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
OCF	Open Connectivity Foundation
OFDM	Orthogonal Frequency Division Multiplexing
OMG	Object Management Group
PAWR	Platforms for Advanced Wireless Research
PCAST	President's Council of Advisors on Science and Technology
PPP	Public Private Partnership
PWG	Public Working Group
QoE	Quality of Experience
R&D	Research and Development
R&I	Research and Innovation
RAT	Radio Access Technology
RDI	Research, Development, Innovation
RFC	Request for Comments
SAE	Society of Automotive Engineers
SDAV	Scalable Data Management, Analysis and Visualization
SDN	Software Defined Networking
SEED	Standard Energy Efficiency Data
SIPRNet	Secret Internet Protocol Router Network
SME	Small and Medium-sized Enterprises
SMLC	Smart Manufacturing Leadership Coalition
SoS	System of Systems
SOTA	State of the Art
SPIRE	Sustainable Process Industry
SRA	Strategic Research Agenda
SSG	Senior Steering Group
Tbit	Terabit
Tbps	Terabit per Second
TRL	Technology Readiness Level
TTIP	Transatlantic Trade and Investment Partnership
TV	Television
UE	User Equipment
UHD	Ultra High Definition
URLLC	Ultra-reliable Low-latency Communications
US	United States
USGS	US Geological Survey
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
V5GTF	Verizon 5G Technology Forum
VDA	Verband Der Automobilindustrie
VPN	Virtual Private Network
ZT-OFDM	Zero-tail OFDM

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1. Introduction

Over the last years, different definitions of the Internet of Things (IoT) have been created that describe the IoT as both a technological system and a concept. For example, in (4), the IoT is defined as “a new era of ubiquitous connectivity and intelligence, where a set of components, products, services and platforms connects, virtualizes, and integrates everything in a communication network for digital processing.” while the IERC definition[2] states that the IoT is “a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.”.

Within PICASSO, we focus less on the connectivity aspect of the IoT, which has received major attention over the last years and has led to mature solutions for IoT-connected devices, and more on the opportunities that the provision of streams of real-time data from a large number of IoT-connected devices with sensing capabilities provides for monitoring, optimization, management, and intelligent service provision in modern large-scale technical systems. In such technical systems, which are often called *cyber-physical systems* (*CPS*), real-time computing elements and physical systems interact tightly. Cyber-physical systems are ubiquitous, as computing devices and software are enabling and enhancing the performance of all except the simplest technical systems. The most challenging class of cyber-physical systems are cyber-physical systems of systems (CPSoS[3]) that are characterized by being spatially distributed, having distributed control, supervision, and management with partial autonomy of the subsystems, are dynamically reconfigured on different time scales, can show emerging behaviors, and involve human interactions (e.g. with operators or managers). Examples of cyber-physical systems of systems are the electrical grid, railway systems, the public transport system of a city, smart buildings, and production processes with many cooperating elements such as robots, machines, warehouses, or large processing plants with many process units.

CPS and CPSoS are equipped with a large number of sensing devices. The IoT will make the access to the information provided by these sensors a lot simpler and more flexible, and the connectivity provided by the Internet of Things will become an enabling technology for cyber-physical systems of systems in which the loop from a myriad of sensors to the way the systems are operated and also to the demands of the users is closed (5). This will enable improved monitoring, management, and hence new levels of energy and resource efficiency, product and service quality, and safe and reliable operation. According to the PICASSO definition, the IoT is seen as an enabling technology for CPS or CPSoS, while other, more encompassing definitions include also applications outside the domain of CPS and CPSoS, such as IoT-connected home entertainment systems or geolocation-enabled tracking infrastructures for consumer items.

The merging of IoT and CPS into closed-loop, real-time *IoT-enabled cyber-physical systems* is seen as an important future challenge. As examples, the international industry-led association *Industrial Internet Consortium* (*IIC*) promotes that “Companies need to close the loop across associated processes.” (6), and our personal interview contacts agree that closing the loop via the IoT is one of the major challenges and opportunities in the CPS and IoT domains. In the EU, this challenge is recognized by several institutions, such as *the ARTEMIS Industry Association* who e.g. believe that the “Internet of Things, and consequently the Things of the Internet, and Cyber-Physical Systems are complementary directions which together will help to shape a society where humans and machines increasingly interact to provide services and solutions for the benefit of society that are inconceivable with the present state-of-the-art technology” (7), and the *European Alliance of IoT Innovation* (*AIOTI*) who see this as a macro-challenge, stating “Getting billions of objects duly connected and managing these to create a

[2] See http://www.internet-of-things-research.eu/about_iot.htm

[3] See e.g. www.cpsos.eu

reliable monitoring/actuating substrate only partially caters for the challenges ahead. These challenges cannot be complete without considering how to handle the huge amount of data produced and how to transform it into useful and actionable knowledge." (8). On the US side, for example the US branch of Samsung sees the CPS draft framework by NIST as an important prerequisite for the future of the IoT (9), and the NSF has recently initiated a successful IoT focus initiative within its CPS section and is currently funding several research projects that cover the idea of using the IoT as an enabler for CPS.

The enormous potential of novel CPS and IoT technologies has been recognized by both the EU and the US. The social and economic challenges are common across the world, and there are opportunities for the EU and the US to work together on these global challenges for mutual benefit, not only in allowing solutions from EU and US providers to be sold within each other's economic areas but also on a world-wide scale (2). In addition to economic benefits, there will be benefits to society and to end-users. Joint research and innovation will lead to a faster development of better solutions and will enable societal challenges to be addressed more efficiently.

The objective of the PICASSO Expert Group on IoT/CPS was to identify the key societal challenges where these technologies will offer a large potential for improvements, to analyze technology strengths and technology gaps in the EU and in the US, and to make proposals for future EU-US collaboration topics on IoT-driven cyber-physical systems, in particular on how to handle the huge amounts of real-time data produced by IoT-connected sensors and how to transform it into useful knowledge and actions that will improve the performance, cost-efficiency, and safety of cyber-physical systems.

The objective of the IoT/CPS-related parts of this report is to provide a selection of EU-US cooperation opportunities on IoT/CPS that were identified within the PICASSO project. The contents were compiled based on several sources. The most important inputs were derived from discussions with the PICASSO Expert Group on IoT/CPS[4] and from personal interviews with external experts that provided valuable insights into the R&I landscapes, needs, gaps, and opportunities on both sides of the pond. This input was enriched with background information from other sources that include e.g. the PICASSO reports (2), (1), and (3), technological and strategic documents and roadmaps that were published by relevant EU and US initiatives and institutions, and a database of R&I projects on the topics of IoT and CPS that are currently funded in the EU and the US.

The contents of the IoT/CPS sections of this report were widely distributed and were validated and refined via different feedback collection efforts. In January 2017, a draft version of the IoT/CPS opportunity report was circulated for questionnaire-based feedback collection, including to leading individual researchers and practitioners in the EU and the US and to the expert networks of the projects and initiatives *AIOTI*, *CPS Summit*, *BILAT USA 4.0*, *TAMS4CPS*, *CPSoS*, *Road2CPS*, *oCPS*, and *CPSE Labs*[5]. Particular focus was given to industrial distribution by the involvement of the industry associations *ARTEMIS-IA*, *Industrial Internet Consortium* (*IIC*), and *SafeTRANS*[6]. In addition, the report contents were presented and discussed with an international audience in an interactive webinar that was held by the PICASSO IoT/CPS Expert Group on February 2, 2017[7], and the report was published on the PICASSO website for public consultation.

Based on a revised version of the IoT/CPS section of the report, in-depth personal interviews (of appr. 30 minutes length each) were subsequently conducted with senior representatives from the US government agencies *NSF* (*National Science Foundation*) and *NIST* (*National Institute of Standards and Technology*), the IoT and CPS units of the European Commission, the *ERA-NET* instrument, the industry-led associations *Industrial Internet*

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[4] See http://www.picasso-project.eu/iotcps-expert-group

[5] http://www.aioti.org; http://cps-vo.org/group/cps-summit; http://www.euussciencetechnology.eu; http://www.tams4cps.eu; www.cpsos.eu; www.road2cps.eu; http://ocps.ele.tue.nl; www.cpse-labs.eu

[6] https://artemis-ia.eu; http://www.iiconsortium.org; http://www.safetrans-de.org

[7] More information and a summary is available at: http://www.picasso-project.eu/newsevents/project-events/iot-cps-webinar-feb2017.

Consortium (*IIC*), *Smart Manufacturing Leadership Coalition* (*SMLC*)[8], and *ARTEMIS-IA*, the *University of California*, the *Intelligent Manufacturing Systems* (*IMS*) global research and business innovation program, and the *National Council of University Research Administrators* (*NCURA Global*), the only US-based H2020 *National Contact Point* (*NCP*). These interviews resulted in valuable governmental, academic, and industrial feedback on the technological contents of the report and were used as a basis for the design of the concrete collaboration opportunities and mechanisms for the IoT and CPS domains. Further, the topics were discussed at the First Transatlantic Symposium on ICT Technology and Policy in Minneapolis in June 2017, and refined. Additional feedback was obtained throughout June 2017-May 2018.

[8] https://smartmanufacturingcoalition.org

2. Research and Innovation Priorities in the EU and the US

This section summarizes the technological research and innovation priorities in the EU and the US in the sectors of the Internet of Things (IoT) and of cyber-physical systems (CPS), and the needs and drivers for important application sectors, including smart cities, smart energy, smart transportation, and smart production.

The section is based on several sources, both from within PICASSO and beyond. In addition to inputs by the PICASSO Expert Group on IoT/CPS and from external experts obtained during our feedback collection efforts with funding agencies, industry, and academia, relevant documents and roadmaps by different strategic initiatives and institutions were analyzed (a graphical overview is given in Figure 1, more details are provided in the subsections below). Many of these documents were developed in year-long efforts by large networks of experts, and if a topic appears in several, or even all, of these documents, it is reasonable to assume that it is seen a high-priority topic. The suitability and correctness of the identified R&I priorities was confirmed during the feedback collection process of the IoT/CPS Expert Group in early 2017 in which funding agency representatives and other experts agreed that the chosen priorities have top priority in the EU and the US.

In addition, several PICASSO reports served as sources. The PICASSO report “Panorama of the ICT landscape in the EU and US” (2) provides a comprehensive overview of the current ICT landscape (including networks, initiatives, policies, and regulations) in the EU and US. Its focus lies on the application sectors of smart cities, smart energy, and smart transportation, but it also gives an overview of the IoT and CPS domains. The PICASSO report “Analysis of Industrial Drivers and Societal Needs” (1) provides an analysis of EU-US industrial drivers and societal needs and barriers for different application and technology domains, which were validated in a major effort via the interviewing and feedback collection from 150 experts from different industrial domains. This report has provided valuable pointers, and it was particularly useful for clarifying the impact that novel technological developments will have on application domains. The summary of the drivers and needs of application domains is partly based on this report.

To get a feel for the R&I funding priorities in the EU and US, and as an input for the PICASSO ICT toolkit *CROSSROADS*, a database of IoT and CPS R&I projects was created that covers the projects currently being funded by the most important funding programmes and agencies, including FP7, H2020, and EUREKA/ITEA on the EU side and the NSF, NIST, and the DoE on the US side. This database was used to identify focus areas that are currently getting funded in the EU and the US[9].

This section is structured as follows: Section 2.1 briefly summarizes the major societal cross-domain challenges in the EU and the US that drive the introduction of novel IoT/CPS technologies. Section 2.2 describes technological developments in the EU and the US that are important enabling technologies for IoT-enabled CPS, but that are not the focus of the R&I priorities that are relevant for PICASSO. Section 2.3 provides a list of R&I priorities for cyber-physical systems that are in the focus of EU and US research and innovation efforts, and section 2.4 does the same for the Internet of Things. Section 2.5 summarizes the major needs and drivers in important application sectors, and section 2.6 closes this part of the report with an analysis and comparison of EU and US research and innovation priorities, based on the previous sections and on expert inputs that were obtained during feedback collection and personal interviews by the IoT/CPS Expert Group with funding agencies, industry associations, and individual researchers and practitioners.

[9] The database does not cover all R&I funding in the EU and the US, which amounts to several hundred projects overall (including more than 300 funded by the NSF on CPS topics alone). To reduce the number of projects to be analyzed, only the projects with the largest financial funding were considered, and only those projects were included that are relevant to the focus of this report, i.e. IoT-enabled CPS. Overall, the database consists of 68 projects on CPS topics and 55 projects on IoT topics.

Figure 1: Documents by these strategic initiatives and institutions were used to create the IoT/CPS R&I priority lists.

2.1. Cross-domain Drivers and Needs

This section briefly summarizes the major overarching societal challenges that are currently seen as the major drivers for the development and deployment of novel IoT/CPS-based technologies in the EU and the US. It is based on the PICASSO reports (2) and (1) and on discussions with the IoT/CPS Expert Group members and was validated during the feedback collection process.

Advancing climate and environmental sciences for sustainability, and the provision of clean, efficient energy are seen as major societal drivers in the EU and the US. In this area, there is major demand by customers and governments, and companies see a large opportunity and are seeking to satisfy needs with both products and services.

Globalization and increased urbanization are seen as a key challenge for the future. The predicted growth of the world population, which is estimated to reach 9 billion by 2050, the move towards cities and mega-districts, and the expected deepening of international integration and globalization will create large challenges to provide energy supply, logistics, health care, security, food, and water. Smart ICT will be crucial for providing interconnectivity, information, and optimization of services to solve these challenges.

Increases in connectivity and autonomy in all domains and the advent of smart and connected devices will drive technology and will provide numerous opportunities for the development of smart ICT solutions for the solution of societal challenges, such as the decarbonization of cities, the grid, production, and transport, or the introduction of renewable energy sources.

Vulnerability, trust and trustworthiness, privacy, (cyber-)security, and safety are crucial drivers that are gaining relevance in all practical domains, particularly in the US.

The **Industrial Internet of Things** is seen as a major driver for the next generation of industrial systems and infrastructures.

2.2. Enabling Technologies

Future IoT-enabled cyber-physical systems will be based on advances in a number of enabling technologies, many of which are currently in the focus of research and innovation programmes and efforts in the EU and US. This section briefly summarizes those enabling technologies that are of the highest importance to IoT-enabled CPS. It is based on the roadmaps and strategic documents that are described in subsequent sections, on the PICASSO reports (2) and (1), on discussions with the IoT/CPS Expert Group members, and on inputs obtained in personal interviews and at the IoT/CPS webinar that was held on Feb. 2, 2017, and the contents were validated during the feedback collection process.

The advancement of **information technology and high-performance computing** is a major focus in both the EU and the US. In this area, major topics include the development of cloud, edge, and fog computing technologies, ubiquitous mobile computing, distributed and heterogeneous systems, novel technologies for data and signal processing, and more generally advances in software engineering and algorithms.

Another area that is currently in the focus of intense R&I efforts is **communication and network technology**, reflecting the enormous growth in connectivity. Here, the current focus is on topics such as reliability and security in communication systems, real-time-capable communication, open and scalable communication and networking architectures, machine-to-machine (M2M) communications, network management and discovery, and broadband wireless and 5G communications (also refer to the 5G sections of this report).

The current trend towards "being always connected" and the need to **connect and power many billions of IoT-enabled devices** poses major challenges that go beyond traditional networking and communication technologies (8). These include the need for ubiquitous connectivity schemes that support the syntactic and semantic integration of heterogeneous IoT sub-systems, mechanisms to provide reliable electricity to power many billions of IoT devices, such as energy harvesting technologies to power autonomous edge devices, scalable registration and discovery of IoT devices/services, bandwidth provision and management for connecting tens of billions of devices, and M2M communication optimization.

The need for highly reliable real-time IoT applications is driving major R&I initiatives and efforts to develop and mature the **Tactile Internet** that will enable low-latency communications in combination with high availability, reliability, and security. Some important topics in this area, which is covered within PICASSO by the 5G Expert Group, are the detection of security threats and anomalies in wireless communications, the orchestration of resources for reliability and dependability, and the virtualization of IoT functions (8).

The ubiquitous access to information via the IoT will also require advances in **pervasive sensing and sensor technologies**. Here, major topics are making sensors less expensive and more affordable, in-memory computing power of sensing devices, increasing the speed of data exchange between sensors and the internet, and the virtualization of sensing.

Major advances are currently also made in the areas of **data processing** and **data analytics**, which are covered in PICASSO by the Big Data Expert Group (also refer to the Big Data section of this report).

2.3. Cyber-physical Systems (CPS)

CPS are one of the key pillars of the European *Digital Single Market Strategy* and the *Digitising European Industry* initiative, the innovation programme *Smart Anything Everywhere*, and other major European initiatives, such as *H2020*, *EUREKA/ITEA*, the *ECSEL Joint Undertaking*, and the *ARTEMIS Industry Association*, the latter two funding large-scale lighthouse projects that are essential to creating CPS reference technology platforms and open interoperability standards, such as *CRYSTAL*, *CESAR*, and *EMC2*. In addition, a large number of smaller CPS-related R&I projects are funded in different EU programmes, where the EC strategy has been to combine these into clusters, e.g. on CPS and on SoS (systems of systems). The EU-level initiatives are complemented by national programmes, such as *Industrie 4.0* in Germany that drives work on CPS in manufacturing, or the Austrian programme *Produktion der Zukunft*. In addition, CPS competence centres have been set up to engage with European SMEs, and several public-private partnerships (PPPs) have been started that are related to CPS or enabling technologies, such as *Factories of the Future* (*FoF*), *Cybersecurity*, *5G*, *Future Internet*, and *Robotics*.

In the US, the CPS *Senior Steering Group* (*SSG*) of the *Networking and Information Technology Research and Development* (*NITRD*) Program is responsible for coordinating programmes, budgets, and policy recommendations for CPS research and development, and CPS-related basic research is mainly being driven by the NSF Cyber-Physical Systems programme that has funded over 350 projects that focus on fundamental CPS research, which has for example led to the creation of a thriving *CPS Virtual Organization* (*CPS-VO*). Other federal agencies have independent, often more applications-oriented research efforts. For example, DARPA is funding a range of large CPS-related projects, agencies such as DoT, DoE, and DHS are implementing mission-specific pograms for e.g. transportation, energy, and CPS security, and NIST has established the Cyber-Physical Systems and Smart Grid Program Office that coordinates its CPS efforts, such as the establishment of a Public Working Group (CPS PWG), the development of a CPS Framework in partnership with industry, academic and government experts, and the establishment of a CPS test bed program. In addition, industrial companies and industry-led associations drive CPS R&I efforts, e.g. the *Smart Manufacturing Leadership Coalition* (*SMLC*), the *Conference of European Directors of Roads* (*CEDR*), and others.

The US definition of CPS is somewhat different to the one generally used in the EU. While EU definitions clearly separate between embedded systems and cyber-physical systems, in the US, CPS are often seen as an extension of embedded systems, as e.g. illustrated by the CPS definitions in (10) and (11). Like in the EU, the US has realized that the benefits of the development and deployment of novel *NIT* (*Networking and Information Technology*, which is the US equivalent of the European term ICT) technologies such as CPS in the coming years and decades is enormous (11), and that IoT advancements will be a crucial enabler for CPS in a large variety of application domains (12). In fact, in the US view the IoT is often seen as a specific example of a CPS, while these two concepts are separated more clearly in the EU. Current US national priorities include health, energy, manufacturing, education, and privacy (10).

2.3.1. Research and Innovation Priorities in the EU

This section summarizes the major research and innovation priorities in the EU in the areas of cyber-physical systems (CPS) and cyber-physical systems of systems (CPSoS).

The major research and innovation priorities in the EU were identified based on different sources. In addition to input by the members of the IoT/CPS Expert Group, inputs that were obtained during feedback collection and personal interviews with funding agencies, industry associations, and individual researchers and practitioners, and PICASSO reports such as (1), relevant strategic documents and roadmaps were analyzed. These include the *Strategic Research Agenda 2016* of the *ARTEMIS IA* (7)**,** the *European Roadmap for Industrial Process Automation* that was developed by the EU project *Process.IT* (13), materials that were prepared during workshops of the EU project *Road2CPS* (14), and the brochure *Proposal of a European Research and Innovation Agenda on Cyber-physical Systems of Systems, 2016-2025* that was published by the consortium of the EU project *CPSoS* (15). In addition, 46 R&I projects were analyzed that are funded by EU-level initiatives including *FP7*, *H2020*, *EUREKA/ITEA*, *ECSEL-JU*, and *ARTEMIS IA*, 37 of which were found to relate to the technological topics described in the following.

Overall, nine R&I priorities were identified, four of which are mentioned in all strategic documents that were analyzed while the fifth topic was mentioned in three of the four analyzed documents. Another three topics are mentioned in two documents while two more topics are seen as important in only a single document. Note that in the following, the item numbers do not indicate priority, but only serve to make the items easily referable.

High-priority Research and Innovation Topics

Four topics are pushed as R&I priorities in all four of the analyzed strategic documents:

1. **(Systems) engineering support for highly dynamic, continuously evolving CPS:** This topic covers all aspects that relate to the engineering for modern CPS and CPSoS. Subtopics include
    - Integrated, virtual engineering of CPSoS over their full life-cycle
    - More agile and shorter development cycles for CPS
    - Heterogeneous modeling of CPS, which covers modeling-related challenges such as model evolution and adaptation, model maintenance, data-based and grey-box modeling, open simulation platforms and formalisms, simulator interoperability and co-simulation, stochastic models, modeling of human behaviors, integration of safety and security aspects into models, and access to user-friendly modeling tools

    Overall, 13 R&I projects were identified that deal with systems engineering support for CPS, which is the largest number for any of the EU CPS R&I priorities.
2. **Trust, (cyber-)security, robustness, resilience, and dependability:** Subtopics include
    - Secure real-time and mixed-criticality systems
    - Resilience to physical attacks
    - Intrusion detection and prevention
    - Certification and component-based recertification of high-dependability applications
    - Trust in large distributed systems

    7 R&I projects were identified in this area, most of which deal with secure real-time and mixed-criticality systems.
3. **Seamless integration, interoperability, flexibility, reconfiguration:** Subtopics include
    - Semantic interoperability, which ensures that different physical artefacts and computing elements 'understand' each other, even if they are implemented in different languages, tools, or platforms
    - Increasing openness and pushing open platforms (while retaining security and safety properties)
    - Auto-reconfiguration, adaptation of CPS elements, e.g. based on learned operational patterns from past examples / historical data
    - Opportunistic flexibility, i.e. taking advantage of the currently accessible opportunities to dynamically improve the quality of service

    4 R&I projects were identified in this area.
4. **Autonomy and humans in the loop:** Subtopics include
    - Socio-technical aspects of CPS
    - Autonomous CPS subsystems and their interaction with human operators
    - Analysis of user behavior, detection of needs and anomalities
    - Visualization and decision support, novel usability and HMI concepts to enable human operators to digest and react to large amounts of data and information quickly and effectively

    One R&I project was identified in this area.

In addition, the following topic was identified as a priority in 3 of the 4 analyzed documents:

5. **Situational awareness in large-scale CPS:** Subtopics include

- Real-time monitoring, exception handling, fault detection, and mitigation of faults and degradation
- Large-scale, real-time data analytics
- Learning, adaptive behavior, and self-diagnosis tools
- Predictive condition monitoring and maintenance

In this area, 3 R&I projects were identified.

Lower-priority Research and Innovation Topics

In addition to the five high-priority topics given above, other topics were identified as important, even though they were only identified in 2 of the strategic documents that were analyzed. These topics are:

6. **Distributed, reliable, and efficient management, control, and automation:** This topic was identified as a priority in 2 of the 4 analyzed documents. Subtopics include
   - Self-organization and structure formation
   - Emerging behavior, deriving e.g. from interactions of autonomous agents
   - Cloud-based real-time control

   In this area, 7 R&I projects were identified.
7. **Validation, verification, and computation of key properties of CPS:** This topic was identified as a priority in 2 of the 4 analyzed documents. 1 R&I project was identified in this area.

In addition, two topics were identified that are mentioned in only a single strategic document. These topics are:

8. **CPS reference designs and architecture principles:** Subtopics include
   - Extending the use of digital platforms to build stronger eco-systems with new business models
   - Integration of functions across application contexts

   1 R&I project was identified in this area.
9. **Open R&I environments, test beds:** In this area, no R&I projects were identified.

2.3.2. Research and Innovation Priorities in the US

This section summarizes the major research and innovation priorities in the US in the areas of cyber-physical systems (CPS) and cyber-physical systems of systems (CPSoS).

The major research and innovation priorities in the US were identified based on inputs by the members of the IoT/CPS Expert Group, inputs that were obtained during feedback collection and personal interviews with funding agencies, industry associations, and individual researchers and practitioners, PICASSO reports, and an analysis of relevant strategic documents, roadmaps, and funded projects. The strategic documents that were analyzed include the report *Designing a Digital Future* by the *President's Council of Advisors on Science and Technology* (*PCAST*) (10), a *CPS Vision Statement* that was published by NITRD (11), the NIST report *Strategic R&D Opportunities for 21st Century CPS* (16), the *Action Plan* that was developed by the EU project *CPS Summit* (12), a White House memorandum on *Multi-Agency Science and Technology Priorities for the FY 2017 Budget* (17), and a workshop report on a bilateral US-German workshop on IoT/CPS that was held in 2016 in Washington DC (18).

In addition, 23 R&I projects were analyzed, most of which are funded by NSF. The projects were selected from the overall list of NSF-funded CPS projects, and only the largest (in terms of funding) projects were chosen that are relevant to Iot-driven large-scale CPS. 19 of these projects were found to relate to the technological topics described in the following.

Overall, ten R&I priorities were identified, seven of which are mentioned in at least three of the strategic documents that were analyzed. Another three topics are mentioned in only one or two roadmaps. Note that in the following, the item numbers do not indicate priority, but only serve to make the items easily referable.

High-priority Research and Innovation Topics

Seven topics are pushed as R&I priorities in at least three of the analyzed strategic documents:

1. **Privacy, cyber-security R&D, and trustworthiness of technical systems:** This topic is seen in several documents as having the highest priority overall. Subtopics include
    - Resilience to cyber-attacks
    - Defending cyber-infrastructure, such as civil and governmental communications networks, electrical power generation and distribution systems, financial systems, logistics, fuels, water, and emergency services
    - Realizing the benefits of collective personal information without compromising the privacy of individuals
    - Trust in technical systems

    In this area, 2 R&I projects were identified.

2. **Situational awareness, diagnostics, prognostics:** The major objectives of this topic are to identify, predict, learn from, and prevent or recover from faults in complex systems. Subtopics include
    - Large-scale data management and analysis
    - Machine learning
    - Real-time monitoring, fault detection and mitigation
    - Ensuring access to and retention of critical community research data collections

    In this area, 5 R&I projects were identified.

3. **Validation of novel technologies via prototypes and test beds:** this area, 2 R&I projects were identified.

4. **Effective and reliable system integration and interoperability:** Subtopics include
    - Semantic interoperability between elements constructed in different formalisms, tools, engineering domains, and sectors
    - Abstractions, modularity and composability to enable a reliable and verifiable assembly of individual CPS elements

    In this area, 1 R&I project was identified.

5. **Autonomy and human-computer interaction:** Subtopics include
    a. Socio-technical aspects of CPS, i.e. leveraging the interaction between people and technology, and between complex infrastructures and human behavior
    b. Models and approaches for autonomous CPS systems, and of humans interacting with them
    c. Social computing to develop novel approaches to enable social collaboration and problem-solving in a networked, online environment

    1 R&I project was identified in this area.

6. **Model-based systems science and engineering methodologies**: Subtopics include
   - Systems engineering based architectures and standards to enable efficient design and development of reliability systems while ensuring interoperability and integration with legacy systems
   - Development of a mature systems science for high-confidence CPS
   - Conceptualizations of the deep interdependencies among engineered systems and the natural world
   - System-wide design
   - Heterogeneous CPS models, which includes modeling-related challenges such as the integration of multi-physics models and models of software to enable co-design of physical engineered and computational elements, common terminologies, modeling languages, and rigorous semantics for describing interactions across heterogeneous systems, and stochastics and uncertainty in models

   1 R&I project was identified in this area.

7. **Validation, verification, and certification:** Subtopics include
   - Rapid online (re-)verification and real-time health monitoring approaches
   - Time-critical and mixed-criticality architectures
   - Dealing with uncertainty, safety, and risk

   In this area, 2 R&I projects were identified.

Lower-priority Research and Innovation Topics

Three R&I topics were identified in two or fewer strategic documents:

8. **Educational technology, education and training for cross-disciplinary CPS:** This topic represents the challenge that science and engineering of CPS are cross-disciplinary in nature, requiring expertise in computer science, mathematics, statistics, engineering, and many other disciplines. Thus, new dynamic, multi-disciplinary education and training approaches and tools are needed to educate a skilled workforce for future CPS.

   In this area, no R&I projects were identified.

9. **Distributed control**, e.g. in the form of adaptive and predictive hierarchical hybrid control, is required to achieve tightly coordinated and synchronized actions and interactions in systems that are intrinsically asynchronous, distributed, and noisy.

   In this area, 4 R&I projects were identified.

10. **Open reference architectures** are needed to create universal definitions for representing ultra-large heterogeneous systems.

    In this area, 1 R&I project was identified.

2.4. The Internet of Things (IoT)

According to a recent European Commission study, the generating market value of the IoT in the EU is expected to exceed one trillion euros in 2020. Consequently, the IoT, like CPS, is a key pillar of the European *Digital Single Market Strategy*, the *Digitising European Industry* initiative, and the innovation programme *Smart Anything Everywhere*. The *Alliance for the Internet of Things* (*AIOTI*) was launched by the EC and key European IoT players in 2015 to develop and support the dialogue and interaction among the various IoT actors in Europe and to facilitate the creation of a European IoT ecosystem, with IoT large-scale pilots being funded to promote IoT take up. The IoT ecosystem is built on the work of the *IoT European Research Cluster* (*IERC*), which brings together 40 EU-funded projects with the aim of defining a common vision, identifying common research challenges and coordinating and encouraging the convergence of ongoing work. In addition, there are other initiatives such as *FIWARE* or *UniversAAL* which are providing open architectures and specifications to allow developers, service providers, enterprises, and other organizations to develop IoT products, as well as 16 cross-sectoral *Future Internet Accelerators* that address different application sectors such as Smart Cities, E-Health, Transport, Energy and Environment, and Manufacturing and Logistics, and others. EU-level initiatives are complemented by national programmes such as Germany's *Industrie 4.0* platform, the UK's IoT initiative, France's '*objets connectés*' and Spain's smart city initiative.

In the US, IoT developments are largely driven by companies instead of R&I programmes or federal agencies, with major players being Google, Cisco, Samsung, and others. The *Department of Commerce* (*DoC*), which estimates that digitization, of which the future of the IoT is a major part, has the potential to boost annual US GDP by up to $2.2 trillion by 2025 (19), is promoting growth of the digital economy and as part of the Digital Economy Agenda. The uptake of IoT technologies is promoted via various industry-driven consortia and alliances that include the *Industrial Internet Consortium* (*IIC*), the *Allseen Alliance* (that is dedicated to providing an open environment for the Internet of Things), and the *Open Connectivity Foundation* (*OCF*) that was founded by major companies (Intel, Microsoft, Samsung, Qualcomm, GE Digital, and Cisco Systems) to work towards a single standard for IoT.

2.4.1. Research and Innovation Priorities in the EU

This section summarizes the major research and innovation priorities in the EU on the Internet of Things (IoT), from the viewpoint that the IoT will be an enabler for future CPS. Thus, topics that relate to enabling technologies (see above), such as communication technologies, are not covered in the following.

The major IoT research and innovation priorities in the EU were identified based on different sources. In addition to input by the members of the IoT/CPS Expert Group and PICASSO reports, relevant strategic documents and roadmaps were analyzed. The main source was the book *Digitising the Industry* that was edited by senior representatives of the AIOTI alliance (8). Furthermore, the *EU-China Joint White Paper on the Internet of Things* by the *EU-China IoT Advisory Group* (20), three white papers by the internationally oriented *IIC* (6) (21) (22), and the roadmap by the EU project *Process.IT* (13) were considered. In addition, 32 R&I projects were analyzed that are funded by EU-level initiatives including *FP7*, *H2020*, *EUREKA/ITEA*, *ECSEL-JU*, and *ARTEMIS IA*. 14 of these projects were found to relate to the technological topics described in the following.

Overall, seven R&I priorities were identified, two of which are mentioned in more than one of the strategic documents that were analyzed. Another four topics are identified in only one of the strategic roadmaps, and one topic was identified based on funded projects alone. Note that in the following, the item numbers do not indicate priority, but only serve to make the items easily referable.

High-priority Research and Innovation Topics

Two topics are pushed as R&I priorities in at least two of the analyzed strategic documents:

1. **Automatic, semantic interoperability and integration of heterogeneous systems and platforms:** Subtopics include
    - Data semantics, semantic models, semantic integration
    - Automatic configuration

   In this area, 4 R&I projects were identified.

2. **Open architectures, platforms, and innovation ecosystems:** Subtopics include
   - Open IoT architectures and cross-domain infrastructures
   - Standarization and certification

   In this area, 2 R&I projects were identified.
3. **Closing the loop - creating a reliable monitoring/actuating IoT substrate:** This topic goes beyond pure connectivity and covers the challenges that arise when trying to transform the deluge of data provided by IoT-connected systems into knowledge and useful actions. This topic is seen as the most demanding IoT "macro-challenge" in (8). Subtopics include
   - Real-time data processing and analytics, i.e. novel methods and tools to transformation data into useful and actionable knowledge
   - Distributed/decentralized reasoning, low-latency cognitive (feedback) loops
   - Humans in the loop and self-management of IoT systems

   In this area, 1 R&I project was identified.
4. **End-to-end IoT security, trust, dependability, and privacy**, for which 1 R&I project was identified.

Lower-priority Research and Innovation Topics

In addition to the high-priority topics, two topics were identified that appear in one of the strategic documents.

5. **Large-scale test beds and pilots**, such as the ones provided by the initiatives *FIWARE* and *FIRE*. 5 R&I projects were identified in this area.
6. **Fully autonomous IoT devices**, for which no R&I project was identified.

One more topic was identified that was not mentioned in any strategic documents:

7. **Smart machine-to-machine (M2M) networks**, for which 1 R&I project was identified.

2.4.2. Research and Innovation Priorities in the US

This section summarizes the major research and innovation priorities in the US on the Internet of Things (IoT). As in the previous section, the topics reflect the viewpoint that IoT will be an enabler for future CPS, and topics that relate to enabling technologies are not covered.

The major IoT research and innovation priorities in the US were identified based on different sources. In addition to input by the members of the IoT/CPS Expert Group and PICASSO reports, relevant strategic documents were analyzed. Due to the current lack of involvement of federal and governmental agencies and programmes in IoT, comprehensive roadmaps are difficult to find in this sector. However, several white papers are available by the internationally oriented *IIC* (6) (21) (22) and by the company *Samsung* (9) that were analyzed, plus a few more general strategic documents that were published by governmental agencies such as the *DoC* (19), the White House (17), and the US Senate (23). In addition, 23 R&I projects were analyzed that are mostly funded by the NSF. 12 of these projects were found to relate to the technological topics described in the following.

Overall, five R&I priorities were identified, three of which are mentioned in at least three of the strategic documents that were analyzed. Another two topics are identified in two or fewer of the strategic documents. Note that in the following, the item numbers do not indicate priority, but only serve to make the items easily referable.

High-priority Research and Innovation Topics

Three priorities are identified in three or more of the strategic documents that were analyzed:

1. **Open architectures, platforms, interoperability:** This topic is seen as highly important, e.g. the DoC sees IoT openness as a grand policy challenge and states that "a free and open global Internet, with minimal barriers to the flow of data and services across borders, is the lynchpin of the digital economy's success". Subtopics include
    - Semantic technologies, semantic models, semantic integration
    - Novel IoT architectures and cross-domain infrastructures
    - Innovation ecosystems

    In this area, 7 R&I projects were identified.
2. **(Cyber-)security, privacy, resilience to faults/attacks, trust:** Subtopics include
    - Risk assessment and management
    - Fault and outage detection
    - Trust and security online
    - Robustification and additional security capabilities of legacy systems in industrial environments
    - Consumer protection

    In this area, 5 R&I projects were identified.
3. **Closing the loop: IoT as an enabler for future CPS:** This topic is very similar to topic 3 in the IoT-EU list above and covers the challenges that arise when trying to transform the deluge of data provided by IoT-connected systems into knowledge and useful actions. Subtopics include
    - Tools and platforms for real-time data analytics and transmission
    - Site-wide integration and convergence of control systems with *information technology* (*IT*) and *operational technology* (*OT*) systems
    - IoT edge devices / smart assets
    - IoT-enabled predictive maintenance and remote monitoring

    In this area, no R&I projects were identified.

Lower-priority Research and Innovation Topics

Another two topics are identified in two or less of the strategic documents:

4. **Human-centered IoT systems**, which acknowledges the fact that human capital remains critical to decision support. No R&I projects were identified in this area.
5. **Promotion of skill-building initiatives**, such as the National Initiative for Cyber Education (NICE). No R&I projects were identified in this area.

2.5. Application Sectors: Drivers and Needs

This section briefly summarizes the major drivers and needs in the application sectors of smart production (which includes smart manufacturing and processing, but not other types of production such as smart farming), smart cities, smart energy, and smart transport. This section is partly based on the PICASSO report (1) that provides a comprehensive survey of three of the four sectors as well as feedback by industrial interview contacts, and on inputs by the IoT/CPS Expert Group and external experts. In addition, the strategic documents and roadmaps that were used to create the survey in sections 2.3 and 2.4 were analyzed for application-relevant information. The results were validated during the feedback collection process.

While each vertical industry and application sector has unique needs (see e.g. (21)), research and innovation actors in both the EU and the US are aware that there are many cross-cutting R&I challenges in IoT and CPS, the solutions to which will benefit multiple sectors. As an example, *NITRD* (11) states in its CPS vision statement that "attempts to establish extensible architectures for unmanned aerial vehicles or self-driving cars in the transportation sector will directly benefit the designers of networked industrial control systems in manufacturing". On the EU side, the research agenda proposed by the *CPSoS* project (15) is an example of this fact, since only four of the R&I priorities they propose target specific application sectors while seven priorities are cross-cutting. Consequently, we have also found in interviews with companies and research institutes (1) that there is a general interest in all of the PICASSO application sectors. As examples, topics such as increased connectivity, increased autonomy, and the need for assurance and cyber-security are seen as being relevant for all application domains.

2.5.1. Smart Production

Making progress on advanced manufacturing and smart production systems is seen as essential in both the EU and the US. Current key drivers in this area are the German initiative *Industrie 4.0* in the EU and the *Industrial Internet of Things (IIoT)* in the US.

Production systems are currently evolving into global, highly integrated cyber-physical systems of systems that go beyond pure production and that cover all parts of the value chain. This evolution is driven by quickly changing customer requirements that are more aware of environmental impact, ask for a high degree of product customization and configurability, and require efficient, yet sustainable production. Major drivers in the production sector are the trend towards zero-waste and environmentally neutral processes and plants, efficient resource usage, site-wide optimal operation, high availability and safety, increases in complexity and flexibility with reduced time to market, and the need for a highly skilled work force for the design and operation of modern production systems.

Novel ICT technologies, in particular CPS technologies and the (industrial) IoT, are seen as vital to preserve the competitiveness on both sides of the Atlantic (15), (11). The major needs in the smart production sector are:

- **Interoperability and standardization:** Production systems consist of thousands of (often proprietary) hardware and cyber components by a large number of manufacturers that have to be integrated with each other and with legacy systems. Interoperability is a key prerequisite for novel ICT technologies that will require global real-time access to all devices at the field and automation levels. Thus, challenges such as plug-and-play reconfiguration, zero-configuration integration of automation systems, real-time analytics and optimization, monitoring and diagnostics, and others depend on the interoperability of technical systems. There is a need for companies to move away from proprietary solutions towards open interfaces and platforms. The production of *Industrie 4.0* compatible automation products is seen as an opportunity for harmonization within the industry, and the expectation is that the cloud and the *IIoT* will be used to connect smart components. Another need that is currently arising is that of complete value chain integration of production systems.
- **Exploiting the IoT - Real-time analytics, situational awareness, predictive maintenance, data-based operation/optimization:** The availability of IoT-connected, financially viable sensors, software and devices will enable manufacturers to generate compelling business value. There is thus an opportunity for automation systems and optimization of processes based on much greater collection of data. Monitoring is also seen as a key driver for the industry. There are many new ideas being promoted such as the "augmented operator" where information is provided to wearables, smart phones, and other smart devices. This is being used to provide information for optimization, asset management, and predictive maintenance to operators as they walk around the factory. A success story by Intel provides a good case for the enormous business value that can be added based on data and real-time analytics (22): In one of its factories, Intel installed sensors on CPU assembly modules that are employed in the

final steps of CPU manufacturing. Using analytics software, Intel was able to reduce the number of machine failures, detect defects on the assembly line, and boost assembly line uptime and productivity. This led to a time and inspection effort reduction by a staggering 90 percent.

- **Cyber-security** is quickly becoming the key issue in smart production with the advent of ubiquitous connectivity in industrial environments.
- **Integrated management and control structures, system-wide management:** With increasing complexity and integration in large production systems, decentralized and system-wide control and management of production complexes will become a major need, with a key area being management to improve energy efficiency. More generally, increases of automation in production systems have additional advantages, such as the reduction of human exposure to dangerous areas through remote operation, and the reduction of personnel requirements (e.g. night shift operators) for the 24/7 operation in production complexes that are never switched off, such as chemical plants.
- **Integrated engineering approaches for cyber-physical systems** is a key need to enable engineers to deal with the challenges that arise from the complexity, quick evolution, and required flexibility of modern production systems. In addition, supply and value chain integration is an important topic in the smart production sector.

The feedback that we have obtained so far indicates that it is (at least potentially) possible for the EU and US to work together in all technological areas of smart production. However, in the production sector there are conflicting strategic and commercial interests between both sides that will be significant barriers, with a major challenge being to find partners who are willing to collaborate.

2.5.2. Smart Cities

The Smart Cities industry is estimated to be valued at more than $400 billion globally by 2020. In contrast to other sectors, the scope that is covered under the smart city keyword is often not clearly defined, and the area of smart cities consequently may cover a very wide scope that goes beyond interactions with citizens and use of their data to also include control and management of energy, waste, buildings, utilities, and infrastructure, as well as social interactions with government, education, and e-health. In some definitions, smart energy and smart transportation are also seen as part of smart cities. These sectors are described later below.

Major drivers in this sector are reductions in greenhouse gas emissions (*decarbonization*), the needs for clean air and water, the need for increased security and safety, efficient use of space, infrastructure, and other resources, globalization, the trend towards migration to cities, increases in autonomous functionality and connectivity, and advances in artificial intelligence.

The major needs in the smart cities sector that will benefit from the development and deployment of novel IoT and CPS technologies are:

- **Interoperability and integration** (of data and infrastructures) is seen as a major challenge. Due to the increase in connectivity, concepts such as integrated smart transportation systems are receiving widespread attention.
- **Cyber-security, safety, and privacy:** As in the other application sectors, cyber-security is seen as a major challenge for smart city platforms and applications. In addition, guaranteeing privacy is essential due to the strong involvement of private citizens.
- **(Real-time) data analytics:** The spread of connectivity are expected to enable novel concepts and solutions for smart city applications such as smart lighting (“Internet of Lighting”), smart building management (“Internet of Buildings”), smart garbage collection, optimal use of water and energy, and monitoring for the safety and well-being of inhabitants.

- **IoT platforms for smart city applications.**

The feedback that we have obtained so far indicates that it is likely that there are collaboration opportunities on different topics, such as interoperability of data, infrastructures, cloud computing, and real-time data analytics. Collaboration on privacy and security topics may be difficult due to differences in regulations and strategic interests.

2.5.3. Smart Energy

The energy sectors in the EU the US have high demands for quality, repeatability and performance, and are mainly driven by green initiatives and the decarbonization of the grid, e.g. in Europe to reduce greenhouse gas emissions by 40% by 2030. The inclusion of renewables and decentralized production are major drivers, as is the improvement of grid stability.

ICT is already exploited in many areas within the energy supply sector and is used to provide availability of services, for management to reduce consumption and CO_2 emissions, to improve stability and safety, and to integrate renewables. The move to the IoT is seen as a key driver in both the EU and the US. For example, PG&E has created the new moniker *Grid of Things* to make the IoT more applicable to utilities, and in Europe the "Internet of Energy" term has been coined. Furthermore, CPS technologies are seen as important for the creation of a smart infrastructure for realizing a smart grid, enabling the optimization and management of resources and facilities and allowing consumers to control and manage their energy consumption.

The major needs in the smart energy sector that will benefit from the development and deployment of novel IoT and CPS technologies are:

- **Cyber-security and safety:** As in the other application sectors, cyber-security is seen as a major challenge for smart energy applications.
- **Novel approaches for the engineering and dynamic management of smart grids with decentralized production / renewables:** There is a major need for novel engineering and dynamic power management methodologies for applications ranging from single devices to complete grids, including using real-time data for optimal energy management.
- **Interoperability and harmonization of standards:** Currently, standards for interoperability are being driven by the EC and EFTA on the EU side and NIST and FERC on the US side. A challenge is the harmonization of interoperability standards developments.
- **Exploiting the IoT and intelligent connectivity for smart grid applications.**

The feedback that we have obtained so far indicates that there is significant pessimism with respect to collaboration opportunities due to differences in the grid topologies, standards, and technologies between the EU and the US, and due to differences in the requirements for Smart Grids (1). However, there may be opportunities for joint research in the areas of smart metering, energy efficiency and management, low-carbon economy, and renewable energy. The *BILAT USA 4.0* project (24) has found that there is interest from EU and US partners in advancing already existing collaborations around energy.

2.5.4. Smart Transportation

The sector of smart transportation covers several modes, i.e. road/automotive, rail, aerospace, and maritime. North America and Europe are expected to become the largest markets for ITS (Intelligent Traffic Systems). Within Europe, sustainability (via the promotion of e.g. electric mobility / decarbonization of transport) is a key driver, with a dramatic anticipated increase in both freight and passenger transport and associated emissions. Other drivers are to reduce casualties (for which autonomous mobility is pushed) and to reduce congestion via ITS. To achieve these goals, EU programmes of enormous size have been set up, such as the Trans-European

Transport Networks (TEN-T) policy with an investment volume of € 400 billion. The drivers in the US are similar to the European ones, with the added driver of homeland security.

ICT is already being used in smart transportation to provide an optimized use of infrastructure to increase capacity and also to improve the safety of road transport, e.g. via traffic management systems that are relying on increased connectivity between cars and between cars and infrastructure. The consensus is that there is an urgent need to deploy novel ICT technologies, such as CPS technologies, to improve efficiency and safety in transportation, with a notable opportunity being increased autonomy which is expected to lead to fundamental changes to traffic operation.

The major needs in the smart transportation sector that will benefit from the development and deployment of novel IoT and CPS technologies are:

- **Interoperability:** There are several areas in which interoperability between heterogeneous transportation systems is essential. These include the uniform compatibility of electric vehicle charging stations with all electric vehicles from the EU and the US, standards and protocols for vehicle-to-vehicle (V2V) communication, integration and compatibility of vehicle-to-infrastructure (V2I) systems (including interoperable interfaces for roadside infrastructure), and harmonized information exchange between transportation systems from the maritime domain. There is also a need for future automation system architectures to be more open.
- **(Cyber-)security and safety:** As in the other application sectors, cyber-security is seen as a major challenge for smart transportation applications. Approaches to mixed criticality are another need here.
- **Intelligent traffic management, drive-by-wire vehicles, autonomy:** ICT is needed for the optimized use of transport infrastructure to increase capacity and to improve safety, using e.g. data collection and processing and new technologies for autonomous vehicles.
- **Systems engineering and supply chain integration**, including interoperability of tools, integration of engineering domains, integration of different disciplines across the supply chain, and integrated systems engineering approaches for future transportation infrastructures.

In addition, education and training of a high-skill work force was identified in several of the transportation domains as a major need for the future.

There is already considerable joint work going on between the EU and US, e.g. developing interoperability of charging stations. In addition, an implementation agreement was signed to boost cooperative activities in the field of research, technology and innovation for all modes of transport (24). Key areas include freight transport and logistics, sustainability, safe and seamless mobility, road traffic management, and human factors. Our analysis (1) showed that further EU-US collaboration might be possible on challenges such as traffic management, autonomous and electric cars, integration of vehicle and infrastructure systems, traffic management using ITS, data collection and processing, and model-based systems engineering.

2.6. Analysis

This section summarizes major conclusions from the overview of the drivers, needs, and research and innovation priorities in the EU and the US that was presented above.

1. The intersection of the IoT and future CPS is an important challenge and opportunity in both the EU and the US.

The CPS and IoT domains are vast, and the development of concrete and feasible collaboration opportunities is only possible by restricting our focus on subsets of these domains. Our analysis has revealed that restricting the scope of the PICASSO work on IoT/CPS to the intersection of the IoT and CPS is a good option, as it is of high relevance in both the EU and the US, and the IoT is seen as an important driver for the design and operation of future CPS.

In the EU, this challenge is recognized by several institutions, such as *the ARTEMIS Industry Association* who believe that the "Internet of Things, and consequently the Things of the Internet, and Cyber-Physical Systems are complementary directions which together will help to shape a society where humans and machines increasingly interact to provide services and solutions for the benefit of society that are inconceivable with the present state-of-the-art technology" (7), and the *European Alliance of IoT Innovation* (*AIOTI*) who see this as a macro-challenge, stating "Getting billions of objects duly connected and managing these to create a reliable monitoring/actuating substrate only partially caters for the challenges ahead. These challenges cannot be complete without considering how to handle the huge amount of data produced and how to transform it into useful and actionable knowledge." (8). On the US side, for example the *Industrial Internet Consortium* (*IIC*) promotes the message that "Companies need to close the loop across associated processes." (6), the US branch of Samsung sees the CPS draft framework by NIST as an important prerequisite for the future of IoT (9), and the NSF is currently funding several research projects that cover the idea of using the IoT as an enabler for CPS.

The IoT/CPS feedback collection process, and in particular the personal interviews that were conducted with senior EU and US representatives, strongly reinforced the importance of the intersection of the IoT and future CPS. All interview partners who were asked about this agreed that this is one of the major challenges in IoT and CPS going forward, both in the EU and the US.

2. There is a significant overlap between R&I priorities in CPS between the EU and the US.

When comparing the R&I priorities between the EU and the US in the CPS area (see Figure 2), it becomes apparent that EU and US actors have identified similar challenges and priorities.

In particular, a comparison of the results shows that five R&I priorities are of high relevance in both the EU and the US:

- Model-based systems engineering
- Trust, (cyber-)security, robustness, resilience, and dependability
- Integration, interoperability, flexibility, and reconfiguration
- Autonomy and humans in the loop
- Situational awareness, diagnostics, and prognostics

In addition, the following common topics of lower priority were identified:

- Validation and verification
- Distributed, reliable, and efficient management, control, and automation
- Open environments, test beds
- CPS reference designs and architecture principles

Our feedback collection efforts have shown that EU and US experts are in agreement with the R&I topics that have been identified in this analysis.

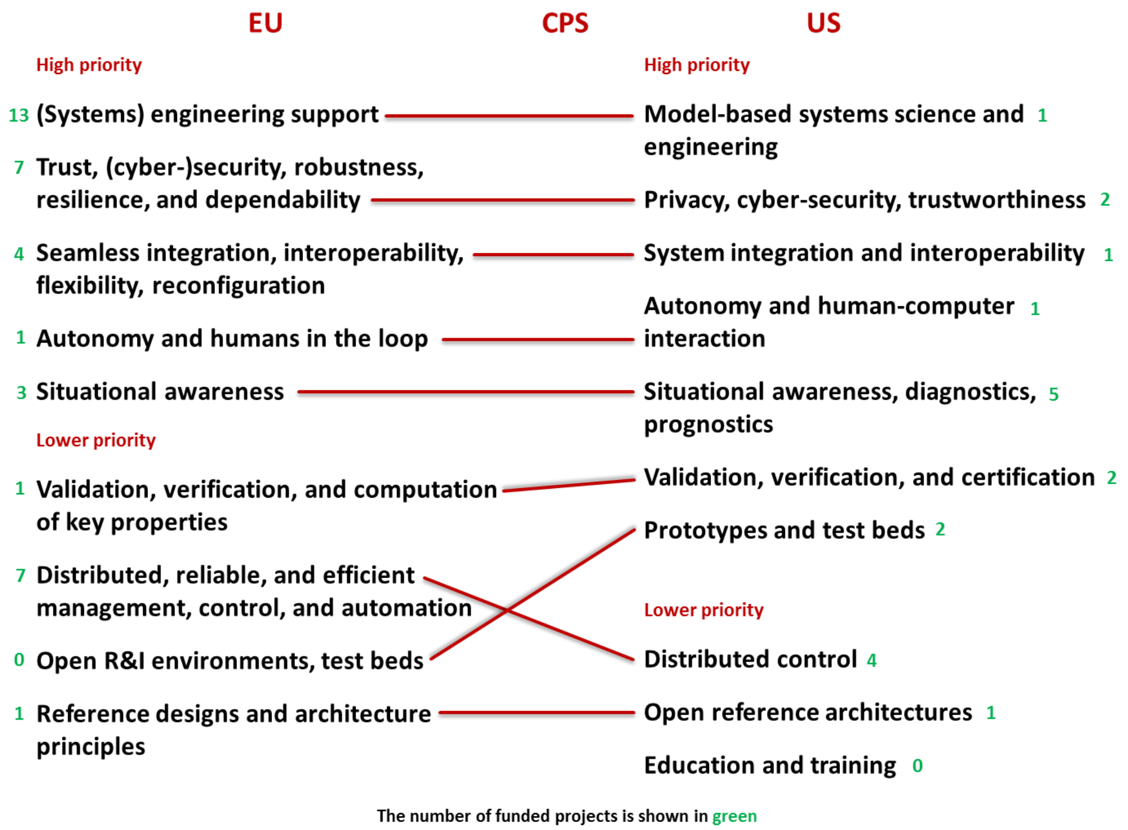

Figure 2: Comparison of CPS topics in the EU and the US.

An analysis of the funded R&I projects on these topics shows that:

- The important topics of **autonomy and human interactions** seem to be underfunded in both, the EU and the US. These topics should receive more funding, and there may be good opportunities for collaboration on these topics.
- Although management, control, and automation were not identified as high-priority topics in this analysis, the large number of projects that are funded in these areas indicate that this topic is seen as important.

3. There is a significant overlap between R&I priorities in IoT between the EU and the US.

There is a significant overlap of the R&I priorities between the EU and the US in the area of IoT (when focusing on topics that are most relevant to using the IoT to enable future CPS), as shown in Figure 3.

A comparison of the results shows that four R&I priorities are of high relevance in both the EU and the US:

- Interoperability and integration
- Closing the loop - IoT as an enabler for CPS
- (Cyber-)security, privacy, resilience to faults/attacks, trust
- Open architectures and platforms

Our feedback collection efforts have shown that EU and US experts are in agreement with the R&I topics that have been identified in this analysis.

An analysis of the funded R&I projects on IoT topics shows that

- The important topic of “closing the loop” seems to be severely underfunded in the IoT domain. This topic is essential for the future of IoT and CPS systems and should receive more funding, and there are very likely good opportunities for collaboration.
- In the EU, there is currently a strong push towards test beds and large-scale IoT pilots, which does not seem to be mirrored in the US (although recent documents indicate that focus will increase in the future).

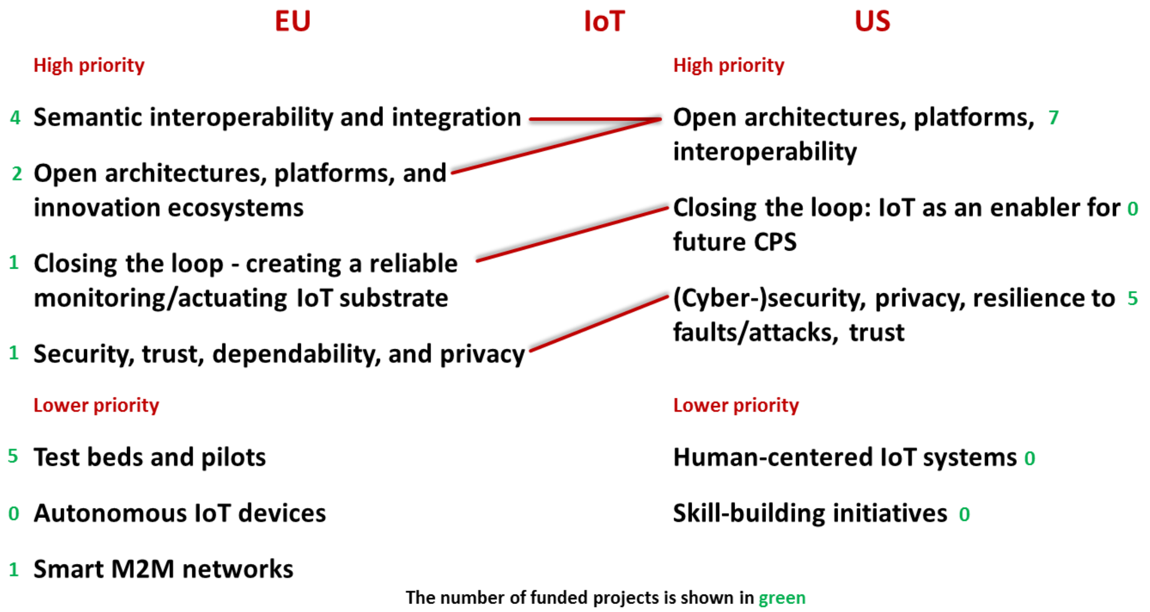

Figure 3: Comparison of IoT topics in the EU and the US.

4. Several R&I priorities are of high relevance in both the CPS and the IoT domains.

Figure 4 shows a comparison of, and mapping between, the high-priority R&I topics in the EU and the US. All of the high-priority IoT topics are linked to equivalent CPS topics, indicating that advancements of the state of the art in these topics will drive progress in both areas. There are several major conclusions that can be drawn from our analysis, and from the feedback that we have obtained from interviews, questionnaires, and the interactive webinar.

Over the last decades, different R&I areas have sprung up for CPS that all aim to provide methods, theories, and tools to compute useful knowledge and to generate useful actions, including model-based systems science and engineering, situational awareness, diagnosis, prognosis, monitoring, management, control, and automation, and validation and verification, and CPS researchers and practitioners have ample experience in these areas. In contrast, the topic of “closing the loop”, i.e. processing data from IoT devices to transform it into useful and actionable knowledge, or into useful actions, is a relatively recent topic in IoT. One major conclusion from our feedback collection efforts is that while the experience that relates to this topic from the CPS arena is a good basis for future R&I efforts (in particular in management, control, and automation), the availability and ubiquity of IoT-connected devices will pose novel challenges that are not present in “pure” CPS, and the topic of **closing the loop in IoT-enabled CPS** is a promising target for future research, innovation, and collaboration efforts.

The topics of **cyber-security, privacy,** and **trust** (or **trustworthiness** as it is referred to in the US) are currently the dominant topics in the US, somewhat more so than in the EU. Recently strategic documents and our interviews indicate that these topics will become even more important in the future in both the EU and the US. Some of our interview contacts indicated (1) that it may be challenging to collaborate on privacy-related topics due to differences in interests and policy between the EU and the US, and collaboration on cyber-security topics may be difficult as well. However, technology-oriented research collaborations on related topics may be feasible, such as attack resilience and intrusion detection or secure real-time and mixed-criticality systems.

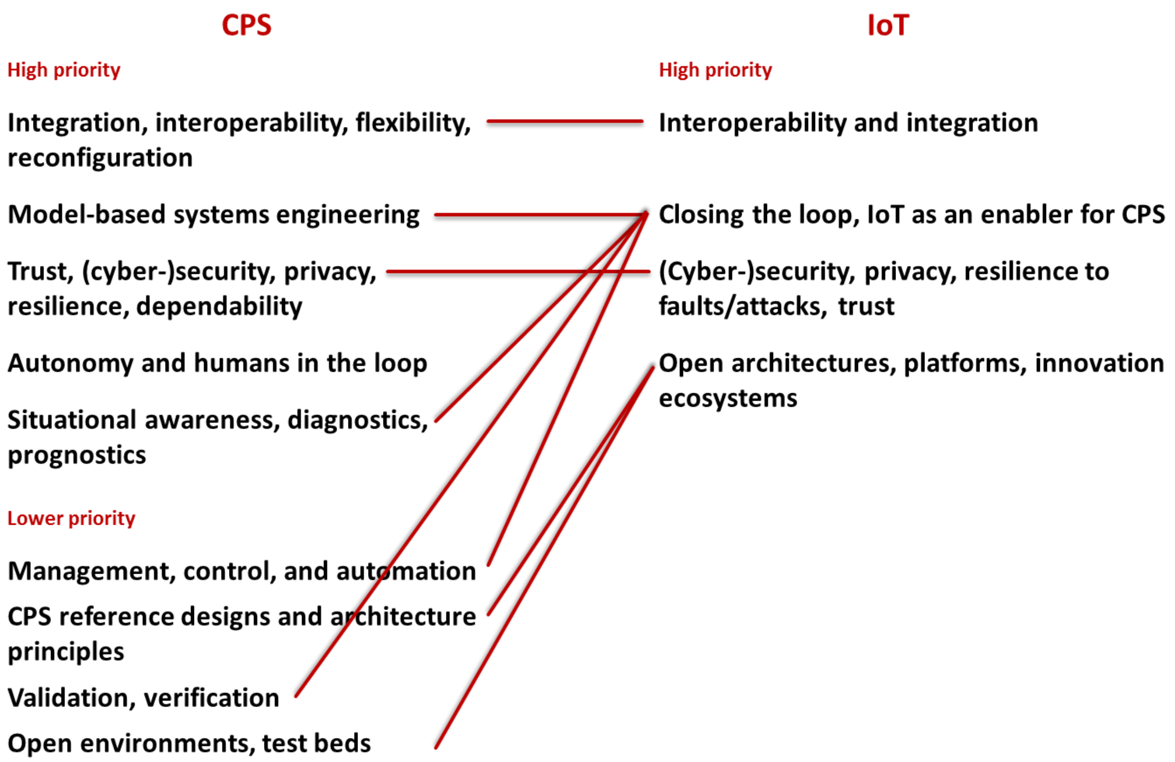

Figure 4: Mappings between CPS and IoT topics in the EU and the US.

Although this fact is not directly reflected in our analysis, our interviews indicate that there is currently a **strong push towards large-scale demonstrators and test beds** not only in the US, but also in the EU (see e.g. (25)), and the importance of joint test beds, demonstrators, and shared infrastructure in particular for EU-US collaboration was pointed out by several interview partners. Thus, this aspect is reinforced in the R&I themes in section 3 and in the collaboration opportunities defined below.

Another conclusion from our interviews and recently released strategic documents is that (**industry-driven) standardization activities** will gain importance in the next years, in particular in the quickly evolving IoT landscape, and that international collaboration will be essential to ensure interoperability and successful integration of future large-scale infrastructures.

Our findings are well aligned with those by other initiatives that work, or have worked, on the identification and promotion of R&I collaborations between the EU and the US, i.e. the EU project *DISCOVERY*[10] (26) that has the main objective to create a transatlantic ICT forum as a sustainable mechanism to support dialogues for EU-North America cooperation in the field of ICT, the EU project *TAMS4CPS*[11] (27) that focuses on modeling and simulation (M&S) for CPS, and the EU project *CPS Summit* (12). There are no contradictions between our results and the findings of these projects, and in particular the overlap with the findings of the *DISCOVERY* and the *CPS Summit* projects is significant (the limited scope of *TAMS4CPS* also restricts the breadth of their analysis).

DISCOVERY has just released a comprehensive survey of ICT research and innovation priorities (26) for which 123 EU and 46 US stakeholders were interviewed, including representatives from academia and industry, decision makers, government institutions, and associations. Out of the 10 most relevant ICT priorities that were identified, 7 relate directly to IoT or CPS and match well with the topics that PICASSO has identified. These priorities include

[10] http://discoveryproject.eu
[11] http://www.tams4cps.eu

privacy, data protection, and cyber-security R&I, threat detection and responses to cyber-attacks, model-centric and predictive engineering methods and tools for smart CPS, IoT integration and platforms, and new ICT platforms and technologies for smart buildings, smart grids, energy storage, electric vehicles, and smart charging infrastructures.

CPS Summit views the CPS foundational challenge as so great that a collaboration would prove to be beneficial for industry, academia, and governments, and it has identified the following technological challenges: the socio-technical character of CPS, systems theory and model-based systems engineering, cyber-security and dependability, interoperability, autonomy, technology platforms, data-driven approaches, verification and abstraction, dealing with uncertainty and risk, and humans in the loop.

5. All of the analyzed application sectors will profit from IoT/CPS advances and collaborations.

Our analysis has shown that institutions in both the EU and the US view CPS and IoT as pervasive technologies that will impact all application sectors and almost all aspects of life, and that **there are many cross-cutting challenges and needs in the four domains of smart production, smart cities, smart energy, and smart transportation**, as illustrated in Figure 5.

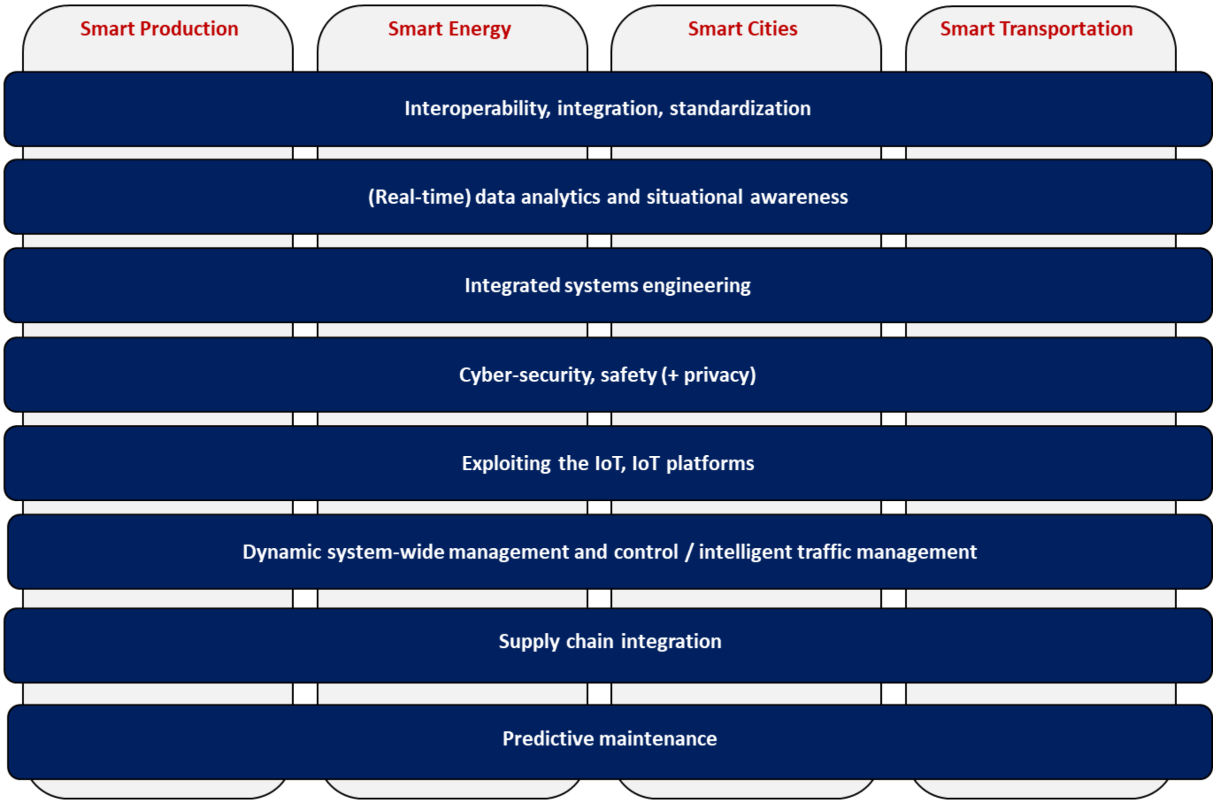

Figure 5: Identified major needs in IoT/CPS-relevant application sectors.

While this does not necessarily mean that all of these challenges can be served adequately by generic, cross-cutting solutions and platforms (since there are application-specific differences in many of the needs and environments of the sectors), it does indicate that the development of cross-cutting new technologies will provide significant benefit to different application sectors.

6. Our analyses, discussions, and interviews have shown that there is significant potential for collaboration on IoT/CPS topics between the EU and the US.

There are many similarities in drivers, needs, challenges, priorities, and programmes being pursued in the EU and the US. It is also clear that there are a number of opportunities where joint R&I between the EU and US would be beneficial, both on technological topics and on application topics, and our discussions with experts (1), members of the IoT/CPS Expert Group, and personal interview partners from funding agencies, industry, and academia indicate that there is willingness of collaboration between the EU and the US. In particular, lightweight collaboration mechanisms are currently favored, and both governmental and non-governmental (e.g. industry-led associations and multi-lateral companies) US actors were identified as promising collaboration partners for EU partners and projects.

This view is reinforced by other EU projects that work on promoting EU-US collaboration, such as the *CPS Summit*, *TAMS4CPS*, *DISCOVERY*, and *BILAT USA 4.0* projects. The latter project has e.g. found that ICT is the single most predominant area targeted for future EU-US cooperation, with promising topics including smart cities, the IoT, CPS, data management and open data, cognitive computing, automation, and cyber-security (24), and the *DISCOVERY* survey (26) shows that there are good perspectives for future EU-North America collaboration in ICT, especially under H2020 but also under US (and Canada) funding programmes, since a majority of respondents indicated interest in collaborative research and innovation.

3. Technology Themes for EU-US Collaboration

The analysis in section 2.6 has shown that there is a large overlap between the current R&I priorities in the EU and the US in the sectors of the IoT and CPS, as well as between the IoT and CPS sectors themselves. This section presents six R&I themes that were developed based on the analysis in section 2, and on discussions with the PICASSO Expert Group on IoT/CPS and with external experts from funding agencies, industry, industry-led associations, and academia.

In item (2) in section 2.6, five CPS-focused R&I themes were identified that have a high priority in both the EU and the US:

- Autonomy and humans in the loop
- Model-based systems engineering
- Trust, (cyber-)security, robustness, resilience, and dependability
- Integration, interoperability, flexibility, and reconfiguration
- Situational awareness, diagnostics, and prognostics

As illustrated in Figure 4 in section 2.6, these themes are related to the high-priority IoT topics, indicating that advancements in the state of the art in these topics will drive progress in both domains, in particular at the intersection of the IoT and CPS.

In addition, our analysis has provided strong evidence (see item (4) in section 2.6) that the R&I theme of "Closing the loop in IoT-enabled cyber-physical systems" is seen as an essential challenge in the EU and the US and that it offers interesting technological challenges that must be solved in the near future to enable the efficient usage of real-time data that is provided via IoT-connected devices.

Subsequent discussions within the Expert Group and with external stakeholders led to a prioritization of these technology themes with respect to their general importance, and to their importance for EU-US collaboration in particular. According to these discussions, the theme **Autonomy and Humans in the Loop** currently has the highest priority and should be in the focus on EU-US collaboration. Two other themes are currently of high importance as well according to our discussions, **Model-based Systems Engineering** and **Trust and Cyber Security**.

The remainder of this section presents draft summaries of all of the six R&I themes.

3.1. Autonomy and Humans in the Loop

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Autonomy in large-scale, complex, open systems, taking into account that such systems are not domain/knowledge-"contained"
- Models of autonomous CPS systems and humans
- Socio-technical aspects of IoT-driven CPS
    - Humans in the loop and collaborative decision making
    - Analysis of user behavior and detection of needs and anomalies
    - Novel approaches for analysis, visualization, and decision support

Why EU-US Collaboration?

Modern large-scale CPS are socio-technical in nature, and taking their interaction with humans into account has been identified as a challenge in both the EU and the US, as has the increasing trend towards autonomy in many areas and the need to predict how autonomous systems will behave when interacting with human actors. The significant overlap of the needs and interests in the EU and the US in this area is a good basis for R&I collaboration, a view that was reinforced during the feedback collection process. In addition, autonomy has recently gained much more importance within the EU R&I landscape, with “autonomous cyber-physical systems” likely becoming a major focus theme in H2020 and FP9.

Relevance to Application Sectors

Our analysis has shown that the need to consider the interactions of humans with technical systems is seen in several application sectors, and that there is an interest in the area of increased autonomy that cuts across all domains, in particular smart cities and smart transportation.

3.2. Model-based Systems Engineering

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Integrated, virtual, full-life-cycle engineering, system-wide design
- Engineering of high-confidence IoT and CPS systems, formal methods for assured design, validation, verification, risk analysis and risk management
- Models of heterogeneous large-scale systems
    - Open simulation and model integration platforms
    - Stochastic models
    - Model adaptation, maintenance, and validation
    - Data-based and grey-box modeling

Why EU-US Collaboration?

A consistent systems science and new integrated model-based engineering methodologies are of importance for the design, optimization, and operation of future IoT-enabled CPS. The documents that were analyzed show that the US view on this topic focuses more on theoretical aspects of systems science for novel CPS (such as the formal conceptualization of the interdependencies of technical systems and the environment) and on reliability aspects while the EU view seems to promote the practical aspects (such as integrated engineering of novel CPS) more, as well as system-wide management and coordination. These somewhat differing views are an argument for collaboration as EU and US groups may complement each other well in systems engineering R&I topics, which was confirmed during personal interviews conducted with senior experts from both sides. The challenges that are seen as important by both sides are similar (e.g. open simulation and model integration platforms and heterogeneous modeling of CPS), which may facilitate the identification of suitable collaboration partners.

Relevance to Application Sectors

Model-based systems engineering approaches and methodologies, as well as novel approaches for system-wide management and coordination, have been identified as major needs in all of the application sectors that we have analyzed.

3.3. Trust, (Cyber-)security, Robustness, Resilience, and Safety

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Exception handling, fault detection and mitigation
- Trustworthiness of technical systems regarding safety, reliability, privacy, and cyber-security
- Behavior-based methodologies to establish trust (e.g. via intrusion detection and prevention based on physical behaviors, resilience to cyber-attacks)
- New engineering perspectives for safety, security, resilience, reliability, and privacy
- Secure real-time and mixed-criticality systems

Why EU-US Collaboration?

Cyber-security is currently one of the dominant topics in the US, is seen as important in the EU as well, and will become even more important over the next years. Although collaboration on data-sensitive or privacy-related topics is most likely not feasible, our analyses and interviews indicate that technology-oriented R&I collaborations on topics such as cyber-security, trustworthiness, safety, attack resilience and intrusion detection, and secure real-time and mixed-criticality systems are seen as feasible and interesting. The large overlap in interests is a good basis for R&I collaborations.

Relevance to Application Sectors

The topics of cyber-security and safety are seen as the key challenges in all of the application sectors that we have analyzed. Thus, EU-US collaborations will benefit all sectors.

3.4. Integration, Interoperability, Flexibility, and Reconfiguration

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Semantic interoperability and semantic models (which ensure that different physical artefacts and computing elements 'understand' each other)
- Joint testbeds and large-scale pilots for CPS and IoT systems, shared infrastructure access
- Openness and open standards, harmonization of standards, establishing shared consensus as a basis for standardization activities
- Automatic configuration, reconfiguration, scalability, and plug-and-play integration of IoT and CPS components
- IoT and CPS architectures and cross-domain infrastructures

Why EU-US Collaboration?

The topics of integration, interoperability, flexibility, and reconfiguration were identified in our analyses as being of the high relevance in the EU and the US in both the CPS and the IoT domains. In particular, semantic interoperability and the need for consensus and open standards are seen as important in all domains and on both sides of the Atlantic. Joint testbeds, large-scale pilots, and shared infrastructure access were identified as essential tools to promote interoperability between heterogeneous infrastructures, and both the US and (in particular) the EU are currently working on large-scale demonstrators, e.g. in the areas of the IoT and smart cities, with indications that these efforts will be reinforced in the next years. IoT-based, next-gen infrastructures with cross national boundaries, which makes joint efforts for interoperability indispensable. The large overlap in topics, interests, and the suitability of shared infrastructure access for collaboration was confirmed during the feedback collection process (in particular in personal interviews with senior experts) and is a good basis for R&I collaboration.

Relevance to Application Sectors

The areas of interoperability and integration are of crucial importance in all of the application sectors that we have analyzed. Novel methodologies for (automatic) reconfiguration will be necessary for the development of future industrial infrastructures and networks, e.g. to reflect the increasing requirements for flexibility in manufacturing systems or to implement future smart grids with a large penetration of renewables.

3.5. Situational Awareness, Diagnostics, and Prognostics

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Large-scale real-time data analytics and data management
- Machine learning, learning methodologies, adaptive behavior
- Predictive condition monitoring and maintenance
- Self-diagnosis tools

Why EU-US Collaboration?

With the increasing pervasiveness of affordable sensing devices in future IoT-enabled CPS and, the intelligent use of data will become crucial to deal with the increasing complexity and to ensure efficient and optimal operation. This fact has been recognized in both the EU and the US, and the large overlap of interests and needs in this area will facilitate the successful establishment of R&I collaborations.

Relevance to Application Sectors

The increasing use of data and of real-time data analytics for the optimization and monitoring of technical systems is seen as a major opportunity, or even a prerequisite, in all of the application sectors that we have identified. Thus, novel theories, tools, and methodologies in this area will benefit all of these application sectors.

3.6. Closing the Loop in IoT-enabled Cyber-physical Systems

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- System-wide management and coordination via IoT-connected devices
- Data-based operation
- Cloud-supported control and management
- Control architectures for IoT-enabled CPS
- Closed-loop control over nondeterministic, variable-delay networks - performance and stability in the face of unpredictability
- Closing the loop in the face of outages, limited bandwidth, latency, and jitter

Why EU-US Collaboration?

Going beyond pure connectivity and using IoT-connected devices for closed-loop applications in technical systems is an almost natural next step that will be the basis for new levels of efficiency, quality, and reliability in next-generation cyber-physical systems. Our analyses and interviews have shown that both the EU and the US technical communities are aware of the enormous potential benefits of “closing the loop” and see this as probably the major technological challenge going forward. It is also recognized that the IoT and future IoT-enabled infrastructures are inherently multi-national and that this challenge cannot be addressed unilaterally, thus making it an excellent subject for future EU-US collaboration activities.

Relevance to Application Sectors

The potential benefits that arise from exploiting the IoT are seen as major drivers for novel ICT developments in all of the application sectors that were analyzed, and closing the loop in IoT-enabled CPS will benefit a diverse range of application scenarios, ranging from future global, highly integrated production systems over smart city applications and the efficient integration of renewables into smart grids to transportation systems and networks for e.g. intelligent traffic management and autonomous driving.

4. Opportunities and Barriers for EU-US Collaboration in Technology Sectors

This chapter gives a brief overview of the EU-US funding and collaboration environments in section 4.1 and summarizes barriers that may hamper EU-US collaboration in section 4.2. Section 4.3 provides recommendations of concrete opportunities that were identified as the most promising mechanisms for technological collaborations on the R&I themes presented in chapter 3.

The contents of sections 4.1 and 4.2 were created by the IoT/CPS Expert Group (with inputs from the Big Data and 5G Expert Groups), and the contents of section 4.3 are based on these sections. Additional sources include inputs and pointers from numerous external experts from EU and US funding agencies, industry associations, and academia that were interviewed by the IoT/CPS Expert Group, the analyses presented in section 2, the PICASSO reports (1) and (2), materials and feedback by the EU projects *DISCOVERY* (26), *BILAT USA 2.0*, *BILAT USA 4.0, CPS Summit*, and *TAMS4CPS*, and the interactive PICASSO IoT/CPS webinar that was held on February 2, 2017.

4.1. The EU-US Funding and Collaboration Environment

4.1.1. EU and US Funding

The US R&I funding landscape is structurally very different to the EU landscape. EU-level funding is mostly centralized and is realized via major funding programmes such as *H2020*, the *ECSEL Joint Undertaking*, and *ERA-NET* (which focuses on pooling and coordinating funding of EU member states for EU joint calls) that provide EU-wide frameworks for R&I funding activities, covering all levels from fundamental over translational and applications-oriented research to knowledge transfer, innovation, and commercial deployment. In the US, the funding landscape is much more fragmented. Research and innovation is mostly funded by federal research programs that are set up by different federal agencies and that reflect directly the government's priorities and interests (3). Research funding is also available at the state level, but state funding normally focuses on specific local needs and is not usable for international collaboration.

Applications-oriented R&I funding is often provided directly by companies or industry-led associations to partnering research institutions in the form of grants, with a focus on short-term returns. Initiatives such as *H2020* or dedicated programs by US agencies usually focus on funding relatively large R&I projects, for which it usually takes months between the funding application and the start of work. On the other hand, direct funding by industry often focuses on a smaller scope and a relatively quick (e.g. within a few weeks) start of work after initial funding talks.

A major contact point in the federal US funding landscape in the areas of IT, computing, networking, and software is the *Networking and Information Technology Research and Development* (*NITRD*) Program, a multi-agency program that coordinates the funding of all federal agencies in this area. It has specific contact points that coordinate research across all agencies, such as CPS research and wireless communications incl. 5G.

The *National Science Foundation* (*NSF*) exclusively funds basic research and has a major CPS research program with more than 350 funded projects, plus funding for IoT research. The NSF has explored collaborations with the EU in the past, most successfully in the areas of environmental health and safety technology. In addition, there are several bilateral cooperation agreements with EU member states, such as the US-German IoT/CPS program, and interview partners have indicated significant interest in future programs for EU-US collaboration in the areas of IoT and CPS. The NSF will not cover EU costs, but it may cover costs for EU researchers visiting the US and vice versa. The NSF has already shown interest on collaborations on low-TRL research and is a good fit because it has a major initiative in CPS, in which energy aspects are of particular interest.

The NSF is a leader in supporting Big Data research efforts as well. These efforts are part of a larger portfolio of Data Science activities. NSF initiatives in Big Data and Data Science encompass research, cyber-infrastructure, education and training, and community building. In addition to funding the Big Data solicitation, and keeping with its focus on basic research, NSF is implementing a comprehensive, long-term strategy that includes new methods to derive knowledge from data; infrastructure to manage, curate, and serve data to communities; and new approaches to education and workforce development. “Big Data” is a new joint solicitation supported by the National Science Foundation (NSF) and the National Institutes of Health (NIH) that will advance the core scientific and technological means of managing, analysing, visualizing, and extracting useful information from large and diverse data sets. This will accelerate scientific discovery and lead to new fields of inquiry that would otherwise not be possible. NIH is particularly interested in imaging, molecular, cellular, electrophysiological, chemical, behavioural, epidemiological, clinical, and other data sets related to health and disease.

In the 5G area, the NSF coordinated the $400 million Advanced Wireless Research Initiative launched in 2016. As a first step, a Project Office for establishing the *Platforms for Advanced Wireless Research* (*PAWR*) has been created. The NSF has explored collaborations with the EU in the past, most successfully in the areas of health and safety technology. In addition, there are several bilateral cooperation agreements with EU member states, e.g. with Finland and Ireland. Potential collaboration mechanisms involving the NSF are e.g. joint workshops and mirrored calls.

The *National Institute of Standards and Technology* (*NIST*) is an important, more applications-oriented player in ICT funding (with a focus on supporting their own labs, not academia in general) and is active in a variety of technological areas and application sectors. In particular, it has a *Cyber Physical Systems Program* and a *CPS Public Working Group* that is currently developing a CPS framework (28), and its wireless networks division has a *5G & Beyond Program* and coordinates the *5G Millimeter Wave Channel Model Alliance* as well as working group developing the *Future Generation Communications R&D Roadmap*. NIST has already shown significant interest in the PICASSO work.

The parent organization of NIST, the *Department of Commerce* (*DoC*), also promotes other activities in the IoT/CPS domain. In 2016, the DoC has set as a policy priority to engage with the EU Digital Single Market initiative in the area of the free and open internet, and it also promotes activities in the telecommunications domain. The *National Telecommunications and Information Administration* (*NTIA*) of the DoC focuses on expanding broadband internet access and expanding the efficient use of spectrum, and it has published a “green paper” that reviews the current technological and policy landscape for the IoT and that highlights potential benefits and challenges, and possible roles for the federal government in fostering the advancement of IoT technologies in partnership with the private sector (29). In this paper, the NTIA promotes a globally connected, open, and interoperable IoT environment and recommends governmental support for US industry initiatives, greater collaboration between (private) standards organizations, the crafting of balanced policy and building coalitions, the enabling of infrastructure availability and access, and the promotion of technological advancement and market encouragement. The NTIA sees the role of government in the promotion of robust interagency coordination, public-private collaboration, and international engagement, while avoiding over-regulation that could stifle IoT innovation. International collaboration is encouraged across a range of activities and topics, including a consistent common policy approach for the IoT, cross-border data flows, privacy, and cyber-security, based on formal dialogues with top international partners on digital economy issues.

Other agencies that are potentially of interest as US partners for PICASSO collaboration mechanisms are the *Department of Energy* (*DoE*) that supports more applications-oriented research and development in areas such as clean energy, environmental cleanup, climate change, and other areas, has a strong track record in collaborations with European universities and research centers, and has shown interest in topics such as grid modernization and integrating renewables, the *Department of State* (*DoS*), the *Department of Homeland Security* (*DHS*), *Department of Defense* (*DoD*) agencies such as *DARPA*, the *Air Force Office of Scientific Research*, the *Army Research Office*, and the *Office of Naval Research*, and US foundations such as *Gordon and Betty Moore Foundation* and the *Blavatnik Family Foundation*. In addition, the *TAMS4CPS* project found that US national labs (such as Sandia) may be suitable contacts regarding funding for collaborations on more applications-oriented research.

The DoD is "placing a big bet on big data" investing approximately $250 million annually (with $60 million available for new research projects) across the military departments in a series of programs that will:

- Harness and utilize massive data in new ways and bring together sensing, perception and decision support to make truly autonomous systems that can maneuver and make decisions on their own.
- Improve situational awareness to help warfighters and analysts and provide increased support to operations. The Department is seeking a 100-fold increase in the ability of analysts to extract information from texts in any language, and a similar increase in the number of objects, activities, and events that an analyst can observe.

The *Defense Information Systems Agency* (*DISA*) offers a cloud-based set of solutions that enables the collection of large amounts of data from across the DoD Information Networks (DODIN) and provides the analytics and visualization tools to make sense of the data. The set of solutions is called *Cyber Situational Awareness Analytical Capabilities* (*CSAAC*) and is available on both *the Nonsecure Internet Protocol Router Network* (*NIPRNet*) and *Secret Internet Protocol Router Network* (*SIPRNet*). By using CSAAC, DoD network analysts and operators have a broader and more comprehensive view of DODIN activity than ever before. CSAAC enables informed decision making and enhances the overall security posture of DoD networks.

According to Deltek Principle Research Analyst Alex Rossino's new calculations, the *Defense Advanced Research Projects Agency*'s (*DARPA*'s) budget requests for big data research and development programs will grow by 39 percent in fiscal year 2016. In the past two years, DARPA's big data investments - which focus on advanced algorithms, analytics and data fusion, among other things - have spiked 69 percent, growing from just under $97 million in FY 2014 to more than $164 million in FY 2016. In addition, in 2012, DARPA initiated the 3-year $100M XDATA program to develop computational techniques and software tools for processing and analyzing massive amounts of mission-oriented information for Defence activities. Furthermore, to encourage future collaboration and innovation across the mathematic, computer science and visualization communities, DARPA open sourced the solutions for the general public.

The DoD and DARPA also support for example a spectrum collaboration challenge, where competitors are reimagining spectrum access strategies and developing new paradigms of collaborative decision-making where radio networks will autonomously collaborate and reason about how to share radio spectrum.

The *Department of Energy* will provide $25 million in funding to establish the *Scalable Data Management, Analysis and Visualization* (*SDAV*) Institute. Led by the Energy Department's Lawrence Berkeley National Laboratory, the SDAV Institute will bring together the expertise of six national laboratories and seven universities to develop new tools to help scientists manage and visualize data on the Department's supercomputers, which will further streamline the processes that lead to discoveries made by scientists using the Department's research facilities. The need for these new tools has grown as the simulations running on the Department's supercomputers have increased in size and complexity. Moreover, the DoE, with the support of partners and allies, has created the SEED Platform Collaborative to help put big data to work on one of the biggest problems in the global effort against the negative effects of climate change - the waste of energy in big buildings. The new *Standard Energy Efficiency Data* (*SEED*) Platform Collaborative creates a remarkable three-year partnership with regional and local governments to help them collect and manage data that tracks energy use in buildings, set aggressive goals for energy efficiency in them, and transform cities and regions into energy-saving leaders.

Other governmental agencies that support Big Data R&I are the *National Institutes of Health* (*NIH*) and the *US Geological Survey* (*USGS*). The NIH has announces that the world's largest set of data on human genetic variation – produced by the international 1000 Genomes Project – is now freely available on the *Amazon Web Services* (*AWS*) cloud. At 200 terabytes – the equivalent of 16 million file cabinets filled with text, or more than 30,000 standard DVDs – the current 1000 Genomes Project data set is a prime example of big data, where data sets become so massive that few researchers have the computing power to make best use of them. AWS is storing the 1000 Genomes Project as a publically available data set for free and researchers only will pay for the computing services that they use. The USGS has financed, through its John Wesley Powell Center for Analysis and Synthesis, a number of projects on Big Data in order to improve its understanding of issues such as species response to climate change, earthquake recurrence rates, and the next generation of ecological indicators. Funding was providing scientists a place and time for in-depth analysis, state-of-the-art computing capabilities, and collaborative tools invaluable for making sense of huge data sets.

Non-governmental actors play a major role in translational and application-oriented R&I, collaboration, and funding in the US and the EU, and are the main drivers in for applications-oriented ICT advancement. Non-governmental actors include multi-national companies (which have an inherently international point of view and are particularly dominant in the IoT sector), and industry-led associations and standardization bodies such as the *Industrial Internet Consortium* (*IIC*), the *International Council on Systems Engineering* (*INCOSE*), the *Smart Manufacturing Leadership Coalition* (*SMLC*), the *Object Management Group* (*OMG*), the *National Coalition for Advanced Manufacturing* (*NACFAM*), the *Conference of European Directors of Roads* (*CEDR*), and others. Our discussions with representatives from industry-led associations have shown that companies and associations are promising potential partners for future EU-US collaborations, also because they are less affected by governmental policy than federal agencies.

4.1.2. EU-US Collaboration

According to research conducted by the *BILAT USA 2.0* project, "nearly one-quarter of individual organisations' policy measures provide funds to other countries as long as the leading organisation is a U.S.-based university or other research institution. About 40% of the measures do not provide funding to non-U.S. institutions. The remaining 40% have specific pre-requisites for allowing receipt of U.S. funds by third countries".

In a recent study, the *DISCOVERY* project (26) analyzed the participation rate of US partners in H2020 projects and found that out of 52 running H2020 projects with US participation (with starting dates before June 2016), only three projects focus on IoT topics, and none on CPS topics, while the majority of projects are in the scope of personal healthcare (due to an existing bilateral agreement on health R&I between the EU and the US and thus eligibility of US organisations for H2020 funding). Two of the three IoT projects are within the scope of the *Future Internet Research & Experimentation* (*FIRE*) European initiative, which previously participated in a successful EU-US collaboration with its US counterpart, the NSF-funded *Global Environment for Networking Innovations* (*GENI*) program. The collaboration focused on the organization of joint thematic workshops and the exchange of personnel between the EU and the US.

Recently, EU-US collaborations have been set up based on coordinated calls and project twinning. To foster technological advances leading to the development of Next Generation Internet (NGI) and Advanced Wireless Networking (AWN) systems and technologies, the EU call "EU-US collaboration on NGI", which was published in the H2020 work programme 2018 – 2020, accepts project proposals that include twinning mechanisms (such as collaborative research initiatives or research exchange fellowships) with entities participating in projects funded by the US (via the program "US-EU Internet Core & Edge Technologies (ICE-T)" that is implemented by NSF) to exchange knowledge and experience and exploit synergies.

On the EU side, there are several examples where specific programmes opened project participation, and even funding in some cases, to US partners. The *Conference of European Directors of Roads* (*CEDR*), a consortium of public national road authorities or equivalents of European countries that focuses on applications-oriented research on road transportation topics, opened a recent call for projects to US participants[12], including the possibility of receiving funding from *CEDR*. The goal of this collaboration effort was to gain access to leading

[12] http://www.cedr.eu/download/other_public_files/research_programme/call_2016/CEDR-Call-2016-Information-Dec-2016.pdf

research experience from the US. The ERA-NET instrument that supports public-public partnerships for joint, transnational activities between EU member states (possibly with EU-level funding contributions) recently organized a workshop with the goal of making US and Brazilian funding agencies aware of the ERA-NET work and to discuss collaboration opportunities [13]. Follow-up activities are planned. In addition, selected ERA-NET programmes complement EU member state funding with external initiatives, including US-based funding. An example is *the Infrastructure Innovation Programme* (*Infravation*) for road infrastructure innovation[14].

Many multi-national companies (which by definition have subsidiaries in different countries that often collaborate) and industry-led associations have a strong track record of international collaboration and are open to participating in EU-US collaboration efforts. As an example, the *Industrial Internet Consortium* (*IIC*) is a global initiative that promotes the growth of the industrial IoT by bringing together partners from around the world, coordinating ecosystem initiatives, and bridging between regional initiatives (such as *Industrie 4.0* in Germany). Particular focus is currently placed on the 27 joint testbed initiatives[15], involving partners from many different countries. These joint testbeds provide realistic industrial environments for joint pre-competitive R&I projects so that new technologies, applications, products, services, and processes from different partners can be initiated, developed, and tested. As an example, the first of these testbeds, *Track&Trace*, was established appr. 2 years ago, is located in Germany, involves partners from the EU, the US, and India, and focuses on the development and testing of future smart, hand-held tools in manufacturing, maintenance, and industrial environments.

While collaboration initiatives between governmental agencies (such as the NSF and the EC) involve only few large organizations and are usually coordinated and set up internally, establishing collaborations between many different actors (such as government agencies on one side and industry-led associations, or even single large enterprises and SMEs on the other side) may require significant coordination and support activities. An example of a non-profit organization that specializes on this kind of match-making is the *Intelligent Manufacturing Systems* (*IMS*) Global Research and Business Innovation Program[16], which is partly funded by the EC. The program aims to integrate and connect US manufacturing industries and associations with EC programmes (where EC-foreign partners must provide their own funding). They focus on two services, direct matchmaking to set up R&I projects with partners from the member states, and thematic project clustering programmes for existing projects that provide collaboration support, such as the organization of workshops for international exchange.

4.2. Barriers

This section summarizes major barriers that must be overcome to implement successful EU-US collaborations. Most of these barriers have been identified in discussions within the IoT/CPS Expert Group and personal interviews done by the IoT/CPS Expert Group with external experts. Additions were provided by the Big Data and 5G Expert Groups.

4.2.1. Structural Differences in Funding Environments

As described in section 4.1, the US R&I funding landscape is structurally very different to the EU landscape along several dimensions.

First, EU-level funding builds on centralized framework programmes that do not have a counterpart in the fragmented US landscape. There are no overarching US or EU programmes currently that focus on closing the gap between centralized EU and decentralized US funding, although programs such as *Intelligent Manufacturing*

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[13] https://www.b2match.eu/jpisgoglobal2016

[14] http://www.infravation.net

[15] http://www.iiconsortium.org/test-beds.htm

[16] http://www.ims.org

Systems (*IMS*, see previous section) provide bridging services for specific sectors. It seems unlikely that such overarching programmes are viable due differences in policy and due to the large administrative overhead that comes with the coordination of many different agencies and companies.

Second, different US funding agencies target specific technology readiness levels. The NSF focuses solely on basic research while other agencies (such as NIST, the DoE, national labs) focus on more applications-oriented translational research, and companies directly fund applications-oriented R&I. On the other hand, EU projects usually target several levels at the same time, and a single project may include basic research work, applications to realistic use cases, and even commercial deployment of novel technologies. Thus, high-level collaboration mechanisms, such as joint funding programmes or calls, are difficult to set up in a way that takes these differences into account. However, lower-level mechanisms that e.g. focus on the integration of US companies or industry-led associations for specific tasks within an EU project will be easier to accomplish.

Finally, there may be differences in the time spans between the application and the start of funding, and the funding cycles are not aligned between the EU and the US. EU projects are complex constructs that involve large consortia of partners from both, academia and industry, and it usually takes several months from the submission of an application to the start of funding. On the other hand, companies often have very specific R&I needs that can be achieved with relatively small effort, and they require a short-term return and a quick start of funding (e.g. within a few weeks) after application. However, EU projects are interesting for US companies for longer-term, more visionary R&I despite these timing differences, because these projects often run for several years, which provides planning security.

4.2.2. Administrative Overhead and Legal Barriers

International collaboration efforts always incur an administrative and bureaucratic overhead that can be a major barrier, as determined by the IoT/CPS expert group. There are many different potential mechanisms for EU-US collaboration, several of which have been successfully implemented before. The EU project *TAMS4CPS* has published proposals for such mechanisms (27), which can be separated into three different groups.

High-level, *top-down*, *heavyweight mechanisms* provide comprehensive frameworks for international collaboration. These include e.g. the **high-level multilateral agreements** between different countries (such as the 2016 Implementing Arrangement that was recently signed between the EU and the US[17]), large **thematic, targeted funding programmes** (such as the joint EC-NIH programme that supports EU-US collaboration in the health sector), and **joint calls** for R&I projects that pool funding all involved countries. High-level mechanisms usually require strong political support, and it often takes many years (estimated in interviews until 2020 when starting now) and a very large amount of work of all involved partners to set up such mechanisms.

Lower-level, *bottom-up*, *lightweight* mechanisms focus on specific collaboration aspects with smaller, targeted actions that can be set up relatively easily and quickly, and that occur a much smaller overhead than top-down programmes. These range from the **organization of joint workshops, conferences, and series of seminars** over support for the **mobility of researchers, staff exchange, fellowships to students, and training and education** and the trans-Atlantic provision of **access to research infrastructure, testbeds, and demonstrators** to (at the upper end in terms of complexity) relatively loose connections between calls for R&I projects, such as **coordinated calls** (for which both sides execute calls on a specific thematic topic that are temporally synchronized and that may support the involvement of external partners from both sides of the Atlantic, but where evaluation and funding is organized separately by each side) and **project twinning** (e.g. by implementing lightweight collaboration actions between existing R&I projects and consortia). The EC workprogrammes include

[17] http://ec.europa.eu/research/iscp/index.cfm?pg=usa

coordinated calls (such as the coordinated NGI initiative described above) as an instrument of a focused international strategy (25).

Finally, *collaboration support mechanisms* do not directly implement collaboration actions but provide support that facilitates the set-up of such actions. These include e.g. the facilitation of US participation in mainstream H2020 projects, the enhancement of framework conditions for trans-Atlantic collaboration, and the promotion of the visibility of EU/US programmes, as e.g. done in the *BILAT USA 4.0*, *PICASSO*, and *DISCOVERY* projects.

Our analysis and the interviews have conclusively shown that heavyweight mechanisms do currently not have a good chance of being successfully implemented in the IoT/CPS sector, particularly in the current political climate and if they require pooling of EU and US funding (see also below)[18]. The major reasons are the large overhead in the face of a lack of clearly visible benefits of such programmes and the fast evolution of the ICT field (and in particular of the IoT) that cannot be suitably reflected over the long time frames that are needed to set up high-level programmes.

Legal requirements are seen as major barriers for EU-US collaboration as well. In fact, many companies, for which the availability of external funding is often not an important requirement in joint R&I projects, see legal requirements as the major barrier for international collaboration. Companies are not interested in signing complex, restrictive legal documents. The initiatives that facilitate collaborations involving companies (such as the *Intelligent Manufacturing Systems* (*IMS*) program) restrict the legal requirements for partners by providing lightweight agreements and MoUs (memoranda of understanding).

It was noted by several interview partners that the need for US partners (in particular companies) to sign H2020 grant and consortium agreements has made it virtually impossible to involve commercial partners in H2020 aspects. However, this requirement has recently been removed under a new "Implementing Arrangement"[19] that was signed in October 2016 by the EU and the US. Under this new agreement, US organizations that do not receive any funding under H2020 are allowed to partake in research efforts and other relevant activities in the scope of EU projects without having to sign grant and consortium agreements, thus providing a new basis for EU-US R&I collaboration under Horizon 2020.

4.2.3. Lack of Clarity of the Benefits of EU-US Collaboration

The IoT/CPS expert group found that a major barrier to international collaboration is a lack of awareness and clarity about the benefits of EU-US collaboration activities for the participants, and a key requirement is the identification of these benefits and their communication to funding agencies, industry, and academia. Obviously, the more administrative and bureaucratic overhead a collaboration measure creates, the larger and more convincing the benefits must be. Questions that must be answered include e.g. "Is there a skill gap which can be complemented by collaboration?", "Is there mutual economic benefit?", "What will be missed if there is no collaboration?", or "What are the common interests?" (see section 2).

Generally, collaborations within the research community are easier to justify than academic-commercial or pure commercial collaboration. The research community is inherently global and universal, and often significant advances in key areas are only possible in international collaboration efforts, e.g. by leveraging what EC academia can contribute, and vice versa. Major success stories of successful international collaboration efforts are e.g. CERN and the nuclear fusion reactor ITER. Another major benefit of EU-US research collaboration is that the

[18] Note that bilateral agreements between the US and a single EU member state are easier to implement than multilateral agreements between the US and the EU. Successful programs have e.g. been implemented between the US and Germany, the US and the UK, and the US and Ireland.

[19] http://ec.europa.eu/research/iscp/index.cfm?pg=usa

expansion of the horizons of scientific human capital (e.g. of students, graduates, post-docs) is a prerequisite for successful scientific research.

The identification of benefits for the inclusion of companies into collaboration efforts is more involved (although smaller companies are likely easier to identify for smaller companies than larger companies). There must be immediate incentives that justify the effort and the release of internal information and IP. Short-term benefits must be identified for concrete commercial and application scenarios within a restricted thematic area (such as additive manufacturing or specific scenarios involving the industrial IoT). Some general benefits for the involvement of companies in EU-US collaboration efforts are that in the globalized age, the merging of technologies from different parts of the world is an important competitive advantage that can lead to economic growth, that collaborations increase global visibility of a company, that different regions possess different strengths that can complement each other, and that collaboration may mitigate risks. For example, the US is strong in software and computing while the EU has unique strengths in smart production and cyber-physical systems development and deployment. In such a case, complementarity can create more than the sum of the parts when bringing different sectors together (provided the collaboration is not too close to commercial interests of the participants).

The advancement of international standardization and the sharing of infrastructure, testbeds, and demonstrators are other key benefits of EU-US collaboration (where again CERN and ITER are good examples of successful shared infrastructure). Infrastructure and testbeds are expensive to build, thus sharing will benefit both sides, and EU-US collaborations on standardization will set the standard for the rest of the world, in particular for the IoT sector in which all players are aware that trying to build a region-specific IoT is doomed to fail. Global efforts are seen as the only way forward.

In its recent survey (26), the *DISCOVERY* project asked respondents to identify the benefits that are most important for EU-US ICT collaboration. Gaining competitive advantages by an extended view of future challenges was identified as the most important benefit, followed by creating overseas relationships, sharing and gaining insights into research activities, and gaining international visibility.

4.2.4. Restrictions due to Intellectual Property Protection

Collaboration may be difficult on topics of **high near-term commercial importance**, i.e. innovation efforts that focus on products and services that may lead to large profitable businesses in the near term. Different regions are in competition, and industrial policy focuses on measures that reinforce own industry. This barrier is seen as important in all analyzed application sectors, and this is also a conclusion by the *BILAT USA 4.0* project that has found a lack of bilateral funding agreements between the EU and the US in areas with immediate economic outcomes. They state that "one reason for the lack of joint funding agreements may be that there are immediate economic outcomes where the US has a competitive advantage compared to the EU in the areas of technology levels, entrepreneurship, supporting start-ups, and venture capital." (24).

It is thus arguably easier to collaborate on basic research than on applied research. An example is the *FET* (*Future and Emerging Technologies*) EC programme that focuses on basic research. Here, it is much easier to involve US partners (even including trans-Atlantic funding) than in other, more applications-oriented programmes, such as the ECSEL Joint Undertaking. One exception is the joint work on international standards and interoperability. While this is of commercial importance, it usually does not require companies to disclose information and technology that affects stand-out features of their products.

The Big Data expert group found that industrial competition between US and EU has a long tradition: It is widely accepted that EU and US are two competing regions, especially on technologically driven industries. Especially in the area of Big Data, Europe has been slow to adopt compared to the United States. More than half of worldwide revenue from big data is expected to come from the USA, and only one in twenty top big data companies is European (30). Thus, it can be very challenging for funding agencies and organisations from these regions, to collaboratively tackle research of high TRL (Technology Readiness Level) or applied research topics. However, tackling basic research subjects and topics can be an alternative.

The 5G expert group has identified this barrier as important for research topics that are already considered as study or work items in global standardization bodies, like 3GPP and IEEE. Hence, it will be easier to collaborate on fundamental research than on applied research.

4.2.5. Lack of Joint EU-US Funding Mechanisms and Policies

Generally, most of the EU funding will be used to fund EU companies and research institutes, and US funding will focus on the support of US organizations and companies. Thus, EU-US collaboration will always be a complement, or even an exception, to local and regional funding. This is not expected to change in the near future and is one of the reasons why high-level mechanisms such as joint calls or thematic, targeted funding programmes are difficult to implement (see above).

The Big Data expert group has also found that joint funding is a challenging task: As already known, US structures (both private and public) who are based in the US, have limited access to EU funding. US structures are eligible for participation in EU projects, but financial support is only available for calls where this is specified, e.g. the "Health" programme in general. In some cases, the financial support to the US partners is not possible even if the call targets collaboration with the USA. Potential US participants are therefore encouraged to contact research and innovation funding organisations in the US to seek support for their participation in Horizon 2020 (unless mirrored calls are established, see example of NGI call above, launched by the EC and by NSF). No jointly agreed mechanism is currently in place for co-funding Horizon 2020 research and innovation projects. On the other side, EU organisations willing to participate in US research programmes, face similar challenges, as it is almost impossible to receive funding from US agencies. Results from the newly signed EU-US agreement (signed in October 2016), which offers new opportunities for research cooperation, remain to be seen.

4.2.6. Export Control and Privacy Restrictions

Topics touching **export control issues**, **sensitive or classified data / information**, or **privacy issues** should be avoided. The EU and US national priorities, rules, and regulations are very different and will be difficult to harmonize, and generally legal and policy differences will be difficult to overcome in these areas. In particular export control issues have been identified in interviews as major blocking factors of international collaborations. Such issues must be dealt with appropriately before starting any collaboration actions.

The Big Data expert group found that data privacy is a complicated issue: The collection and manipulation of Big Data, as its proponents have been saying for several years now, can result in real-world benefits. However, it can also lead to big privacy problems (31). Both the EU and the US, have established a number of laws, policies and directives dictating the use of personal data by organisations and institutions willing to benefit from them. There are many differences between the laws regarding data privacy in the European Union and the United States, with the E.U. generally allowing more rights to the individual. With no single law providing comprehensive treatment to the issue, America takes a more ad-hoc approach to data protection, often relying on a combination of public regulation, private self-regulation, and legislation (32). Even after the US and the EU signed the EU-US Privacy Shield Framework (33), open issues remain, making it very challenging and complicated for organisations coming from these different regions to collaborate on research topics related to personal data.

4.2.7. Lack of Awareness and Knowledge

A lack of awareness and knowledge of EU and US actors of the other side is detrimental to collaboration. E.g., *BILAT USA 4.0* found that interested US actors may be unaware of how EU funding schemes operate (including misconceptions on how US partners can participate in H2020), and are not aware of the R&I priorities of the other side. In addition, it is often straightforward to connect to other initiatives within the US, but the EC landscape is fragmented, and the responsibilities may not be clear to US agencies.

This barrier is confirmed by an investigation of the *DISCOVERY* project (26) that identified as main barriers the lack of information on funding opportunities and programmes, the lack of knowledge about specific research areas and topics that are open to international cooperation, difficulties to understand the rules of participation in other countries, and a lack of partner search tools and methods.

Currently, several EC projects are working on solutions for these issues, including *PICASSO*, *TAMS4CPS*, *DISCOVERY*, and *BILAT USA 4.0.*

4.2.8. Lack of Interoperability and Standards

A **lack of interoperability and (device) standards** can be a barrier to collaboration. This is true for several of the application sectors, as described in section 2.5 and, in more detail, in (1). In addition, IoT/CPS systems were noted by our interview contacts as sometimes being highly regulated, which can stifle innovation.

4.3. Collaboration Opportunities

This section summarizes recommendations and opportunities for EU-US collaboration in the IoT and CPS sectors that were synthesized based on discussions with EG members, inputs from external experts from EU and US funding agencies, companies, industry-led associations, and academia, and an analysis of the results of projects that work towards EU-US collaboration development.

This section is at this stage speculative, since the success probability of future collaboration mechanisms that involve governmental actors will depend on the regulatory framework and conditions that will be enacted by the new US administration, and on the new directions that will be emphasized over the next months. Governmental actors are currently in a waiting mode, and it is seen as unlikely that any collaboration mechanisms can successfully be set up within the next months at the least. Mechanisms that focus on EU collaborations with non-governmental US actors may have a higher chance of success in the short term as commercial companies and associations are less affected by federal policy.

The following major conclusions can be drawn from the analyses and barriers described in the previous sections:

- While heavyweight collaboration measures are not considered to have a high probability of success in the IoT/CPS sector at this stage, **lightweight collaboration actions** are seen as being promising, in particular those with low complexity that are relatively easy to set up (e.g. joint workshops and staff exchange), and most of the contacted interview partners **indicated interest in setting up such mechanisms**. At the program level, coordinated calls and project twinning are seen as the only options with reasonable chances for success. However, since the set-up of these mechanisms takes significant effort and a long time, they should not be seen as primary mechanisms for EU-US collaboration in the near future.
- In addition to governmental agencies, **private companies and industry-led associations** were identified as promising partners for EU-US collaboration actions, because they are more interested in R&I results than funding (they often can provide their own funding or may even offer funding means to academic participants), are less affected by governmental policy than federal agencies, and are inherently internationally oriented, i.e. not focused on national boundaries. The set-up of collaboration actions involving many potential partners (e.g. enterprises and SMEs) will require **significant coordination, support, and facilitation efforts**. However, even if only governmental agencies are involved, the large disparity between the centralized EU and the decentralized US funding landscape may require facilitation support.

- EU-US collaboration projects on technological topics should focus on aspects that do not require companies to release IP that is too closely related to stand-out features of their products. Thus, collaboration actions might either focus on **pre-competitive R&I with a low-*TRL* (*Technology Readiness Level*)** or on other efforts that do not require access to sensitive company-internal IP, such as increasing **interoperability**, developing **international standards**, **joint demonstration**, **testbeds**, or **business model development**. In addition, there may be opportunities to collaborate on topics such as **energy, air, and water with a focus on developing parts of the world** (e.g., Africa, India, Latin America). Within this space, commercial opportunities may be more limited in the near term than in the US and in EU countries.
- One key requirement for the successful initiation of EU-US collaboration actions is **benefit assessment and promotion**. Collaboration actions will only be set up if the expected benefits are larger than the administrative overhead, and if these benefits are made very clear to all participants, such as funding agencies and private companies. The required benefits grow with the complexity of setting up and executing collaboration measures. While it is relatively easy to identify convincing benefits for research collaboration, the benefits of more applications- and innovation-oriented collaborations are less clear. In particular for private companies and industry-led associations, it is important to clearly identify the business and commercial benefits of collaboration actions, which is a non-trivial task that usually has to focus on a concrete technological or business scenario.
- Since private companies and industry-led associations are not interested in entering complex and restrictive legal relationships, measures that focus on improving framework conditions for EU-US collaboration should target the **reduction of legal requirements**. The new Implementing Arrangement that was signed in October 2016 by the EU and the US provides a good basis for the inclusion of US-based companies and associations.

Based on these conclusions and the other contents of the IoT/CPS section of the opportunity report, the following concrete collaboration opportunities are defined. Within PICASSO, these opportunities will be validated, refined, and promoted.

4.3.1. Roadmapping and Benefit Assessment

The first step in future EU-US collaboration measures in the areas of the IoT and cyber-physical systems should focus on roadmapping and the identification, assessment, and promotion of benefits.

The most desirable mechanism for this is the organization of **joint, thematic EU-US workshops** that are co-funded by the EC and suitable US partners (such as NSF, NIST, or industry associations like IIC and SMLC) – alternatively, there could be a "pair" of workshops in the topic, one funded by the EU and one by the US. Such workshops should focus on specific technological topics (i.e. a subset of the technology themes that are described in section 2) and should aim at fulfilling the following objectives:

- Bring together **a diverse group of experts from academia, industry, and government** to discuss specific joint collaboration opportunities.
- Identify **specific R&I topics and concrete technology and application scenarios** that can serve as the basis for targeted collaboration programmes and calls.
- **Synthesize a list of benefits** that can be used to justify the effort of collaboration actions to all involved parties, including researchers, industry and industry-led associations, and the EU and US funding providers (such as the EC, the NSF, or specific industrial consortia that are willing to open their funding to the outside).
- Generate **proposals for facilitation mechanisms** that can be used to identify suitable participation and funding structures within the diverse EU and US funding landscapes.

- Develop and disseminate **white papers** that concisely summarize the concrete scenarios, potential involved participants, benefits, and facilitation mechanisms and can serve as a basis for the definition of concrete R&I projects, calls, or coordinated work programmes.

The Trans-Atlantic Symposia on ICT Technology and Policy initiated by the PICASSO project are examples of such workshops: the first edition took place in Minneapolis, hosted by Technological Leadership Institute, University of Minnesota (June 2017), the second edition takes plane in Washington, DC in June 2018, hosted by Wilson Centre. On a longer time horizon, it is recommended to set up a dedicated CSA (Coordination and Support Action) that continues these roadmapping and benefit assessment activities, leading into concrete calls and project proposals (see below).

4.3.2. Facilitation and Industry-focused Research and Innovation

The set-up of collaboration actions involving many potential partners (e.g. enterprises, industry-led associations, and SMEs), and the elaboration of ways to link the centralized EU funding structure and the decentralized US structure will require significant coordination and facilitation effort that cannot be supplied by the funding agencies and the potential partners alone.

An **organization or network is needed that serves as a central contact point, coordinator, and facilitator** for the set-up and execution of **EU-US collaboration actions with many potential partners**, and for the integration **of non-governmental US entities into H2020 projects** (possibly inspired by the *Intelligent Manufacturing Systems* (*IMS*) Global Research and Business Innovation Program that provides similar support for the manufacturing sector). Such an organization must bring together entities from academia, industry, and the funding environment to define specific collaboration actions and topics, analyze and promote potential benefits of collaboration with/to these entities, identify suitable collaboration mechanisms and funding structures for a specific collaboration action, and support the partners in the execution of the collaboration action (e.g. by supporting the organization of collaboration workshops).

4.3.3. Lightweight Joint Research and Innovation

While top-down mechanisms such as joint targeted funding programmes and joint EU-US calls are currently seen as being too complex to set up, setting up **coordinated calls** between the EU and the US and **twinning of projects** are seen as interesting options for collaborative R&I.

It is recommended that **a joint, targeted EU-US collaboration work programme** - even on small scale - is set up based on the results of dedicated roadmapping and benefit analysis efforts (such as those described above). The closing dates of **coordinated calls** that are started against this work programme are synchronized between the EU and US, but proposals and projects are evaluated and funded separately (alternatively or additionally, the EC could open up calls for self-funded US partners). Calls should require project proposals to integrate mandatory (lightweight) collaboration items, such as short-term student, researcher, and staff exchanges between EU and US partners and regular joint workshops for knowledge and experience transfer. The involvement of **non-governmental partners**, such as enterprises, SMEs, and industry-led associations should be encouraged and supported by a facilitation mechanism or organization, as described in section 4.3.2. Collaborations of regional EU entities (e.g. cities) with regional US entities (e.g. with cities or US states) may be a viable option as well, albeit with limited impact.

Since a fruitful EU-US exchange of IoT, CPS, and application experts is seen as an important mechanism to advance the state of the art in these domains, a separate lightweight program should be set up that provides **fellowship and exchange funding** for students and researchers to work and study abroad, and that promotes knowledge transfer between the EU and the US by funding **joint workshops**, **conferences**, and **seminar series** on IoT and CPS topics. This program should provide a **twinning option** that allows to link these collaboration actions to running R&I projects.

Standards and interoperability define future markets and are often a basis for product development, and there is currently a strong push towards large-scale demonstrators and test beds not only in the US, but also in the EU (see e.g. (25)). The importance of **joint testbeds**, **demonstrators**, **and shared infrastructure** in particular for EU-US collaboration was pointed out by several interview partners from both, the EU and the US. Such test beds and demonstrators provide realistic, large-scale scenarios for the evaluation of all kinds of novel technologies (including those that are defined in section 3) and are thus an important prerequisite for the successful transfer of novel technology into practice. In addition, **(industry-driven) standardization activities** will gain importance over the next years, in particular in the quickly evolving IoT landscape, and international collaboration will be essential to ensure the interoperability and successful integration of future large-scale infrastructures.

Infrastructure sharing and the development and joint usage of **large-scale test beds and demonstrators** should become a focus area of EU-US collaborative research and innovation funding. The EU and US should launch **synchronized initatives** that (a) provide financial support and administrative assistance for researchers and industry representatives to do **joint experiments on existing infrastructure** in the IoT, CPS, and relevant application domains, and that (b) provide support for the set-up of **new testbeds and demonstrators** on high-priority technology topics. Successful international testbed and infrastructure initiatives should be used as an inspiration (such as the joint testbed initiative of the *Industrial Internet Consortium*), and **companies and industry-led associations should be encouraged to contribute to infrastructure sharing initiatives**.

5. Conclusions

This report outlines new **technology themes** and **collaboration opportunities and mechanisms** that have been identified as being promising for EU-US collaboration in the areas of IoT and CPS. The themes and opportunities were synthesized based on comprehensive analyses of the EU and US research and innovation priorities in the technology sectors and related application domains, the EU-US funding and collaboration landscape, and technological and policy barriers for EU-US collaboration. The contents of this report have been validated and refined extensively, e.g. based on in-depth discussions and online distribution and feedback actions with a large network of international experts, analytical research by the Expert Groups, PICASSO results, and other feedback collection mechanisms such as a public consultation on the PICASSO website.

The opportunity report provides a common view on priorities and future cooperation opportunities between the EU and the US and is a strong basis and guideline for concrete EU-US collaboration actions of the PICASSO project.

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Opportunity Report

“Towards Enhanced EU-US ICT Pre-competitive Collaboration”

Big Data

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Executive Summary

This report describes the major results that were obtained by the PICASSO Expert Group on Big Data throughout the duration of the PICASSO project. The major contributions of this report are:

- **Technology themes** (chapter 3) and **collaboration opportunities and mechanisms** (section 4.3) that have been identified as being promising for EU-US collaboration in the Big Data sector, synthesized based on comprehensive analyses of:
- The **EU and US research and innovation priorities** in the technology sectors and related application domains (chapter 2),
- The **EU-US funding and collaboration landscape** (section 4.1), and
- **Barriers for EU-US collaboration** (section 4.2).

In chapter 3 of this report, the PICASSO Expert Group on Big Data has defined technology themes that are promising for EU-US collaboration:

- Interoperability and Standardization
- Adding a semantic layer to Big Data technology
- Integrating Linked Data and Big Data technology
- Enable discovery of deeper, fresher insights from all enterprise data resources
- Improve efficiency, effectiveness, and decision-making
- Facilitate more timely, agile response to business opportunities, threats, and challenges
- Provide a single view of diverse data resources throughout the business chain
- Support tighter security, protection, and governance of data throughout its lifecycle
- Improve the scale, efficiency, performance, and cost-effectiveness of data/analytics platforms

In addition to the technological topics presented in chapter 3, the Big Data Expert Group has identified opportunities in the areas of the Big Data ecosystem, standardization and regulation, and education and workforce.The contents of this report are based on in-depth discussions with a large network of international experts, analytical research by the Expert Groups, preliminary PICASSO results (i.e. the reports (1), (2), and (3)) and other feedback collection mechanisms such as a public consultation on the PICASSO website. Moreover, a dedicated workshop was organized (Transatlantic Workshop on Public Private Partnerships for Big Data Research and Innovation and Workforce Development[1]) in Versailles, France, on November 20, 2017 as a partnership between the **US National Science Foundation (NSF) Big Data Regional Innovation Hubs, the EU Big Data Value Association (BDVA), the PICASSO project, and INRIA**, with more than 50 EU and US participants from both academia and industry, to discuss and conclude on specific collaboration opportunities on Big Data between EU and US and potential collaboration mechanisms and initiatives. Adding to the above, the Big Data opportunity report was circulated for feedback collection and validation by members of various industrial and research-oriented associations and projects such as the *Big Data Value Association* (*BDVA*), *Big Data Europe*, and *NESSI ETP*. Moreover, members of other initiatives and US government agencies such as the *IEEE Big Data Initiative*, *South Big Data Regional Innovation Hub* and the *National Institute of Standards and Technology* (*NIST*), have also validated the contents of this report.

[1] http://www.picasso-project.eu/2017/11/27/trans-atlantic-workshop-on-public-private-partnerships-for-big-data/

The contents and the outcomes of this report are mainly addressed to the research community and policy makers willing to enhance collaboration between the two regions by defining common big data opportunities and challenges, both technological and societal, to be mutually tackled therefore maximise the impact of big data in a number of societal challenges.

The opportunity report provides a common view on priorities and future cooperation opportunities between the EU and the US and is a strong basis and guideline for concrete EU-US collaboration actions of the PICASSO project.

The PICASSO Project

The aim of the 30-months PICASSO project is (1) to reinforce EU-US collaboration in ICT research and innovation focusing on the pre-competitive research in key enabling technologies related to societal challenges - 5G Networks, Big Data, Internet of Things and Cyber Physical Systems, and (2) to support the EU-US ICT policy dialogue by contributions related to e.g. privacy, security, internet governance, interoperability, ethics.

PICASSO is oriented to industrial needs, provides a forum for ICT communities and involves 24 EU and US prominent specialists in the three technology-oriented ICT Expert Groups - 5G, Big Data, and IoT/CPS - and an ICT Policy Expert Group, working closely together to identify policy gaps in the technology domains and to take measures to stimulate the policy dialogue in these areas. A synergy between experts in ICT policies and in ICT technologies is a unique feature of PICASSO.

A number of analyses will be accomplished, as well as related publications, that will for a major part be made public and contribute to the project's outreach. Dedicated communication and dissemination material will be prepared that should support the operational work and widespread dissemination though different channels (website, social media, publications …). The outreach campaign will also include 30+ events, success stories, factsheets, info sessions, and webinars.

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List of Acronyms

3GPP	3rd Generation Partnership Program
4G	4^{th} Generation
5G	5^{th} Generation
AI	Artificial Intelligence
AIOTI	Alliance of IoT Innovation
AV	Autonomous Vehicle
AWS	Amazon Web Services
B2B	Business-to-business
B2C	Business-to-customer
BBI	Bio-based Industries
BD	Big Data
BDVA	Big Data Value Association
BDVPPP	Big Data Value Public Private Partnership
CEDR	Conference of European Directors of Roads
CERN	Conseil Européen pour la Recherche Nucléaire
CPS	Cyber-physical System
CPSoS	Cyber-physical System of Systems
CPS-VO	CPS Virtual Organization
CPU	Central Processing Unit
CS	Clean Sky
CSAAC	Cyber Situational Awareness Analytical Capabilities
D2D	Device-to-Device
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DISA	Defense Information Systems Agency
DoC	Department of Commerce
DoD	Department of Defense
DoDIN	DoD Information Networks
DoE	Department of Energy
DoS	Department of State
DoT	Department of Transportation
DSL	Digital Subscriber Line
DSM	Digital Single Market
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EeB	Energy-efficient Buildings
EG	Expert Group
EPI	European Platform Initiative
ERA	European Research Area
EU	European Union
FBMC	Filter-Bank Multi-Carrier
FCC	Federal Communications Commission
FCH	Fuel Cells and Hydrogen
FET	Future and Emerging Technologies
FIRE	Future Internet Research & Experimentation
FoF	Factories of the Future
FP7	Framework Programme 7

FY	Financial Year
Gbps	Gigabit per second
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GENI	Global Environment for Networking Innovations
GFDM	Generalized Frequency-Division Multiplexing
GHz	Gigahertz
H2020	Horizon 2020
H2M	Human-to-machine
HD	High-definition
HMI	Human Machine Interface
HPC	High Performance Computing
HPUE	High Performance User Equipment
IA	Industry Association
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IERC	IoT European Research Cluster
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IM	Innovative Medicine
IMS	Intelligent Manufacturing Systems
INCOSE	International Council on Systems Engineering
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Rights
ISM	Industrial, Scientific, Medical
ITER	International Thermonuclear Experimental Reactor
ITS	Intelligent Traffic System
ITU	International Telecommunication Union
JTI	Joint Technology Initiative
JU	Joint Undertaking
LTE	Long Term Evolution
M2M	Machine-to-Machine
M&S	Modeling and Simulation
MEC	Mobile Edge Computing
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MoU	Memorandum of Understanding
ms	Millisecond
NACFAM	National Coalition for Advanced Manufacturing
NB-IoT	Narrowband IoT
NCP	National Contact Point
NCURA	National Council of University Research Administrators
NFV	Network Function Virtualization
NGI	Next Generation Internet
NGMN	Next Generation Mobile Networks
NIH	National Institutes of Health
NIPRNet	Nonsecure Internet Protocol Router Network
NISD	Network and Information Security Directive

NIST	National Institute of Standards and Technology
NIT	Networking and Information Technology
NITRD	Networking and Information Technology Research and Development
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
OCF	Open Connectivity Foundation
OFDM	Orthogonal Frequency Division Multiplexing
OMG	Object Management Group
PAWR	Platforms for Advanced Wireless Research
PCAST	President's Council of Advisors on Science and Technology
PPP	Public Private Partnership
PWG	Public Working Group
QoE	Quality of Experience
R&D	Research and Development
R&I	Research and Innovation
RAT	Radio Access Technology
RDI	Research, Development, Innovation
RFC	Request for Comments
SAE	Society of Automotive Engineers
SDAV	Scalable Data Management, Analysis and Visualization
SDN	Software Defined Networking
SEED	Standard Energy Efficiency Data
SIPRNet	Secret Internet Protocol Router Network
SME	Small and Medium-sized Enterprises
SMLC	Smart Manufacturing Leadership Coalition
SoS	System of Systems
SOTA	State of the Art
SPIRE	Sustainable Process Industry
SRA	Strategic Research Agenda
SSG	Senior Steering Group
Tbit	Terabit
Tbps	Terabit per Second
TRL	Technology Readiness Level
TTIP	Transatlantic Trade and Investment Partnership
TV	Television
UE	User Equipment
UHD	Ultra High Definition
URLLC	Ultra-reliable Low-latency Communications
US	United States
USGS	US Geological Survey
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
V5GTF	Verizon 5G Technology Forum
VDA	Verband Der Automobilindustrie
VPN	Virtual Private Network
ZT-OFDM	Zero-tail OFDM

Table of Contents

1. Introduction

1.1. Purpose of the Report

This report provides a detailed overview of the current status of collaboration between EU and US in the area of Big Data, while presenting an in-depth analysis of technological themes-priorities and funding-supporting mechanisms available in each region, aiming on supporting big data research.

Findings of this report are based on various sources (i.e. from PICASSO project deliverables, online sources, reports, etc.) and inputs deriving from the Big Data Expert Group while roadmaps and reports produced by high level organisations and structures (i.e. European Commission, White House Science and Technology Office, NIST, etc.) have been extensively analysed and taken into account. Adding to the above, a database of more than 300 Big Data research projects has been created and analysed, including information both for EU and for US funded projects, funded by different initiatives, programmes and funding agencies.

The content and the outcomes of this report are mainly addressed to the research community and policy makers willing to enhance collaboration between the two regions by defining common big data opportunities and challenges, both technological and societal, to be mutually tackled therefore maximise the impact of big data in a number of societal challenges.

1.2. Technological Context

Data has become a key asset for the economy and our societies similar to the classic categories of human and financial resources. Whether it is geographical information, statistics, weather data, research data, transport data, energy consumption data, or health data, the need to make sense of "Big data" is leading to innovations in technology and the development of new tools and new skills.

Big data refers to large amounts of data produced very quickly by a high number of diverse sources. Data can either be created by people or generated by machines, such as sensors gathering climate information, satellite imagery, digital pictures and videos, purchase transaction records, GPS signals, etc. It covers many sectors, from healthcare to transport and energy. Generating value at the different stages of the data value chain will be at the centre of the future knowledge economy (4).

Moreover, in a recent study 69% of corporate executives named greater data variety as the most important factor, followed by volume (25%), with velocity (6%) trailing – indicating that the big opportunity lies in integrating more sources of data, not bigger amounts (5).

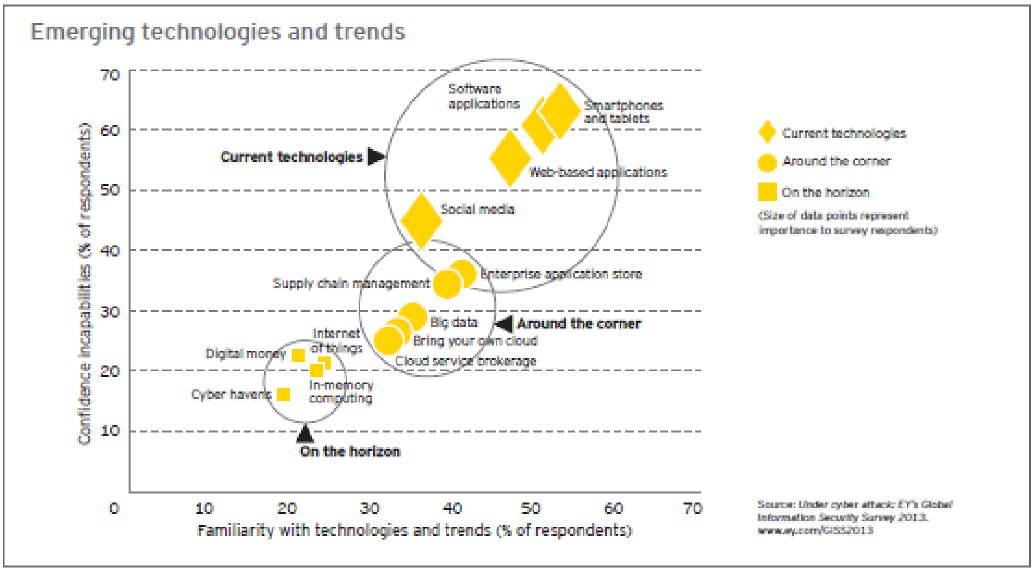

Figure 1: Big Data as an Emerging Technology **(6)**.

Big data is generating an intense amount of attention among businesses, media and even consumers, along with analytics, cloud-based technologies, digital channels and data visualization. These are all part of the current diverse ecosystem created by the technology megatrends. Some even herald the potential transformative power of the current trends as rivalling that of the internet. Yet, as in the early days of the internet, there is uncertainty about just what Big Data is, its potential benefits and the associated risks (6).

Both the EU and the US are funding numerous research and innovation activities related to Big Data in order to tackle a number of societal challenges, identified by policy makers and structures. However, performing joint research for Big Data is a challenge that cannot be overseen, as both regions face common challenges that can be jointly tackled. The Big Data sections of this report present an overview of research and innovation activities, action plans, funding opportunities, and challenges that both regions implement, in order to tackle a multi-angled topic such as Big Data. Moreover, we try to identify similarities and differences between these two regions, and any opportunities that need to be taken into account by policy makers for setting up joint funding schemes and initiatives.

The Big Data sections of this report were circulated for feedback collection and validation by members of various industrial and research-oriented associations and projects such as the *Big Data Value Association* (*BDVA*), *Big Data Europe*, and *NESSI ETP*. Moreover, members of other initiatives and US government agencies such as the *IEEE Big Data Initiative*, *South Big Data Regional Innovation Hub* and the *National Institute of Standards and Technology* (*NIST*), have also validated the contents of this report.

2. Research and Innovation Priorities in the EU and the US

This section presents an overview of the research and innovation priorities both in the EU and the US in the area of Big Data technologies. It provides an extensive analysis of the actions plans defined and implemented in both regions (EU and US) in order to support and boost growth of the Big Data sector, while it presents facts and information regarding the most critical application sectors, as these have been defined by top-tier structures and organizations. Adding to the above, the current report provides a summary of the most critical needs and drivers for some key application sectors such as smart cities, transportation and energy.

The findings of this section are based on various sources (i.e. from PICASSO project, deliverables, online sources, reports, etc.) and inputs deriving from the Big Data Expert Group. Roadmaps and reports produced by high level organisations and structures (i.e. European Commission, White House Science and Technology Office, NIST, etc.) have been extensively analysed and are presented in this section. Adding to the above, a database of more than 300 Big Data research projects has been created, including information both for EU and for US funded projects, funded by different initiatives, programmes and funding agencies

2.1. Big Data Technology Enablers

Big Data technologies are heavily dependent on various enabling technologies and fields that are being or will be applied to drive radical change in the Big Data field in general. Recent or future innovations in Data Storage technologies, IoT, Computation Capacity and other fields, are only some of the technology sectors that heavily influence the future of Big Data.

1) **Data Storage:** Data Storage can be considered as a critical key technology enabler for Big Data. As the cost for storing and maintaining complete data sets available for analytics (i.e. less than $600 to buy a disk drive with the capacity to store all of the world's music (7)), and new data technologies are on the way (i.e. Helium Drives, Shingled Magnetic Recording Drivers, etc.), companies and users will be able to store more and more data. The continued reduction of storage hardware costs, and improved data efficiency capabilities like de-duplication, and compression have become pervasive. In the most recent EMC Digital Universe research (8), IDC predicts the amount of digital data generated in each of the next two years will double, and will continue to double every two years for the rest of the decade.

2) **Computational Capacity:** Extremely large volumes of data have traditionally not been captured and processed for various reasons, most notably because the cost to do so was far greater than the value of insights companies could derive from its analysis. However, multiple factors and new technologies have lowered the cost and technology barrier for effective data processing, allowing companies of all sizes, to be able to unlock the value contained in different data sources. For instance, it is difficult for conventional relational databases to handle unstructured data, so software frameworks like Hadoop(R), for distributed storage and parallel processing of large datasets have been introduced to process non-structured data at high speed; making it easier to perform a more comprehensive analysis of big data (6). Big Computing at small prices, has given the opportunity to a number of organisations to look at, and deal with, data in ways not possible before. It's this computational capacity that has the real potential to transform data from a compliance burden into a business asset (9).

3) **Data Availability:** The third enabler is the increase in availability of data, especially of unstructured data types such as images, video, and audio. The EMC Digital Universe study predicts 30% of all digital data by the end of the decade will be security related with the majority being images, video, and audio. Traditional analytics cannot leverage these data types.

4) **Internet of Things (IoT):** The fourth enabler is the rapid growth of data from network-connected devices such as sensors. The EMC Digital Universe study predicts that 10% of all digital data will be

generated by network connected devices by the end of the decade. Today, network-connected devices generate about 2% of all digital data. Smart companies like GE, are leveraging this data to provide differentiated services. For example, a GE Wind Turbine contains about 20,000 sensors that generate 400 data points per second. The sensor data is analyzed in near real time to maximize the efficiency. This data is also stored and used for deeper analytics to improve maintenance and parts replacement. A GE Wind Turbine is more efficient and has higher availability enabled by next generation analytics. For more information, also refer to the IoT/CPS sections of this report.

5) **Data Analytics Tools:** The fifth enabler is a new set of analytics tools designed specifically to analyse large amounts of data, both structured (i.e. log data) and unstructured (images). Tools such as Hadoop, and Splunk were designed to analyse large data sets. These new analytics tools have been created through the Open Source community and have a low initial cost to at least get started. Next generation analytics has become affordable for big companies but smaller companies are also using these tools to find new revenue, and provide differentiated services.

2.2. EU Priorities & Landscape

In **July 2014** (10), the **European Commission** outlined a new strategy on Big Data, supporting and **accelerating the transition towards a data-driven economy in Europe**. The data-driven economy will stimulate research and innovation on data while leading to more business opportunities and an increased availability of knowledge and capital, in particular for SMEs, across Europe.

In the same strategic paper, the **European Commission admits** that **the European digital economy has been slow** in embracing the data revolution **compared to the USA** and also lacks comparable industrial capability. As a result, there are **fewer successful data companies in Europe than in the US** where large players have recognised the need to invest in tools, systems and new data-driven processes. However, significant new opportunities exist in a number of European industrial sectors (including health, smart factories (Industry 4.0), and agriculture) where the application of these methods is still in its infancy and global dominant players have not yet emerged. Moreover, since 2014, the figures have significantly improved for the EU but it still remains on 2nd position worldwide.

Monitoring Data Market, International Comparison, 2014, Units (000), EUR Million

N.	Name		EU	U.S.	Japan	Brazil
1.1	Number of Data Workers		6,102	10,457	3,344	1,031
2.1	Number of Data Companies		243,610	277,821	95,919	34,840
4.1	Value of the Data Market		€ 50,454	€ 103,935	€ 22,228	€ 5,289
4.2	Value of the Data Economy	Direct Impacts	€ 46,607	€ 99,398	€ 21,367	€ 5,289
		Backward Indirect impacts	€ 2,081	€ 4,536	€ 860	€ 217

Figure 2: Monitoring Data Market, International Comparison **(11)**.

2.2.1. EU Big Data Strategy

In order to tackle this, the European Commission has initiated a number of actions in order to support Big Data as a whole, and not only from the research oriented side. Moreover, to be able to seize these opportunities that Big Data presents and compete globally in the data economy, the EU (10):

- **Supports "lighthouse" data initiatives (in the shape of large-scale pilot actions)** capable of improving competitiveness, quality of public services and citizen's life
- **Develops enabling technologies**, underlying infrastructures and skills, particularly to the benefit of SMEs
- **Extensively shares, uses and develops its public data** resources and research data infrastructures
- Focuses **public R&I** on technological, legal and other bottlenecks
- Makes sure that the relevant **legal framework and policies** are data-friendly
- **Accelerates the digitisation of public administration** and services to increase their efficiency, and
- **Uses public procurement** to bring the results of data technologies to the market.

Adding to the above, the European Commission has designed and implements actions on various areas and topics, such as “soft” infrastructures, framework conditions, research and innovation topics, regulatory issues, etc.

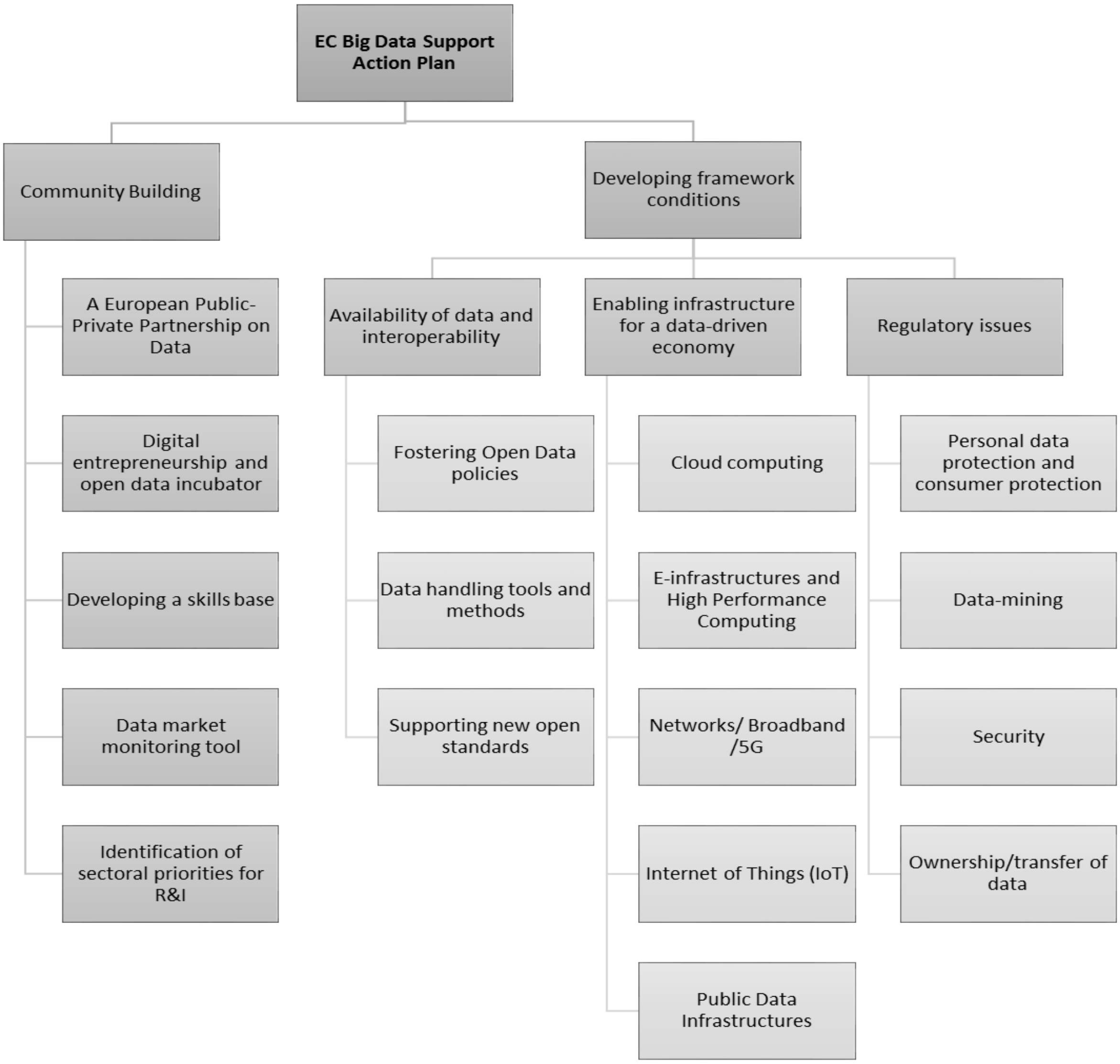

Figure 3: Big Data Support Action Plan.

2.2.2. Research & Innovation Priorities

Until today, the European Commission, through its main **Research & Innovation Funding Tool – H2020**, has issued a number of calls to support R&I projects in the Big Data area. More specifically, the **LEIT-ICT Work Programme** has issued the following calls and funded **55 projects** in total:

Table 1: Big Data related projects funded in H2020.

ICT-15-2014 - Big data and Open Data Innovation and take-up	13 Projects
ICT-22-2014 - Multimodal and Natural computer interaction	11 Projects
ICT-16-2015 - Big data - research	10 Projects
ICT-14-2016-2017 - Big Data PPP: cross-sectorial and cross-lingual data integration and experimentation	7 Projects
ICT-15-2016-2017 - Big Data PPP: Large Scale Pilot actions in sectors best benefitting from data-driven innovation	2 Projects
ICT-17-2016-2017 - Big data PPP: Support, industrial skills, benchmarking and evaluation	1 Projects
ICT-18-2016 - Big data PPP: privacy-preserving big data technologies	4 Projects
ICT-35-2016 - Enabling responsible ICT-related research and innovation	7 Projects

The 2016 calls have been designed according to the **Strategic Research and Innovation Agenda**, issued by **Big Data Value Association**. The Big Data Value Association (**BDVA**) is the industry-led private counterpart to the EU Commission to implement the **Big Data Value Public Private Partnership programme (BDV PPP)**. BDVA has over **170 members** all over Europe with a well-balanced composition of large and small and medium-sized industries as well as research organizations[2]. BDVA, has identified a number of challenges and outcomes that need to be tackled through research and innovation activities, thus shaping research and innovation priorities for the European Commission to serve (12).

Table 2: Big Data Value Association Research Priorities.

Data Management	
Challenges	**Outcomes**
1. Semantic annotation of unstructured and semi-structured data **2.** Semantic interoperability **3.** Data quality **4.** Data management lifecycle **5.** Data provenance **6.** Integration of data and business processes **7.** Data-as-a-service	**1.** Techniques and tools for handling unstructured and semi-structured data. **2.** Languages and techniques for semantic interoperability such as standardized data models and interoperable architectures for different sectors enriched through semantic terminologies **3.** Languages, techniques and tools for measuring and assuring data quality, **4.** Methods and tools for a complete data management lifecycle **5.** Languages and tools for data provenance **6.** Methods and Tools for the sound integration of analytics results from data and business processes **7.** Data-as-a-service model and paradigm
Data Processing Architectures	
Challenges	**Outcomes**

[2] http://www.bdva.eu/

1. Processing of data-in-motion and data-at-rest **2.** Decentralization **3.** Heterogeneity **4.** Scalability **5.** Performance	**1.** Real-time architectures for data-in-motion **2.** Decentralized architectures **3.** Techniques and tools for processing real-time heterogeneous data sources **4.** Scalable and dynamical data approaches **5.** Efficient mechanisms for storage and processing
Data Analytics	
Challenges	**Outcomes**
1. Semantic and knowledge-based analysis **2.** Content validation **3.** Analytics frameworks & processing **4.** Advanced business analytics and intelligence **5.** Predictive and prescriptive analytics	**1.** Improved models and simulations **2.** Semantic analysis **3.** Event and pattern discovery **4.** Multimedia (unstructured) data mining **5.** Deep learning techniques for business intelligence
Data Protection	
Challenges	**Outcomes**
1. Robust data anonymity **2.** Generic and easy to use data protection approach **3.** Risk based approaches	**1.** Robust anonymisation algorithms **2.** Protection against reversibility **3.** Pattern hiding **4.** Multiparty mining
Data Visualisation and User Interaction	
Challenges	**Outcomes**
1. Visual data discovery **2.** Interactive visual analytics of multiple scale data **3.** Collaborative, intuitive, and interactive visual interfaces **4.** Interactive visual data exploration and querying in a multi-device context	**1.** Scalable data interactive visualization approaches and tools **2.** Cross-platform data visualization frameworks **3.** New paradigms for interactive visual data exploration, discovery, and querying **4.** 3D visualization techniques and tools **5.** Personalized end-user centric data interactive visualization mechanisms **6.** Domain-specific data interactive visualization approaches **7.** Techniques and tools for visualization of interrelated/linked data **8.** Plug-and-play reusable components for data visualization

Throughout the project analysis that we undertook, we have been able to **categorise** most **EU funded projects**, from **Big Data H2020 related calls**, according to their technical or non-technical orientation. The following figure shows the resulting distribution:

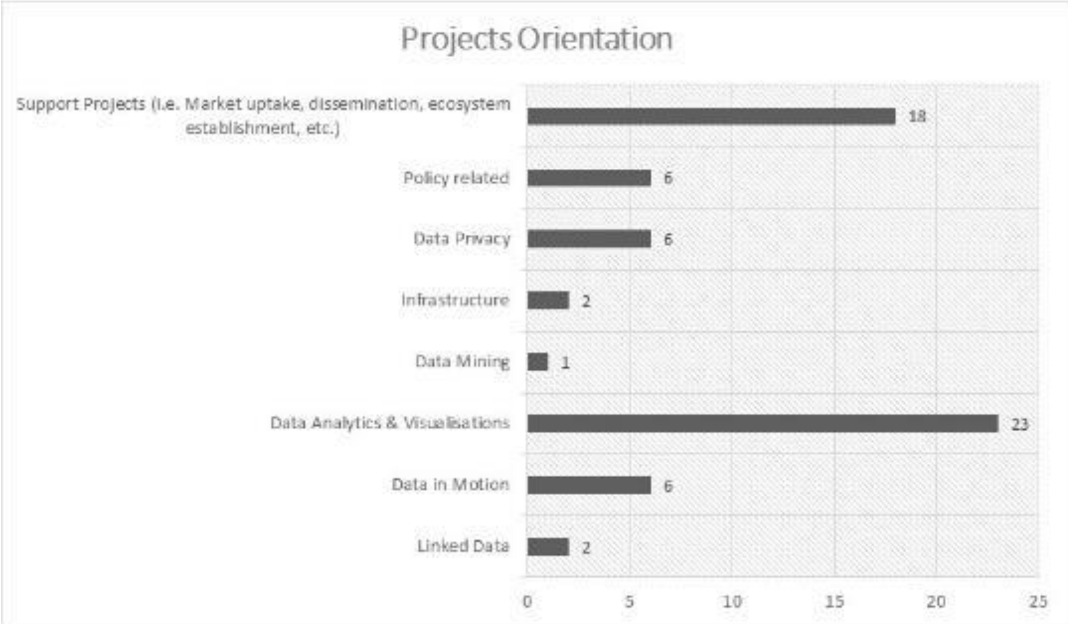

Figure 4: Big Data EU projects orientation.

An overall outcome that can be derived from the above analysis is that, so far, the **European Commission has funded** a large amount of research projects towards **Data Analytics and Visualisation**, which do not target a specific application sector (with some exceptions such as the two ICT-15-2016 lighthouses are a major invest; the two projects TT and DataBio which have a joint budget of 35 MEUR. Two more of such lighthouses are envisioned for the 2017 call). Moreover, the European Commission has allocated a large amount of resources to **fund projects aiming to create an ecosystem around Big Data** and therefore **enhance the creation of such an ecosystem** in order to commercially explore the value of Big Data for the benefit of the people.

2.3. US Priorities & Landscape

The US has made a first critical and important step towards **supporting the Big Data sector**, in 2012, by launching a $200 Million investment plan for R&D, for initiating projects to solve some of the Nation's most pressing challenges. The **"Big Data Research and Development Initiative"** (13) was supported by **six Federal departments and agencies** in order to improve the tools and techniques needed to access, organize, and glean discoveries from huge volumes of digital data. The following departments and agencies were supporting this initiative:

1. National Science Foundation (NSF)
2. National Institutes of Health (HHS/NIH)
3. Department of Energy (DOE)
4. Department of Defense (DOD)
5. Defense Advanced Research Projects Agency (DARPA)
6. US Geological Survey – Big Data for Earth System Science (USGS)

Each of these agencies/departments have issued calls for funding Big Data projects in their area of interest such as **analytics, energy, security**, etc.

2.3.1. US Big Data Strategy

Following to the 2012 **"Big Data Research and Development Initiative"**, the US has launched a strategic plan in order to support that initiative by guiding Federal agencies as they develop and expand their individual mission-driven programs and investments related to Big Data. The **"Federal Big Data Research and Development Strategic Plan"** (14) was published on **May 2016**, by the **Networking and Information Technology Research and Development (NITRD)** Program, in order to guide Big Data research towards National priorities such as science, medicine, and security; ensuring the Nation's continued leadership in research and development; and enhancing the Nation's ability to address pressing societal and environmental issues facing the Nation and the world through research and development.

The plan is based on inputs from a series of Federal agency and public activities, and a shared vision:

"We envision a Big Data innovation ecosystem in which the ability to analyze, extract information from, and make decisions and discoveries based upon large, diverse, and real-time datasets enables new capabilities for Federal agencies and the Nation at large; accelerates the process of scientific discovery and innovation; leads to new fields of research and new areas of inquiry that would otherwise be impossible; educates the next generation of 21st century scientists and engineers; and promotes new economic growth."

The Plan is built around seven strategies that represent key areas of importance for Big Data research and development (R&D). Priorities listed within each strategy highlight the intended outcomes that can be addressed by the missions and research funding of NITRD agencies.

→ **Strategy 1:** Create next-generation capabilities by leveraging emerging Big Data foundations, techniques, and technologies

→ **Strategy 2:** Support R&D to explore and understand trustworthiness of data and resulting knowledge, to make better decisions, enable breakthrough discoveries, and take confident action

→ **Strategy 3:** Build and enhance research cyberinfrastructure that enables Big Data innovation in support of agency missions

→ **Strategy 4:** Increase the value of data through policies that promote sharing and management of data

→ **Strategy 5:** Understand Big Data collection, sharing, and use with regard to privacy, security, and ethics

→ **Strategy 6:** Improve the national landscape for Big Data education and training to fulfil increasing demand for both deep analytical talent and analytical capacity for the broader workforce

→ **Strategy 7:** Create and enhance connections in the national Big Data innovation ecosystem

2.3.2. Research & Innovation Priorities

Higher-level Priorities

The **"Federal Big Data Research and Development Strategic Plan"** sets a number of Research and Supportive priorities related to Big Data, which all Funding and Research agencies have to take into account before allocating resources to specific projects. Figure 5 illustrates these priorities:

Figure 5: US Big Data research priorities.

Moreover, **NSF** has identified a number of research and technological priorities (15) that need to be addressed through funding projects. The following table summarises all priorities:

Table 3: NSF Big Data research priorities.

Collection, Storage, and Management of "Big Data"	Data Analytics	Research in Data Sharing and Collaboration
Data representation, storage, and retrieval	Computational, mathematical, statistical, and algorithmic techniques for modelling high-dimensional data	Tools for distant data sharing, real-time visualization, and software reuse of complex data sets
New parallel data architectures, including clouds	Learning, inference, prediction, and knowledge discovery for large volumes of dynamic data sets	Cross-disciplinary model, information and knowledge sharing
Data management policies, including privacy and access	Data mining to enable automated hypothesis generation, event correlation, and anomaly detection	Remote operation and real time access to distant data sources and instruments
Communication and storage devices with extreme capacities	Information infusion of multiple data sources	
Sustainable economic models for access and preservation		

Last but not least, the **Executive Office of the President, President's Council of Advisors on Science and Technology (PCAST)**, released a report on Big Data Privacy, **"Big Data: A Technological Perspective"** (16) in which they define some key research themes that need to be addressed and supported through policy over the following years.

Table 4: Big Data research priorities according to PCAST.

Big Data Analytics	Big Data Infrastructure	Privacy Protection
Data mining	Cloud	Cryptography and encryption
Data fusion and information integration	Big Data Centres	Privacy Mechanisms
Image and speech recognition		
Social-network analysis		

R&I Project Analysis

By taking into account the above and by analyzing the available information from **130** Research and Innovation projects funded by **NSF, NIH** and **DARPA**, we have managed to identify what are the most critical technical subjects funded, in a project level. The table below, represents an "umbrella" taxonomy of these projects:

Table 5: Technological Domains for Big Data Projects.

Technological Domain(s)	Funded Projects
Data Analytics	**45**
Data Analytics, Privacy	**2**
Data Analytics, Visualization	**1**
Data Analytics, Processing	**1**
Big Data Curriculum	**1**
Biology	**1**
Chemistry, Analytics	**1**
Cloud Computing	**1**
Clustering	**1**
Collaboration, Interactions	**1**
Crowdsourcing, Visual Analytics	**1**
Data Mining	**1**
Datasets, Linguistics, Behavior	**1**
Decision Making	**2**
Economy	**2**
Eco-Routing	**1**
Healthcare	**1**
Image Data	**1**
Image Data, Cyber Security, Digital Entertainment	**1**
Infrastructure	**33**
Medicine, Analytics	**1**
Microbial Organisms, Genome	**1**
New Media, Social Networks, Training	**1**
Space	**1**
STEM (Data Analytics, E-Learning)	**5**
Video, Images, Multimedia Forensics	**1**
Visualization	**21**
Water Supply, Smart Cities	**1**
Grand Total	**130**

Big Data Regional Innovation Hubs

What is also important to mention is that in 2015, NSF launched **the Big Data Regional Innovation Hubs program (BD Hubs)** (17) to foster regional, cross-sector collaborations and multi-sector projects to foster innovation with Big Data. As a complement to the institutional gateways, the regional hubs provide the ability to engage with local or regional stakeholders, e.g., city, county, and state governments, as well as permit a focus on regional issues. These collaborative activities and partnerships play a critical role in building and sustaining a successful national Big Data innovation ecosystem. The four hubs, financed by the call are:

- **Northeast BD Hub**
- **South BD Hub**
- **Midwest BD Hub**
- **West BD Hub**

The figure below[3] shows the geographical representation of the four Hubs:

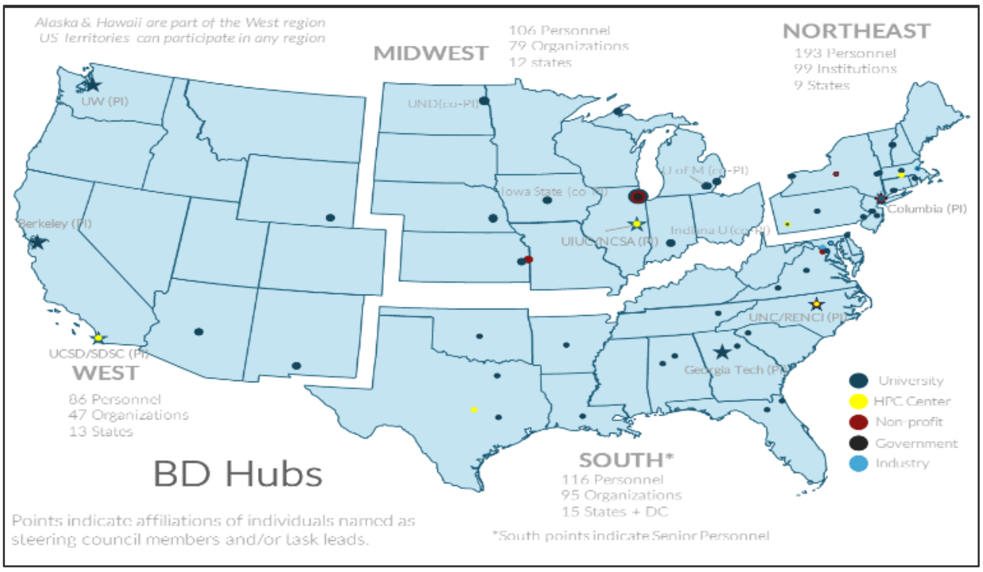

Figure 6: Big Data US Hubs[4].

More specifically, all four hubs have identified their technological and application priorities related to their exact needs, as they have been identified by the partners. The table below shows a detailed analysis of all Rings (Parallel priorities) and Spokes (Vertical priorities) for each Hub.

Table 6: Big Data Hubs Priorities.

Hubs	Rings (Horizontal Priorities/Technical)	Spokes (Vertical priorities/Application Sectors)
Northeast BD Hub	1.Data Literacy 2.Data Sharing 3.Ethics 4.Privacy & Security	Education Finance Cities & Regions Health Energy Discovering Science
South BD Hub	1.Sharing & Infrastructure	Health Disparities & Analytics

[3] BIG DATA REGIONAL INNOVATION HUBS &SPOKES: Accelerating the Big Data Innovation Ecosystem, Fen Zhao, Staff Associate, Strategic Innovation, CISE Directorate, Office of the Assistant Director , National Science Foundation

[4] Graphic taken from: BIG DATA REGIONAL INNOVATION HUBS &SPOKES: Accelerating the Big Data Innovation Ecosystem, Fen Zhao, Staff Associate, Strategic Innovation, CISE Directorate, Office of the Assistant Director , National Science Foundation

	Development 2.Economic Modelling, Security & Policy	Coastal Hazards Industrial Big Data Materials & Manufacturing Habitat Planning
Midwest BD Hub	1.Data Science 2.Resources: Data, Tools & Services 3.Education Training & Workforce Development	Business Analytics Metropolitan Sciences Food-Energy-Water Digital Agriculture Transportation Advanced Manufacturing Health & Biomedical Sciences Network Sciences
West BD Hub	1. Accelerating Innovation for National Priorities 2.Strengthening Our Data Science Community 3.Fostering Cross-Cutting Teams	Metro Data Science Precision Medicine Managing Natural Resources and Hazards Big Data Technology Data-enabled Scientific Discovery and Learning

What can be seen from this table is that some application sectors are critical for all Big Data Hubs. More specific, **Health, Smart Cities, Manufacturing** and **Hazard prevention** are the most common ones.

2.4. Postgraduate Education on Big Data

There are an average of 1,894 Big Data jobs posted on Dice (18) on any given day, Dice spokeswoman Rachel Ceccarelli said. That's up 41 percent year on year; two years ago, only 438 such jobs were listed (18). How those jobs would be filled, however, wasn't entirely clear. Until recently, big-data education programs were few and far between. In the last few years, graduate, undergraduate, and professional-education programs have begun popping up to address this gaping need. Now that they've begun to emerge, the demand is considerable. In order to capture the overall essence of education on Big Data related themes, we have gone through an extensive desktop research of a large volume of Master courses related to Big Data, mainly from EU and US universities. In addition we also documented some Master degrees coming from universities located in Asia and Oceania, in order to create a "rough" comparison among all regions, although this is a task that is not related to this current study.

Table 7: No of Big Data related Masters per region.

Continent	No of Big Data related Masters
Asia	10
Europe	114
North America	53
Oceania	3
Grand Total	180

From our desktop research, we discovered that there are at least 167 Masters courses offered by EU and US universities. From these 167 degrees, 114 are offered by EU universities and 53 by US universities. What needs to be mentioned at this stage is that these Master courses are directly related to Big Data according to each universities' statements about their programme and have been categorized as Big Data programmes in the StudyPortals international database (19).

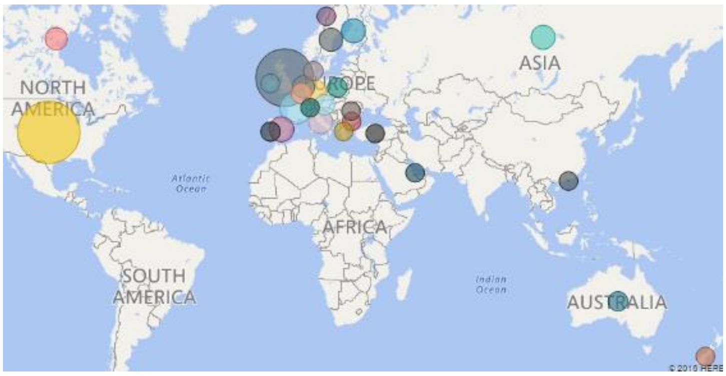

Figure 7: Big Data related Masters geographical distribution.

An impressive finding from this analysis is that there is a clear diversification of titles among all these courses. The most common title among courses is Data Science (28) and Data Analytics (13), while only 17 of them contain the term "Big Data" in their titles.

Table 8: No of Common Big Data Master Titles.

Title	No of titles
Data Science	28
Data Analytics	13
Information Technology	6
Business Analytics	4
Computer Science	3
Big Data Analytics	2
Analytics	2
Data Mining & Knowledge Management	2
Data Science for Management	2
Computational Science	2
Data Studies	2
Data Telecommunications and Networks	2
Database Systems	2
……………	…….

A valuable outcome of this exercise is that, as with any new field, colleges and universities are catching up. There are more than a few different names, including Analytics, Data Science, Business Analytics, and every possible combination of those words, and they're offered by all kinds of departments, from engineering and computer science to business and marketing. What matters, more than the name, is that the programs find the right balance between technical computer skills, business and marketing knowledge, and statistical analysis. Most programs are interdisciplinary, because it takes the right combination of experts to teach so many different areas.

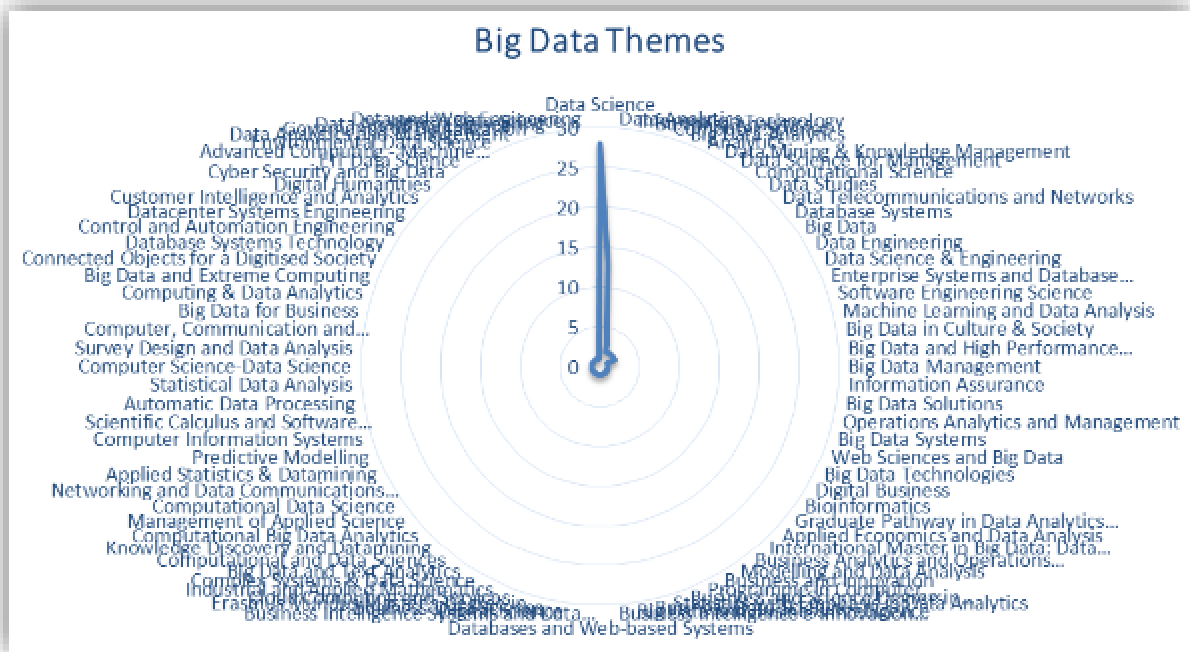

Figure 8: Big Data themes.

2.5. Application Sectors

2.5.1. EU Application Sectors

The European Commission has already acknowledged (4) and embraced that generating value at the different stages of the data value chain will be at the centre of the future knowledge economy. Good use of data can bring opportunities also to more traditional sectors such as transport, health and manufacturing. Improved analytics and processing of data, especially Big Data, will make it possible to:

- transform Europe's service industries by generating a wide range of innovative information products and services;
- increase the productivity of all sectors of the economy through improved business intelligence;
- better address many of the challenges that face our societies;
- improve research and speed up innovation;
- achieve cost reductions through more personalised services
- increase efficiency in the public sector.

Following from the above, the European Commission has already defined which **domains are critical for EU** and is supporting Big Data Research and Innovation projects in all of the following domains, known as **Societal Challenges** (20):

Health, demographic change and wellbeing; | Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy; | Secure, clean and efficient energy; | Smart, green and integrated transport; | Climate action, environment, resource efficiency and raw materials; | Europe in a changing world - inclusive, innovative & reflective societies; | Secure societies - protecting freedom and security of Europe and its citizens.

**All images above are courtesy of the Big Data Europe Project (https://www.big-data-europe.eu)*

Furthermore, the European Commission, has indicated a number or priority sectors in the **ICT-15-2016-2017** (21)**.** These priority sectors are **health, energy, environment, earth observation, geospatial, transport, manufacturing, finance and media**.

What is also critical to mention at this stage is that through our analysis, we have identified which and how many projects the European Commission has funded under each societal challenge. Until December 2016, the Commission has funded **14** projects in **Health, demographic change and wellbeing**, followed by **9** projects in **Smart, green and integrated transport** and **7** in **Europe in a changing world - inclusive, innovative and reflective societies** and **7** in **Secure societies - protecting freedom and security of Europe and its citizens** respectively. Also, it is important to point out that **6** projects have been funded in the **Media & Social Media Industry**, showing the importance of Social Media Data from a business and sociological perspective. Adding to the above, **13** projects have been funded dealing with **Horizontal technological and non-technological themes**, which affect and can be applied in in more than one sectors. More information can be found in Figure 9 below.

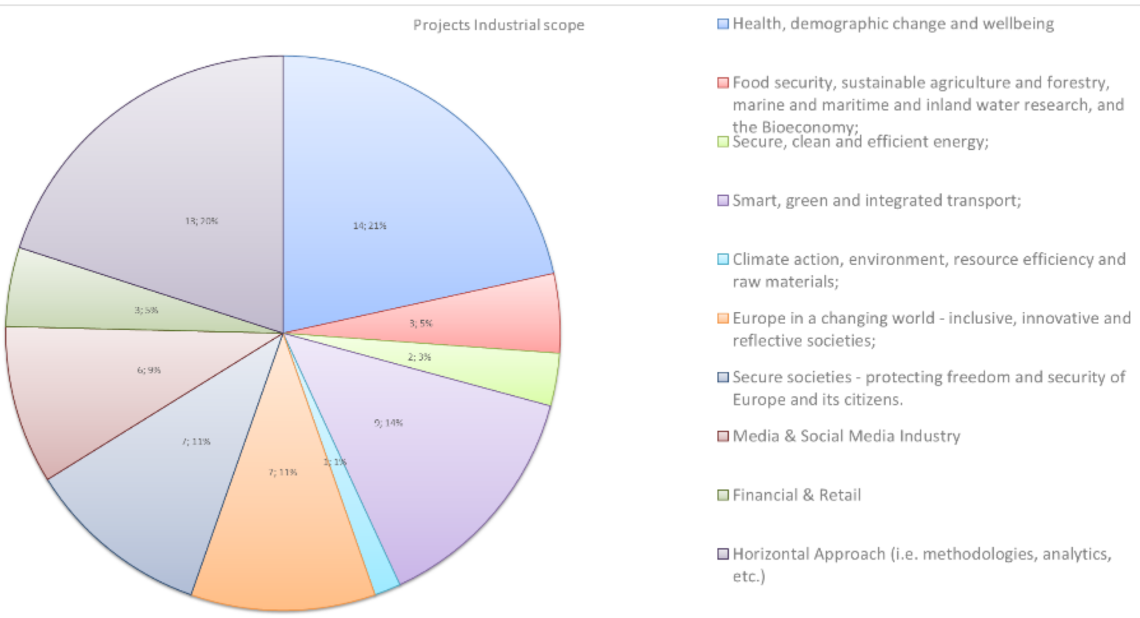

Figure 9: Big Data Projects Scope.

2.5.2. US Application Sectors

Higher-level Application Sectors

A number of strategic documents have been analysed in order to capture what are the application sectors (industrial sector) which US are mainly targeting. The following documents have been used for this analysis: NIST Big Data Interoperability Framework (22), NSF Big Data Research priorities (15), Dr. John P. Holdren, (Assistant to the President for Science and Technology and Director of the Office of Science and Technology

Policy) statements (13) and the “Big Data: A Technological Perspective” (16) , released by the Executive Office of the President, President’s Council of Advisors on Science and Technology.

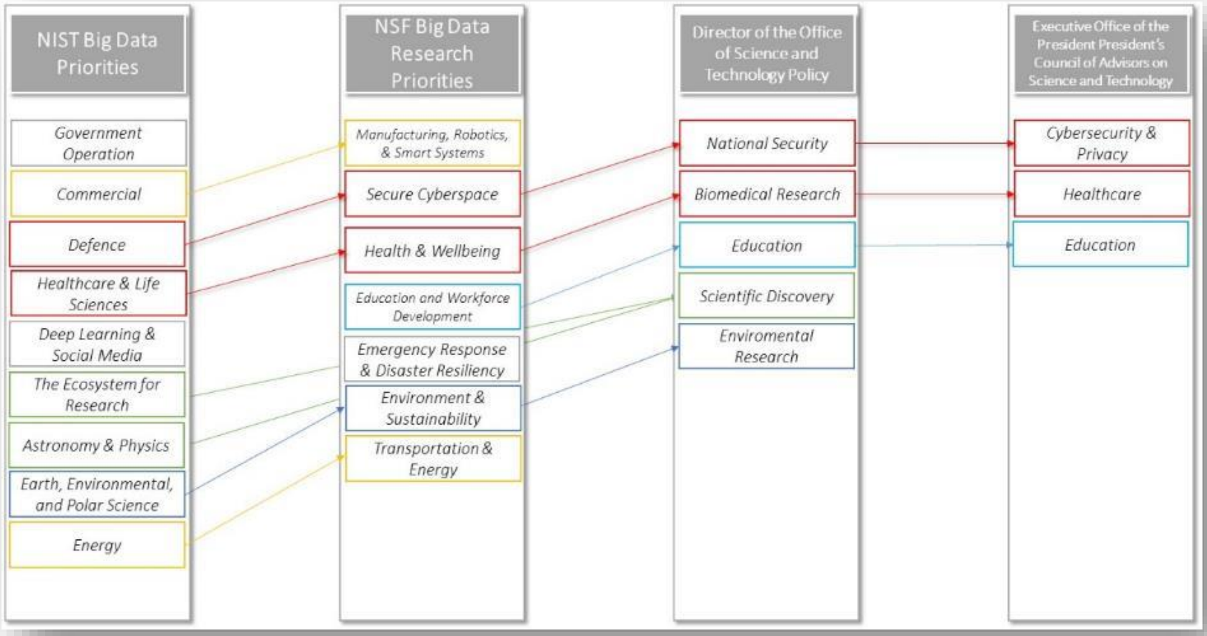

Figure 10: Big Data relevant Application Sectors (US).

What can be shown by the above figure is that sectors such as **Defence, Healthcare** and **Education** are the most important application sectors, as defined by the policy**.**

R&I Project Analysis

By taking into account the above and by analysing **153** Research and Innovation projects funded by NSF, NIH and DARPA, we have identified which application domains have been funded the most. From the table below, one can see that **Computer Science** (including Data Analytics, Data Processing, Data Visualisation) domain and is the most funded area. This happens mainly because a number of projects do not focus on only one application or industrial area but can be applied to a number of different sectors.

Table 9: US Big Data R&I projects analyzed by application sectors.

Technological Area	Funded Projects
Bio	1
Computer Science	**100**
Crowd Sourcing	1
Education	6
Electronics	1
Facilities Management	1
Finance	1
Healthcare	**26**
Human Networks	1
Infrastructure	2
Life Sciences	1
Linguistics	1

Materials	1
Media	3
Networks	4
Relied Logistics	1
Space	1
STEM	1
Grand Total	**153**

2.6. Conclusions

Both regions (EU & US) are already implementing solid policies related to Big Data customised specifically to their needs and challenges that they face and urgent to tackle. However, despite several similarities, critical differences exits making each policy unique for each region

2.6.1. Similarities & Differences at Design & Implementation Level

Similarities between policies in both regions exist and are evident from the policy reports generated by the federal government or agencies in charge of these policies.

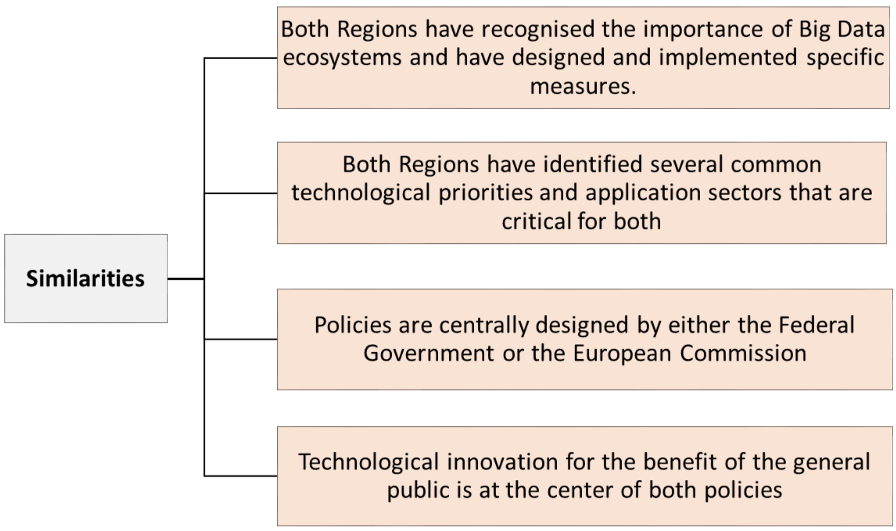

Figure 11: Significant Big Data Similarities.

Moreover, a number of significant differences exist, when policies from the two regions are being compared. Most differences are related to the implementation model between the two regions.

Figure 12: Significant Big Data Differences.

Specific information on similarities and differences in technological and application domains can be found in the below section.

2.6.2. Similarities & Differences in Technology and Application Domains

Technology Domains

From our analysis, throughout the whole document and by taking into account input from several sources such as Expert Group Members, other PICASSO deliverables and Policy papers, common research and innovation topics have been identified. **Data Analytics**, **Data Protection & Privacy**, **Data Processing Architecture** and **Data Visualisation and User Interaction** are the technological priorities that are in the heart of policies and strategies for both regions. However, each region also gives emphasis to additional technological domains such Big Data Infrastructures and Ethics (for the US) and Data Management (for the EU).

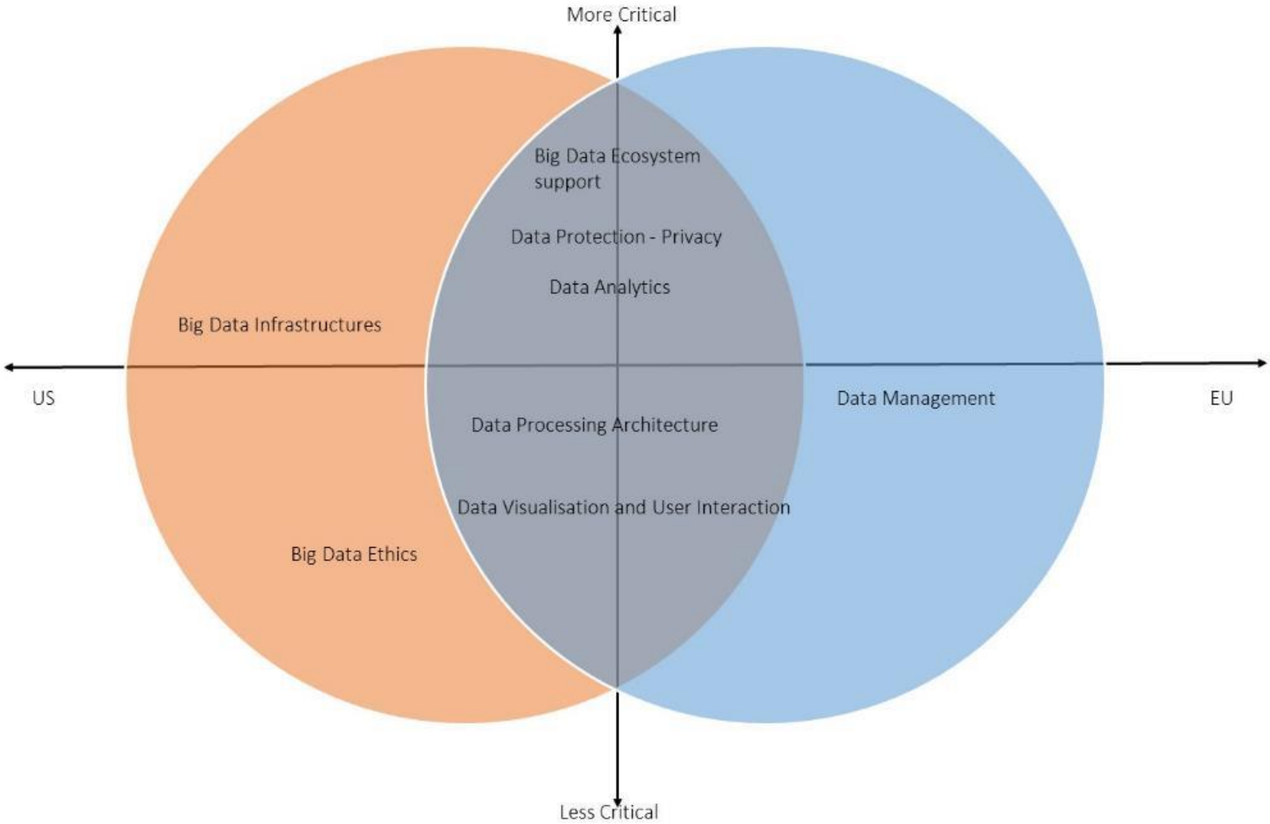

Figure 13: EU-US Common Big Data Priorities.

Application Domains

From our analysis, it can be seen that some application sectors are of extreme importance, both for the US and for the EU. **Health**, **Security**, **Smart Energy** and **Environment** are the most critical sectors for both regions. Moreover, sectors such as **Smart Transportation**, **Government**, **Manufacturing (Smart Production)**, **Finance** and **Agriculture** are also under a common microscope, although it seems that these sectors receive less support. Last but not least, what can also be seen is that the US has identified the domain of **Natural Resources and Hazards** as extremely important while the EU has given a significant attention and support to the **Media** domain.

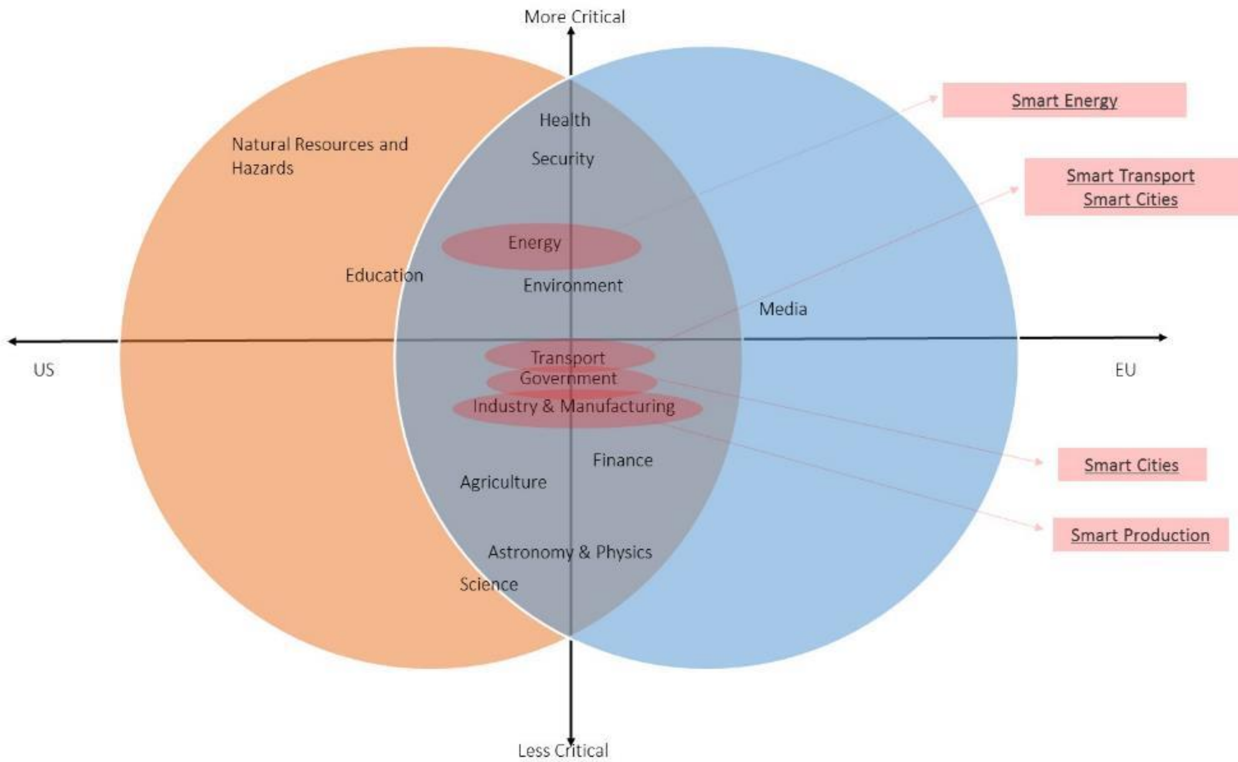

Figure 14: US & EU Common Big Data Application Sectors.

3. Technology Themes for EU-US Collaboration

Throughout the process of generating the Big Data opportunity report, a number of policy and technological reports have been taken into account in order to shape a clear set of technological opportunities for collaboration between the EU and US. In addition feedback from the Big Data Expert Group has been also taken into account for formulating a concrete picture. From the elaboration of this feedback, we have been able to identify a number of technological opportunities that are of highest priority of both regions. What needs to be mentioned is that set of opportunities will be updated in the forthcoming months taking into account additional feedback and input from external experts and policy makers willing to contribute. The most important technological opportunities are:

1. Interoperability and Standardization
2. Adding a semantic layer to Big Data technology
3. Integrating Linked Data and Big Data technology
4. Enable discovery of deeper, fresher insights from all enterprise data resources
5. Improve efficiency, effectiveness, and decision-making
6. Facilitate more timely, agile response to business opportunities, threats, and challenges
7. Provide a single view of diverse data resources throughout the business chain
8. Support tighter security, protection, and governance of data throughout its lifecycle
9. Improve the scale, efficiency, performance, and cost-effectiveness of data/analytics platforms

4. Opportunities and Barriers for EU-US Collaboration in Technology Sectors

This chapter gives a brief overview of the EU-US funding and collaboration environments in section 4.1 and summarizes barriers that may hamper EU-US collaboration in section 4.2. Section 4.3 provides recommendations of concrete opportunities that were identified as the most promising mechanisms for technological collaborations on the R&I themes presented in chapter 3, and the recommendations will be refined, validated, and promoted during the remainder of the PICASSO project.

The contents of sections 4.1 and 4.2 were created by the IoT/CPS Expert Group (with inputs from the Big Data and 5G Expert Groups), and the contents of 4.3 are based on these sections. Additional sources include inputs and pointers from numerous external experts from EU and US funding agencies, industry associations, and academia that were interviewed by the IoT/CPS Expert Group, the analyses presented in section 2, the PICASSO reports (2) and (1), materials and feedback by the EU projects *DISCOVERY* (23), *BILAT USA 2.0*, *BILAT USA 4.0, CPS Summit*, and *TAMS4CPS*, and the interactive PICASSO IoT/CPS webinar that was held on February 2, 2017.

4.1. The EU-US Funding and Collaboration Environment

4.1.1. EU and US Funding

The US R&I funding landscape is structurally very different to the EU landscape. EU-level funding is mostly centralized and is realized via major funding programmes such as *H2020*, the *ECSEL Joint Undertaking*, and *ERA-NET* (which focuses on pooling and coordinating funding of EU member states for EU joint calls) that provide EU-wide frameworks for R&I funding activities, covering all levels from fundamental over translational and applications-oriented research to knowledge transfer, innovation, and commercial deployment. In the US, the funding landscape is much more fragmented. Research and innovation is mostly funded by federal research programs that are set up by different federal agencies and that reflect directly the government's priorities and interests (3). Research funding is also available at the state level, but state funding normally focuses on specific local needs and is not usable for international collaboration.

Applications-oriented R&I funding is often provided directly by companies or industry-led associations to partnering research institutions in the form of grants, with a focus on short-term returns. Initiatives such as *H2020* or dedicated programs by US agencies usually focus on funding relatively large R&I projects, for which it usually takes months between the funding application and the start of work. On the other hand, direct funding by industry often focuses on a smaller scope and a relatively quick (e.g. within a few weeks) start of work after initial funding talks.

A major contact point in the federal US funding landscape in the areas of IT, computing, networking, and software is the *Networking and Information Technology Research and Development* (*NITRD*) Program, a multi-agency program that coordinates the funding of all federal agencies in this area. It has specific contact points that coordinate research across all agencies, such as CPS research and wireless communications incl. 5G.

The *National Science Foundation* (*NSF*) exclusively funds basic research and has a major CPS research program with more than 350 funded projects, plus funding for IoT research. The NSF has explored collaborations with the EU in the past, most successfully in the areas of environmental health and safety technology. In addition, there are several bilateral cooperation agreements with EU member states, such as the US-German IoT/CPS program, and interview partners have indicated significant interest in future programs for EU-US collaboration in the areas of IoT and CPS. The NSF will not cover EU costs, but it may cover costs for EU researchers visiting the US and vice versa. The NSF has already shown interest on collaborations on low-TRL research and is a good fit because it has a major initiative in CPS, in which energy aspects are of particular interest.

The NSF is a leader in supporting Big Data research efforts as well. These efforts are part of a larger portfolio of Data Science activities. NSF initiatives in Big Data and Data Science encompass research, cyber-infrastructure, education and training, and community building. In addition to funding the Big Data solicitation, and keeping with its focus on basic research, NSF is implementing a comprehensive, long-term strategy that includes new methods to derive knowledge from data; infrastructure to manage, curate, and serve data to communities; and new approaches to education and workforce development. “Big Data” is a new joint solicitation supported by the National Science Foundation (NSF) and the National Institutes of Health (NIH) that will advance the core scientific and technological means of managing, analyzing, visualizing, and extracting useful information from large and diverse data sets. This will accelerate scientific discovery and lead to new fields of inquiry that would otherwise not be possible. NIH is particularly interested in imaging, molecular, cellular, electrophysiological, chemical, behavioural, epidemiological, clinical, and other data sets related to health and disease.

In the 5G area, the NSF coordinated the $400 million Advanced Wireless Research Initiative launched in 2016. As a first step, a Project Office for establishing the *Platforms for Advanced Wireless Research* (*PAWR*) has been created. The NSF has explored collaborations with the EU in the past, most successfully in the areas of health and safety technology. In addition, there are several bilateral cooperation agreements with EU member states, e.g. with Finland and Ireland. Potential collaboration mechanisms involving the NSF are e.g. joint workshops and mirrored calls.

The *National Institute of Standards and Technology* (*NIST*) is an important, more applications-oriented player in ICT funding (with a focus on supporting their own labs, not academia in general) and is active in a variety of technological areas and application sectors. In particular, it has a *Cyber Physical Systems Program* and a *CPS Public Working Group* that is currently developing a CPS framework (24), and its wireless networks division has a *5G & Beyond Program* and coordinates the *5G Millimeter Wave Channel Model Alliance* as well as working group developing the *Future Generation Communications R&D Roadmap*. NIST has already shown significant interest in the PICASSO work.

The parent organization of NIST, the *Department of Commerce* (*DoC*), also promotes other activities in the IoT/CPS domain. In 2016, the DoC has set as a policy priority to engage with the EU Digital Single Market initiative in the area of the free and open internet, and it also promotes activities in the telecommunications domain. The *National Telecommunications and Information Administration* (*NTIA*) of the DoC focuses on expanding broadband internet access and expanding the efficient use of spectrum, and it has recently published a “green paper” that reviews the current technological and policy landscape for the IoT and that highlights potential benefits and challenges, and possible roles for the federal government in fostering the advancement of IoT technologies in partnership with the private sector (25). In this paper, the NTIA promotes a globally connected, open, and interoperable IoT environment and recommends governmental support for US industry initiatives, greater collaboration between (private) standards organizations, the crafting of balanced policy and building coalitions, the enabling of infrastructure availability and access, and the promotion of technological advancement and market encouragement. The NTIA sees the role of government in the promotion of robust interagency coordination, public-private collaboration, and international engagement, while avoiding over-regulation that could stifle IoT innovation. International collaboration is encouraged across a range of activities and topics, including a consistent common policy approach for the IoT, cross-border data flows, privacy, and cyber-security, based on formal dialogues with top international partners on digital economy issues.

Other agencies that are potentially of interest as US partners for PICASSO collaboration mechanisms are the *Department of Energy* (*DoE*) that supports more applications-oriented research and development in areas such as clean energy, environmental cleanup, climate change, and other areas, has a strong track record in collaborations with European universities and research centers, and has shown interest in topics such as grid modernization and integrating renewables, the *Department of State* (*DoS*), the *Department of Homeland Security* (*DHS*), *Department of Defense* (*DoD*) agencies such as *DARPA*, the *Air Force Office of Scientific Research*, the *Army Research Office*, and the *Office of Naval Research*, and US foundations such as *Gordon and*

Betty Moore Foundation and the *Blavatnik Family Foundation*. In addition, the *TAMS4CPS* project found that US national labs (such as Sandia) may be suitable contacts regarding funding for collaborations on more applications-oriented research.

The DoD is “placing a big bet on big data” investing approximately $250 million annually (with $60 million available for new research projects) across the military departments in a series of programs that will:

- Harness and utilize massive data in new ways and bring together sensing, perception and decision support to make truly autonomous systems that can maneuver and make decisions on their own.
- Improve situational awareness to help warfighters and analysts and provide increased support to operations. The Department is seeking a 100-fold increase in the ability of analysts to extract information from texts in any language, and a similar increase in the number of objects, activities, and events that an analyst can observe.

The *Defense Information Systems Agency* (*DISA*) offers a cloud-based set of solutions that enables the collection of large amounts of data from across the DoD Information Networks (DODIN) and provides the analytics and visualization tools to make sense of the data. The set of solutions is called *Cyber Situational Awareness Analytical Capabilities* (*CSAAC*) and is available on both *the Nonsecure Internet Protocol Router Network* (*NIPRNet*) and *Secret Internet Protocol Router Network* (*SIPRNet*). By using CSAAC, DoD network analysts and operators have a broader and more comprehensive view of DODIN activity than ever before. CSAAC enables informed decision making and enhances the overall security posture of DoD networks.

According to Deltek Principle Research Analyst Alex Rossino's new calculations, the *Defense Advanced Research Projects Agency*'s (*DARPA*’s) budget requests for big data research and development programs will grow by 39 percent in fiscal year 2016. In the past two years, DARPA's big data investments - which focus on advanced algorithms, analytics and data fusion, among other things - have spiked 69 percent, growing from just under $97 million in FY 2014 to more than $164 million in FY 2016. In addition, in 2012, DARPA initiated the 3-year $100M XDATA program to develop computational techniques and software tools for processing and analyzing massive amounts of mission-oriented information for Defence activities. Furthermore, to encourage future collaboration and innovation across the mathematic, computer science and visualization communities, DARPA open sourced the solutions for the general public.

The DoD and DARPA also support for example a spectrum collaboration challenge, where competitors are reimagining spectrum access strategies and developing new paradigms of collaborative decision-making where radio networks will autonomously collaborate and reason about how to share radio spectrum.

The *Department of Energy* will provide $25 million in funding to establish the *Scalable Data Management, Analysis and Visualization* (*SDAV*) Institute. Led by the Energy Department’s Lawrence Berkeley National Laboratory, the SDAV Institute will bring together the expertise of six national laboratories and seven universities to develop new tools to help scientists manage and visualize data on the Department’s supercomputers, which will further streamline the processes that lead to discoveries made by scientists using the Department’s research facilities. The need for these new tools has grown as the simulations running on the Department’s supercomputers have increased in size and complexity. Moreover, the DoE, with the support of partners and allies, has created the SEED Platform Collaborative to help put big data to work on one of the biggest problems in the global effort against the negative effects of climate change - the waste of energy in big buildings. The new *Standard Energy Efficiency Data* (*SEED*) Platform Collaborative creates a remarkable three-year partnership with regional and local governments to help them collect and manage data that tracks energy use in buildings, set aggressive goals for energy efficiency in them, and transform cities and regions into energy-saving leaders.

Other governmental agencies that support Big Data R&I are the *National Institutes of Health* (*NIH*) and the *US Geological Survey* (*USGS*). The NIH has announces that the world’s largest set of data on human genetic variation – produced by the international 1000 Genomes Project – is now freely available on the *Amazon Web*

Services (*AWS*) cloud. At 200 terabytes – the equivalent of 16 million file cabinets filled with text, or more than 30,000 standard DVDs – the current 1000 Genomes Project data set is a prime example of big data, where data sets become so massive that few researchers have the computing power to make best use of them. AWS is storing the 1000 Genomes Project as a publically available data set for free and researchers only will pay for the computing services that they use. The USGS has financed, through its John Wesley Powell Center for Analysis and Synthesis, a number of projects on Big Data in order to improve its understanding of issues such as species response to climate change, earthquake recurrence rates, and the next generation of ecological indicators. Funding was providing scientists a place and time for in-depth analysis, state-of-the-art computing capabilities, and collaborative tools invaluable for making sense of huge data sets.

Non-governmental actors play a major role in translational and application-oriented R&I, collaboration, and funding in the US and the EU, and are the main drivers in for applications-oriented ICT advancement. Non-governmental actors include multi-national companies (which have an inherently international point of view and are particularly dominant in the IoT sector), and industry-led associations and standardization bodies such as the *Industrial Internet Consortium* (*IIC*), the *International Council on Systems Engineering* (*INCOSE*), the *Smart Manufacturing Leadership Coalition* (*SMLC*), the *Object Management Group* (*OMG*), the *National Coalition for Advanced Manufacturing* (*NACFAM*), the *Conference of European Directors of Roads* (*CEDR*), and others. Our discussions with representatives from industry-led associations have shown that companies and associations are promising potential partners for future EU-US collaborations, also because they are less affected by governmental policy than federal agencies.

4.1.2. EU-US Collaboration

To our knowledge, no specific calls are currently published for foreigners' participation within H2020 (3). According to research conducted by the *BILAT USA 2.0* project, "nearly one-quarter of individual organisations' policy measures provide funds to other countries as long as the leading organisation is a U.S.-based university or other research institution. About 40% of the measures do not provide funding to non-U.S. institutions. The remaining 40% have specific pre-requisites for allowing receipt of U.S. funds by third countries".

In a recent study, the *DISCOVERY* project (23) analyzed the participation rate of US partners in H2020 projects and found that out of 52 running H2020 projects with US participation (with starting dates before June 2016), only three projects focus on IoT topics, and none on CPS topics, while the majority of projects are in the scope of personal healthcare (due to an existing bilateral agreement on health R&I between the EU and the US). Two of the three IoT projects are within the scope of the *Future Internet Research & Experimentation* (*FIRE*) European initiative, which previously participated in a successful EU-US collaboration with its US counterpart, the NSF-funded *Global Environment for Networking Innovations* (*GENI*) program. The collaboration focused on the organization of joint thematic workshops and the exchange of personnel between the EU and the US.

On the EU side, there are several examples where specific programmes opened project participation, and even funding in some cases, to US partners. The *Conference of European Directors of Roads* (*CEDR*), a consortium of public national road authorities or equivalents of European countries that focuses on applications-oriented research on road transportation topics, opened a recent call for projects to US participants[5], including the possibility of receiving funding from *CEDR*. The goal of this collaboration effort was to gain access to leading research experience from the US. The ERA-NET instrument that supports public-public partnerships for joint, transnational activities between EU member states (possibly with EU-level funding contributions) recently organized a workshop with the goal of making US and Brazilian funding agencies aware of the ERA-NET work and to discuss collaboration opportunities[6]. Follow-up activities are planned. In addition, selected ERA-NET

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[5] http://www.cedr.eu/download/other_public_files/research_programme/call_2016/CEDR-Call-2016-Information-Dec-2016.pdf
[6] https://www.b2match.eu/jpisgoglobal2016

programmes complement EU member state funding with external initiatives, including US-based funding. An example is *the Infrastructure Innovation Programme* (*Infravation*) for road infrastructure innovation[7].

Many multi-national companies (which by definition have subsidiaries in different countries that often collaborate) and industry-led associations have a strong track record of international collaboration and are open to participating in EU-US collaboration efforts. As an example, the *Industrial Internet Consortium* (*IIC*) is a global initiative that promotes the growth of the industrial IoT by bringing together partners from around the world, coordinating ecosystem initiatives, and bridging between regional initiatives (such as *Industrie 4.0* in Germany). Particular focus is currently placed on the 27 joint testbed initiatives[8], involving partners from many different countries. These joint testbeds provide realistic industrial environments for joint pre-competitive R&I projects so that new technologies, applications, products, services, and processes from different partners can be initiated, developed, and tested. As an example, the first of these testbeds, *Track&Trace*, was established appr. 2 years ago, is located in Germany, involves partners from the EU, the US, and India, and focuses on the development and testing of future smart, hand-held tools in manufacturing, maintenance, and industrial environments.

While collaboration initiatives between governmental agencies (such as the NSF and the EC) involve only few large organizations and are usually coordinated and set up internally, establishing collaborations between many different actors (such as government agencies on one side and industry-led associations, or even single large enterprises and SMEs on the other side) may require significant coordination and support activities. An example of a non-profit organization that specializes on this kind of match-making is the *Intelligent Manufacturing Systems* (*IMS*) Global Research and Business Innovation Program[9], which is partly funded by the EC. The program aims to integrate and connect US manufacturing industries and associations with EC programmes (where EC-foreign partners must provide their own funding). They focus on two services, direct matchmaking to set up R&I projects with partners from the member states, and thematic project clustering programmes for existing projects that provide collaboration support, such as the organization of workshops for international exchange.

4.2. Barriers

This section summarizes major barriers that must be overcome to implement successful EU-US collaborations. Most of these barriers have been identified in discussions within the IoT/CPS Expert Group and personal interviews done by the IoT/CPS Expert Group with external experts. Additions were provided by the Big Data and 5G Expert Groups.

4.2.1. Structural Differences in Funding Environments

As described in section 4.1, the US R&I funding landscape is structurally very different to the EU landscape along several dimensions.

First, EU-level funding builds on centralized framework programmes that do not have a counterpart in the fragmented US landscape. There are no overarching US or EU programmes currently that focus on closing the gap between the funding structures the gap between centralized EU and decentralized US funding, although programs such as *Intelligent Manufacturing Systems* (*IMS*, see previous section) provide bridging services for specific sectors. It seems unlikely that such overarching programmes are viable due differences in policy and

[7] http://www.infravation.net

[8] http://www.iiconsortium.org/test-beds.htm

[9] http://www.ims.org

due to the large administrative overhead that comes with the coordination of many different agencies and companies.

Second, different US funding agencies target specific technology readiness levels. The NSF focuses solely on basic research while other agencies (such as NIST, the DoE, national labs) focus on more applications-oriented translational research, and companies directly fund applications-oriented R&I. On the other hand, EU projects usually target several levels at the same time, and a single project may include basic research work, applications to realistic use cases, and even commercial deployment of novel technologies. Thus, high-level collaboration mechanisms, such as joint funding programmes or calls, are difficult to set up in a way that takes these differences into account. However, lower-level mechanisms that e.g. focus on the integration of US companies or industry-led associations for specific tasks within an EU project will be easier to accomplish.

Finally, there may be differences in the time spans between the application and the start of funding. EU projects are complex constructs that involve large consortia of partners from both, academia and industry, and it usually takes several months from the submission of an application to the start of funding. On the other hand, companies often have very specific R&I needs that can be achieved with relatively small effort, and they require a short-term return and a quick start of funding (e.g. within a few weeks) after application. However, EU projects are interesting for US companies for longer-term, more visionary R&I despite these timing differences, because these projects often run for several years, which provides planning security.

4.2.2. Administrative Overhead and Legal Barriers

International collaboration efforts always incur an administrative and bureaucratic overhead that can be a major barrier, as determined by the IoT/CPS expert group. There are many different potential mechanisms for EU-US collaboration, several of which have been successfully implemented before. The EU project *TAMS4CPS* has published proposals for such mechanisms (26), which can be separated into three different groups.

High-level, *top-down*, *heavyweight mechanisms* provide comprehensive frameworks for international collaboration. These include e.g. the **high-level multilateral agreements** between different countries (such as the 2016 Implementing Arrangement that was recently signed between the EU and the US[10]), large **thematic, targeted funding programmes** (such as the joint EC-NIH programme that supports EU-US collaboration in the health sector), and **joint calls** for R&I projects that pool funding all involved countries. High-level mechanisms usually require strong political support, and it often takes many years (estimated in interviews until 2020 when starting now) and a very large amount of work of all involved partners to set up such mechanisms.

Lower-level, *bottom-up*, *lightweight* mechanisms focus on specific collaboration aspects with smaller, targeted actions that can be set up relatively easily and quickly, and that occur a much smaller overhead than top-down programmes. These range from the **organization of joint workshops, conferences, and series of seminars** over support for the **mobility of researchers, staff exchange, fellowships to students, and training and education** and the trans-Atlantic provision of **access to research infrastructure, testbeds, and demonstrators** to (at the upper end in terms of complexity) relatively loose connections between calls for R&I projects, such as **coordinated calls** (for which both sides execute calls on a specific thematic topic that are temporally synchronized and that may support the involvement of external partners from both sides of the Atlantic, but where evaluation and funding is organized separately by each side) and **project twinning** (e.g. by implementing lightweight collaboration actions between existing R&I projects and consortia). The EC is currently planning to include coordinated calls and twinning into future work programmes as an instrument of a focused international strategy. It is e.g. planned to launch coordinated calls with Brazil, Japan and South Korea in the future (27).

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[10] http://ec.europa.eu/research/iscp/index.cfm?pg=usa

Finally, *collaboration support mechanisms* do not directly implement collaboration actions but provide support that facilitates the set-up of such actions. These include e.g. the facilitation of US participation in mainstream H2020 projects, the enhancement of framework conditions for trans-Atlantic collaboration, and the promotion of the visibility of EU/US programmes, as e.g. done in the *BILAT USA 4.0*, *PICASSO*, and *DISCOVERY* projects.

Our analysis and the interviews have conclusively shown that heavyweight mechanisms do currently not have a good chance of being successfully implemented in the IoT/CPS sector, particularly in the current political climate and if they require pooling of EU and US funding (see also below)[11]. The major reasons are the large overhead in the face of a lack of clearly visible benefits of such programmes and the fast evolution of the ICT field (and in particular of the IoT) that cannot be suitably reflected over the long time frames that are needed to set up high-level programmes.

Legal requirements are seen as major barriers for EU-US collaboration as well. In fact, many companies, for which the availability of external funding is often not an important requirement in joint R&I projects, see legal requirements as the major barrier for international collaboration. Companies are not interested in signing complex, restrictive legal documents, and initiatives that facilitate collaborations involving companies (such as the *Intelligent Manufacturing Systems* (*IMS*) program) restrict the legal requirements for partners by providing lightweight agreements and MoUs (memoranda of understanding).

It was noted by several interview partners that the need for US partners (in particular companies) to sign H2020 grant and consortium agreements has made it virtually impossible to involve commercial partners in H2020 aspects. However, this requirement has recently been removed under a new "Implementing Arrangement"[12] that was signed in October 2016 by the EU and the US. Under this new agreement, US organizations that do not receive any funding under H2020 are allowed to partake in research efforts and other relevant activities in the scope of EU projects without having to sign grant and consortium agreements, thus providing a new basis for EU-US R&I collaboration.

4.2.3. Lack of Clarity of the Benefits of EU-US Collaboration

The IoT/CPS expert group found that a major barrier to international collaboration is a lack of awareness and clarity about the benefits of EU-US collaboration activities for the participants, and a key requirement is the identification of these benefits and their communication to funding agencies, industry, and academia. Obviously, the more administrative and bureaucratic overhead a collaboration measure creates, the larger and more convincing the benefits must be. Questions that must be answered include e.g. "Is there a skill gap which can be complemented by collaboration?", "Is there mutual economic benefit?", "What will be missed if there is no collaboration?", or "What are the common interests?" (see section 2).

Generally, collaborations within the research community are easier to justify than academic-commercial or pure commercial collaboration. The research community is inherently global and universal, and often significant advances in key areas are only possible in international collaboration efforts, e.g. by leveraging what EC academia can contribute, and vice versa. Major success stories of successful international collaboration efforts are e.g. CERN and the nuclear fusion reactor ITER. Another major benefit of EU-US research collaboration is that the expansion of the horizons of scientific human capital (e.g. of students, graduates, post-docs) is a prerequisite for successful scientific research.

The identification of benefits for the inclusion of companies into collaboration efforts is more involved. There must be immediate incentives that justify the effort and the release of internal information and IP. Short-term

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[11] Note that bilateral agreements between the US and a single EU member state are easier to implement than multilateral agreements between the US and the EU. Successful programs have e.g. been implemented between the US and Germany, the US and the UK, and the US and Ireland.

[12] http://ec.europa.eu/research/iscp/index.cfm?pg=usa

benefits must be identified for concrete commercial and application scenarios within a restricted thematic area (such as additive manufacturing or specific scenarios involving the industrial IoT). Some general benefits for the involvement of companies in EU-US collaboration efforts are that in the globalized age, the merging of technologies from different parts of the world is an important competitive advantage that can lead to economic growth, that collaborations increase global visibility of a company, that different regions possess different strengths that can complement each other, and that collaboration may mitigate risks. For example, the US is strong in software and computing while the EU has unique strengths in smart production and cyber-physical systems development and deployment. In such a case, complementarity can create more than the sum of the parts when bringing different sectors together (provided the collaboration is not too close to commercial interests of the participants).

The advancement of international standardization and the sharing of infrastructure, testbeds, and demonstrators are other key benefits of EU-US collaboration (where again CERN and ITER are good examples of successful shared infrastructure). Infrastructure and testbeds are expensive to build, thus sharing will benefit both sides, and EU-US collaborations on standardization will set the standard for the rest of the world, in particular for the IoT sector in which all player are aware that trying to build a region-specific IoT is doomed to fail. Global efforts are seen as the only way forward.

In its recent survey (23), the *DISCOVERY* project asked respondents to identify the benefits that are most important for EU-US ICT collaboration. Gaining competitive advantages by an extended view of future challenges was identified as the most important benefit, followed by creating overseas relationships, sharing and gaining insights into research activities, and gaining international visibility.

4.2.4. Restrictions due to Intellectual Property Protection

Collaboration may be difficult on topics of **high near-term commercial importance**, i.e. innovation efforts that focus on products and services that may lead to large profitable businesses in the near term. Different regions are in competition, and industrial policy focuses on measures that reinforce own industry. This barrier is seen as important in all analyzed application sectors, and this is also a conclusion by the *BILAT USA 4.0* project that has found a lack of bilateral funding agreements between the EU and the US in areas with immediate economic outcomes. They state that “one reason for the lack of joint funding agreements may be that there are immediate economic outcomes where the US has a competitive advantage compared to the EU in the areas of technology levels, entrepreneurship, supporting start-ups, and venture capital.” (28).

It is thus arguably easier to collaborate on basic research than on applied research. An example is the *FET* (*Future and Emerging Technologies*) EC programme that focuses on basic research. Here, it is much easier to involve US partners (even including trans-Atlantic funding) than in other, more applications-oriented programmes, such as the ECSEL Joint Undertaking. One exception is the joint work on international standards and interoperability. While this is of commercial importance, it usually does not require companies to disclose information and technology that affects stand-out features of their products.

The Big Data expert group found that industrial competition between US and EU has a long tradition: It is widely accepted that EU and US are two competing regions, especially on technologically driven industries. Especially in the area of Big Data, Europe has been slow to adopt compared to the United States. More than half of worldwide revenue from big data is expected to come from the USA, and only one in twenty top big data companies is European (29). Thus, it can be very challenging for funding agencies and organisations from these regions, to collaboratively tackle research of high TRL (Technology Readiness Level) or applied research topics. However, tackling basic research subjects and topics can be an alternative.

The 5G expert group has identified this barrier as important for research topics that are already considered as study or work items in global standardization bodies, like 3GPP and IEEE. Hence, it will be easier to collaborate on fundamental research than on applied research.

4.2.5. Lack of Joint EU-US Funding Mechanisms and Policies

Generally, most of the EU funding will be used to fund EU companies and research institutes, and US funding will focus on the support of US organizations and companies. Thus, EU-US collaboration will always be a complement, or even an exception, to local and regional funding. This is not expected to change in the near future and is one of the reasons why high-level mechanisms such as joint calls or thematic, targeted funding programmes are difficult to implement (see above).

The Big Data expert group has also found that joint funding is a challenging task: As already known, US structures (both private and public) who are based in the US, have limited access to EU funding. US structures are eligible for participation in EU projects, but financial support is only available for calls where this is specified, e.g. International Cooperation calls targeting collaboration with the USA or the "Health" programme in general. Potential US participants are therefore encouraged to contact research and innovation funding organisations in the US to seek support for their participation in Horizon 2020. No jointly agreed mechanism is currently in place for co-funding Horizon 2020 research and innovation projects. On the other side, EU organisations willing to participate in US research programmes, face similar challenges, as it is almost impossible to receive funding from US agencies. Results from the newly signed EU-US agreement (signed in October 2016), which offers new opportunities for research cooperation, remain to be seen.

4.2.6. Export Control and Privacy Restrictions

Topics touching **export control issues**, **sensitive or classified data / information**, or **privacy issues** should be avoided. The EU and US national priorities, rules, and regulations are very different and will be difficult to harmonize, and generally legal and policy differences will be difficult to overcome in these areas. In particular export control issues have been identified in interviews as major blocking factors of international collaborations. Such issues must be dealt with appropriately before starting any collaboration actions.

The Big Data expert group found that data privacy is a complicated issue: The collection and manipulation of Big Data, as its proponents have been saying for several years now, can result in real-world benefits. However, it can also lead to big privacy problems (30). Both the EU and the US, have established a number of laws, policies and directives dictating the use of personal data by organisations and institutions willing to benefit from them. There are many differences between the laws regarding data privacy in the European Union and the United States, with the E.U. generally allowing more rights to the individual. With no single law providing comprehensive treatment to the issue, America takes a more ad-hoc approach to data protection, often relying on a combination of public regulation, private self-regulation, and legislation (31). Even after the US and the EU signed the EU-US Privacy Shield Framework (32), open issues remain, making it very challenging and complicated for organisations coming from these different regions to collaborate on research topics related to personal data. Moreover, the situation in EU is no homogenous across member states; e.g., Directive on Protection of Personal Data needs to be ratified and implemented by the member states, which may lead to inconsistencies.

4.2.7. Lack of Awareness and Knowledge

A lack of awareness and knowledge of EU and US actors of the other side is detrimental to collaboration. E.g., *BILAT USA 4.0* found that interested US actors may be unaware of how EU funding schemes operate (including misconceptions on how US partners can participate in H2020), and are not aware of the R&I priorities of the other side. In addition, it is often straightforward to connect to other initiatives within the US, but the EC landscape is fragmented, and the responsibilities may not be clear to US agencies.

This barrier is confirmed by an investigation of the *DISCOVERY* project (23) that identified as main barriers the lack of information on funding opportunities and programmes, the lack of knowledge about specific research areas and topics that are open to international cooperation, difficulties to understand the rules of participation in other countries, and a lack of partner search tools and methods.

Currently, several EC projects are working on solutions for these issues, including *PICASSO*, *TAMS4CPS*, *DISCOVERY*, and *BILAT USA 4.0.*

4.2.8. Lack of Interoperability and Standards

A **lack of interoperability and (device) standards** can be a barrier to collaboration. This is true for several of the application sectors and, in more detail, in (1). In addition, IoT/CPS systems were noted by our interview contacts as sometimes being highly regulated, which can stifle innovation.

4.3. Collaboration Opportunities

This section provides an overview of potential opportunities for collaboration between EU and US in the area of Big Data (note that technological opportunities are given in chapter 3). Chapter 3 together with the sections below provide a holistic picture for collaboration in Research & Innovation topics, Education and Additional Collaboration Opportunities between the two regions, in order to jointly tackle challenges that have been identified by the policy makers. The current section has been updated with findings and proceedings from the **Transatlantic Workshop on Public Private Partnerships for Big Data Research and Innovation and Workforce Development**[13], which was held in Versailles, France, on November 20, 2017 as a partnership between the **US National Science Foundation (NSF) Big Data Regional Innovation Hubs, the EU Big Data Value Association (BDVA), the PICASSO project, and INRIA.** The workshop was **conceived as a kick-off for an ongoing collaboration** aimed at helping both the **EU and the US cultivate partnerships and develop a workforce** poised to advance and apply data science now and in the future. The workshop had three stated goals:

- To **determine best practices for supporting collaborative research programs** in data science, with a special focus on public-private partnerships and innovation in the areas of smart cities, transportation, health, and the nexus of environment, food, energy, and water;
- To **identify promising areas for bilateral EU-US research and data sharing**, especially among the US National Science Foundation's Big Data Regional Innovation Hubs and Spokes program and the EU Big Data Value Public-Private Partnership program; and
- To **examine ways to develop the burgeoning discipline of data science** in order to train a skilled workforce capable of keeping up with the rapid growth in opportunities to collect, analyze, and apply data.

4.3.1. Big Data Ecosystem Opportunities

Moreover, from our analysis, it is obvious that establishing and supporting a **Big Data Ecosystem** for creating value and getting the most out of Big Data, is the highest priority for both regions. Both the US and the EU have indicated the importance of such an ecosystem (in numerus policy briefs) and are implementing specific activities for supporting such an initiative.

More specific, the **US Big Data SSG** (Big Data Senior Steering Group) has identified the need for **"development testbeds" or "sandboxes" to** enable conversion of agency-funded R&D results into innovative production capabilities, as well as for engaging in proofs of concept with both open source and proprietary commercial off-the-shelf solutions. On the other hand, the **EU commission** has launched a number of **"Lighthouse Projects"** in

[13] http://www.picasso-project.eu/2017/11/27/trans-atlantic-workshop-on-public-private-partnerships-for-big-data/

order to take existing technologies and apply the, to innovative use cases (with possibly slight adaptation and enhancement of the technologies).

The implementation of a joint programme or set of projects for establishing international partnerships to jointly tackle specific challenges will give a huge boost to Big Data industry. Such a Joint program/project would enable the sharing of experiences, results, and capabilities among agencies and organisation, shorten the development phase of a project, and allow agencies and organisation to assimilate and integrate new results and solutions quickly. Industry engagement in the program would demonstrate broader utility, foster better interoperability, and potentially provide long-term sustainability of solutions. Pilots and testbed infrastructure could be shared among agencies and organisation, thereby helping to maximize investments and share the benefits of projects and technologies that would otherwise remain isolated.

4.3.2. Standardisation & Regulation

Adding to the technological priorities, additional collaboration opportunities exist in non-technological areas such as standardisation and regulation.

Standardisation is a key enabler in the field of Big Data. There are already a number of standardisation initiatives at a world-wide level such as the ISO/IEC Joint Technical Committee (JTC) 1 Working Group (WG) on Big Data, the IEEE Standards Association standards related to Big-Data applications and specifically IEEE P2413, and the ITU "Recommendation ITU-T Y.3600" for Big Data services. However, a joint EU-US standardisation board working on this subject, could fill in an existing large gap and bring both regions to the technological forefront.

Moreover, regulation is also a key enabler in the field for global adoption of services and this is already well recognised with activities such as Safe Harbour and Privacy Shield. However, a Joint initiative between the two regions will create a fertile and fruitful environment in which the industry could operate without having to individually overcome the burden of different policies and regulations for each region.

4.3.3. Opportunities in Education & Workforce

What can also be extracted from this exercise is that **there is a great potential for EU and US universities to collaborate in order to fulfil the huge demand of Big Data graduates**, and cooperate in order to learn from each other, mutually sharing experiences. Moreover, the cooperation of educational institutions and businesses, coming from both regions will benefit both sides in order to better understand the needs and, possibly, define new ways and curriculums for tackling them. Adding to the above, at a skills level it was noted that it is difficult to recruit for smart jobs. There are also issues of transferring engineers between the EU and US. If an EU engineer wishes to work in the US there is a need to learn and get US qualifications even though they may have very good European qualifications. This makes the transfer of people and skills difficult. There is also a need to retrain on US standards if engineers are engaged in sectors where different standards apply. Here, the role of education is critical, as harmonization of skills, standards and the process of accreditation would all be beneficial.

4.3.4. Big Data for Smart Cities[14]

Transatlantic collaborations will be essential to identifying smart city initiatives and examining their successes and failures. Improved data sharing, standardization, and interoperability, especially for publicly-generated or crowdsourced data, could be undertaken by specialized working groups jointly funded by the EU and US. These

[14] Update from the Transatlantic Workshop on Public Private Partnerships for Big Data Research and Innovation and Workforce Development

collaborations would also uncover and potentially improve synergies for areas where public perceptions and priorities differ between the US and the EU, especially in regard to data collection and use. Different attitudes toward crime, for example, would impact what data is collected, how it is shared, and where it is applied.

4.3.5. Big Data and the Environment-Food-Energy-Water Nexus[15]

EU Lighthouse projects partners and US BD Hubs and Spokes-affiliated researchers should examine their projects for matchmaking possibilities that can lead to improved data sharing, interoperability, and international standards. For example, JTC-1 is an ISO in use across several projects and could serve as a model for others. Transatlantic webinars or conferences should be convened to answer questions about sensors, including the strengths and weaknesses of various products, how they can be used, and how their data can be interpreted and applied. Studying US and EU citizen science projects could also yield valuable lessons. Additional data processing and improved metadata would also lead to a better understanding of how data is collected, accessed, used, and shared, and inspire improvements.

4.3.6. Big Data for Better Health[16]

Big Data are already considered as critical for the Health sector. With a growing need for efficient and accessible healthcare, companies and healthcare organizations are starting to invest in applications and analytical tools that help healthcare stakeholders identify value and opportunities, in fields such as[17]:

- **Build sustainable healthcare systems:** The healthcare industry is constantly faced with competitive and legislative pressure and must determine ways to reduce the cost of care, while efficiently managing resources. Healthcare organizations should focus on understanding the patient and improving patient care by promoting effective resource utilization.
- **Collaborate to improve care and outcomes:** Healthcare organizations should improve patient engagement and personalize healthcare initiatives that improve the quality and efficiency of care. Understanding a patient individually is important when designing tailored yet effective healthcare programs.
- **Increase access to healthcare:** A major issue with healthcare is access. In order for the population to thrive, healthcare must be available and accessible. Educating consumers on preventive care can improve health and reduce the demand and waste of healthcare resources.

EU and US should synchronise their efforts mainly on reinventing electronic health records by incorporating machine learning advancements to automate clinical documentation and on performing meta-analyses on EHR data quality, which would inform data model standardization. These activities could achieve much-needed interoperability and standardization, thus enabling more sharing of data sets with strong privacy protections. As Health data are directly related to nearly all aspects of one's life, including the physical environment, living conditions, education, lifestyle, economic stability, and social support systems, by integrating these fields with traditional medical data into mHealth initiatives could generate more advanced models and insights.

[15] Update from the Transatlantic Workshop on Public Private Partnerships for Big Data Research and Innovation and Workforce Development

[16] Update from the Transatlantic Workshop on Public Private Partnerships for Big Data Research and Innovation and Workforce Development

[17] https://www.business2community.com/big-data/why-is-big-data-important-in-healthcare-0576823

Moreover, adoption of the Blue Button Standard[18] which allows patients to view and download their personal health records, is also a critical joint theme both for EU and for the US.

4.3.7. Potential Collaboration Mechanisms

The Big Data expert group has found that the following mechanisms, which are derived from discussions with EG members, interview results, outcomes from the the Transatlantic Workshop on Public Private Partnerships for Big Data Research and Innovation and Workforce Development and propositions made by TAMS4CPS EU Project (26), are suitable to promote collaboration, targeting both the participation of US organisations to EU initiatives and vice versa.

1) **Provide matching funds to EU or US organisations** for participating to international programmes
2) **Enhance the visibility of existing research tools**, such as Marie Skłodowska-Curie actions, ERC, etc.
3) **Provide funding to supportive activities**, such as joint workshops, seminars of conferences.
4) **Provide funding for US organisations in H2020** and vice versa.
5) **Highlight and Upgrade the role of existing structures**, such as the **TABC – TransAtlantic Business Council**
6) **Establish Bilateral Thematic Structures**, for example a joint structure with BDVA and US Big Data US Hubs (Big Data EU-US Task Force for Enhancing Collaboration)
7) **Establish joint calls, twinning of research projects, co-fund schemes**
8) **Active support of the mobility of researchers, staff exchange, fellowships to students, trans-Atlantic training and education**

[18] https://en.wikipedia.org/wiki/Blue_Button

5. Conclusions and Outlook

This report outlines new **technology themes and priorities** and **collaboration and cooperation opportunities and mechanisms** that have been identified as being promising for EU-US collaboration in Big Data. The themes and opportunities were synthesized based on comprehensive analyses of the EU and US research and innovation priorities in the technology sectors and related application domains, the current EU and US policy environment and priorities, the EU-US funding and collaboration landscape, and technological and policy barriers for EU-US collaboration. The contents of this report have been validated and refined extensively, e.g. based on in-depth discussions and online distribution and feedback actions with a large network of international experts, analytical research by the Expert Groups, preliminary PICASSO results, and other feedback collection mechanisms such as a public consultation on the PICASSO website.

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Opportunity Report

"Towards Enhanced EU-US ICT Pre-competitive Collaboration"

5G

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ICT Policy, Research and Innovation for a Smart Society

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Executive Summary

This report describes the major results that were obtained by the PICASSO Expert Group on 5G in the first half of the PICASSO project. The major contributions of this report are:

- **Technology themes** (chapter 3) and **collaboration opportunities and mechanisms** (section 4.3) that have been identified as being promising for EU-US collaboration, synthesized based on comprehensive analyses of:
- The **EU and US research and innovation priorities** in the technology sectors and related application domains (chapter 2),
- The **EU-US funding and collaboration landscape** (section 4.1), and
- **Barriers for EU-US collaboration** (section 4.2).

The contents and outcomes of this report are mainly addressed at individuals, public and private organisations as well as policy makers who are interested in EU-US 5G (or wireless) research collaboration and plan to take actions in the future. The contents of this report are based on in-depth discussions with a large network of international experts, analytical research by the PICASSO Expert Groups (5G, IoT/CPS, Big Data and Policy), preliminary PICASSO results (i.e. the reports (1), (2), and (3)) and other feedback collection mechanisms such as a public consultation on the PICASSO website. This report was circulated for consultation and feedback collection to leading individual researchers and practitioners in the EU and the US, to the 5G Expert Group members, and other initiatives. Valuable feedback has been received from representatives of European Commission's 5G Unit, 5G-PPP, FCC, NSF, 5G Lab Germany, National Instruments, Nokia, Ericsson and CWC Oulu.

In chapter 3 of this report, the PICASSO Expert Group on 5G has defined technology themes that are promising for EU-US collaboration: Technologies that have niche market shares yet will have strong societal impact

1. Connecting the last billion – ultra large cell
2. mmWave technology at carrier frequencies beyond 100 GHz
3. Narrowband IoT devices for goods tracking in global supply chain management
4. Ultra-wide band RF IC at mmWave frequency
5. V2X for regional niche markets
6. Satellite communications for broadband access in oceans
7. Spectrum farming

In section 4.3, the 5G Expert Group promotes recommendations for EU-US collaboration actions, in particular coordinated and mirrored calls, and analyses challenges and opportunities of an upcoming EC-NSF collaboration programme.

The PICASSO Project

The aim of the 30-months PICASSO project is (1) to reinforce EU-US collaboration in ICT research and innovation focusing on the pre-competitive research in key enabling technologies related to societal challenges - 5G Networks, Big Data, Internet of Things and Cyber Physical Systems, and (2) to support the EU-US ICT policy dialogue by contributions related to e.g. privacy, security, internet governance, interoperability, ethics.

PICASSO is oriented to industrial needs, provides a forum for ICT communities and involves 24 EU and US prominent specialists in the three technology-oriented ICT Expert Groups - 5G, Big Data, and IoT/CPS - and an ICT Policy Expert Group, working closely together to identify policy gaps in the technology domains and to take measures to stimulate the policy dialogue in these areas. A synergy between experts in ICT policies and in ICT technologies is a unique feature of PICASSO.

A number of analyses will be accomplished, as well as related publications, that will for a major part be made public and contribute to the project's outreach. Dedicated communication and dissemination material will be prepared that should support the operational work and widespread dissemination though different channels (website, social media, publications …). The outreach campaign will also include 30+ events, success stories, factsheets, info sessions, and webinars.

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List of Acronyms

3GPP	3rd Generation Partnership Program
4G	4th Generation
5G	5th Generation
AI	Artificial Intelligence
AIOTI	Alliance of IoT Innovation
AV	Autonomous Vehicle
AWS	Amazon Web Services
B2B	Business-to-business
B2C	Business-to-customer
BBI	Bio-based Industries
BD	Big Data
BDVA	Big Data Value Association
BDVPPP	Big Data Value Public Private Partnership
CEDR	Conference of European Directors of Roads
CERN	Conseil Européen pour la Recherche Nucléaire
CPS	Cyber-physical System
CPSoS	Cyber-physical System of Systems
CPS-VO	CPS Virtual Organization
CPU	Central Processing Unit
CS	Clean Sky
CSAAC	Cyber Situational Awareness Analytical Capabilities
CWC	Centre for Wireless Communications
D2D	Device-to-Device
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DISA	Defense Information Systems Agency
DoC	Department of Commerce
DoD	Department of Defense
DoDIN	DoD Information Networks
DoE	Department of Energy
DoS	Department of State
DoT	Department of Transportation
DSL	Digital Subscriber Line
DSM	Digital Single Market
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EeB	Energy-efficient Buildings
EG	Expert Group
EPI	European Platform Initiative
ERA	European Research Area
EU	European Union
FBMC	Filter-Bank Multi-Carrier
FCC	Federal Communications Commission
FCH	Fuel Cells and Hydrogen
FET	Future and Emerging Technologies
FIRE	Future Internet Research & Experimentation
FoF	Factories of the Future

FP7	Framework Programme 7
FY	Financial Year
Gbps	Gigabit per second
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GENI	Global Environment for Networking Innovations
GFDM	Generalized Frequency-Division Multiplexing
GHz	Gigahertz
H2020	Horizon 2020
H2M	Human-to-machine
HD	High-definition
HMI	Human Machine Interface
HPC	High Performance Computing
HPUE	High Performance User Equipment
IA	Industry Association
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IERC	IoT European Research Cluster
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IM	Innovative Medicine
IMS	Intelligent Manufacturing Systems
INCOSE	International Council on Systems Engineering
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Rights
ISM	Industrial, Scientific, Medical
ITER	International Thermonuclear Experimental Reactor
ITS	Intelligent Traffic System
ITU	International Telecommunication Union
JTI	Joint Technology Initiative
JU	Joint Undertaking
LTE	Long Term Evolution
M2M	Machine-to-Machine
M&S	Modeling and Simulation
MEC	Mobile Edge Computing
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MoU	Memorandum of Understanding
ms	Millisecond
NACFAM	National Coalition for Advanced Manufacturing
NB-IoT	Narrowband IoT
NCP	National Contact Point
NCURA	National Council of University Research Administrators
NFV	Network Function Virtualization
NGI	Next Generation Internet
NGMN	Next Generation Mobile Networks
NIH	National Institutes of Health
NIPRNet	Nonsecure Internet Protocol Router Network

NISD	Network and Information Security Directive
NIST	National Institute of Standards and Technology
NIT	Networking and Information Technology
NITRD	Networking and Information Technology Research and Development
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
OCF	Open Connectivity Foundation
OFDM	Orthogonal Frequency Division Multiplexing
OMG	Object Management Group
PAWR	Platforms for Advanced Wireless Research
PCAST	President's Council of Advisors on Science and Technology
PPP	Public Private Partnership
PWG	Public Working Group
QoE	Quality of Experience
R&D	Research and Development
R&I	Research and Innovation
RAT	Radio Access Technology
RDI	Research, Development, Innovation
RFC	Request for Comments
SAE	Society of Automotive Engineers
SDAV	Scalable Data Management, Analysis and Visualization
SDN	Software Defined Networking
SEED	Standard Energy Efficiency Data
SIPRNet	Secret Internet Protocol Router Network
SME	Small and Medium-sized Enterprises
SMLC	Smart Manufacturing Leadership Coalition
SoS	System of Systems
SOTA	State of the Art
SPIRE	Sustainable Process Industry
SRA	Strategic Research Agenda
SSG	Senior Steering Group
Tbit	Terabit
Tbps	Terabit per Second
TRL	Technology Readiness Level
TTIP	Transatlantic Trade and Investment Partnership
TV	Television
UE	User Equipment
UHD	Ultra High Definition
URLLC	Ultra-reliable Low-latency Communications
US	United States
USGS	US Geological Survey
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
V5GTF	Verizon 5G Technology Forum
VDA	Verband Der Automobilindustrie
VPN	Virtual Private Network
ZT-OFDM	Zero-tail OFDM

Table of Contents

1. Introduction

5th generation (5G) networks are the proposed next telecommunications standard beyond the current 4G/LTE-standard. 5G networks will not only be an evolution of current generations of mobile networks but are characterized as a revolution in the ICT field that will enable highly efficient, ultra-reliable, secure, and delay-critical services. Hence, it will affect not only the ICT sector itself, but will also have a tremendous impact on vertical industries. European players defined a common strategy by making crucial investments in 5G technologies, taking related measures to focus and strengthen their capabilities, and involve partners from vertical sectors in a very early stage. In 2013, the EC and leading industry players formed the 5G Infrastructure Public Private Partnership (5G PPP) - an initiative for the EU ICT industry to achieve a competitive advantage in the global marketplace by contributing to the research and investigations of the new technologies that will characterize 5G.

Many research and development activities have been carried out within the last years to tackle key technological challenges in order to meet 5G requirements in terms of throughput, latency, reliability, energy efficiency, coverage, and battery lifetime. Many R&D projects show very promising research results. These results will flow into standardization activities and will be verified in large field test trials and testing within the next years. According to recent 5G roadmaps, first commercial products will most probably enter the market around 2020. However, some research issues are still open and even new challenges appear that exceed 5G requirements.

Within PICASSO, the members of the 5G Expert Group monitor and analyse the current 5G technology developments carefully. It can be stated that these current “mainstream” developments cover a lot of topics, take up an incredible pace, and address the requirements of a broad range of applications. Both, EU and US players do have good positions in the race towards 5G and face global competition. In order to detect research opportunities for collaboration in a pre-competitive environment, the PICASSO 5G Expert Group entered into intense discussions on topics, applications and markets, which are not or only partially addressed in 5G roadmaps yet and will generate large societal impact.

The 5G sections of this report describe key enabling technologies, provide an overview on research and innovation priorities in EU and US as well as on application domains in four vertical sectors, and conclude with an analysis of our studies. We propose seven research and innovation themes, their related research topics, describe the rationale and benefits for EU – US collaboration as well as their relevance to application domains. With respect to an upcoming EC-NSF collaboration programme in 2018, this report analyses possible challenges of the calls and meanwhile provides several recommendations.

This report was circulated for consultation and feedback collection to leading individual researchers and practitioners in the EU and the US, to the 5G Expert Group members, and other initiatives. Valuable feedback has been received from representatives of European Commission’s 5G Unit, 5G-PPP, FCC, NSF, 5G Lab Germany, National Instruments, Nokia, Ericsson and CWC Oulu. As one of the major outputs of the PICASSO project and the 5G Expert Group, this report will serve as knowledge bases and initial guidelines to individuals, public and private organisations as well as policy makers who are interested in EU-US 5G (or wireless) research collaboration and plan to take actions in the future.

2. Research and Innovation Priorities in the EU and the US

This section summarizes the technological research and innovation priorities of the EU and the US in the sector of 5G and summarizes the needs and drivers for society and important vertical sectors, including automotive, industry, health and energy.

2.1. Cross-domain Drivers and Needs

This section briefly summarizes the major overarching societal challenges that are currently seen as the major drivers for the development and deployment of novel 5G-based technologies in the EU and the US. It is based on the PICASSO reports (2) and (1), on discussions with the 5G EG (Expert Group) members, and on the H2020 EU Framework Program for Research and Innovation.

The mobile internet has shown to be a true success story. Today, more than 5 billion people have access to the internet through a mobile connection (4), significantly more than via wired connection. It is the vision of 5G to **provide ubiquitous mobile connectivity to the last billion**, most of them living in sparsely populated areas.

The negative impact of **counterfeit and pirated products** on the global market is about USD 200 billion p.a. (5). These goods are often substandard and can even be dangerous, posing health and safety risks that range from mild to life-threatening. Economy-wide counterfeiting and piracy undermine innovation, which is key to economic growth. 5G, and especially NB-IoT technologies will enable several applications, which protect products and goods from counterfeiting and piracy.

Health, demographic change and wellbeing are major societal drivers in the EU and the US. New markets will emerge in the future, and companies see a large opportunity to satisfy needs in both products and services. One of the challenges is the growing world population, which put an incentive on the **agricultural** sector to increase production. New ICT technologies and 5G communications can provide the tools for more efficient farming, and reduce waste in all steps of the food supply chain.

Secure, clean and efficient energy is seen as a key challenge for the future. The shift towards renewable and decentralized energy production is a central R&I topic in both, the EU and US. Goals are to reduce energy consumption, the development of alternative mobile energy sources, and the creation of a smart electricity grids. Future 5G networks will be able to recognize and regulate energy production very fast and are therefore a key building block.

The need for **smart, green and integrated transport** is a huge driver in both, the EU and US. 5G will lay the foundation for the creation of smart infrastructure and connected vehicles, resulting in less congestion and fewer accidents, hence, more road safety and security.

Privacy, security, trust and safety are crucial drivers that are gaining relevance in all practical domains in the EU and US.

2.2. 5G and its Enabling Technologies

The fifth generation of mobile communications (5G) will be a revolution in the networking domain. It extends the cellular network from content delivery to a control network that opens up new doors to new applications. Next Generation Mobile Networks (NGMN) describes 5G as follows in their 5G White Paper (6):

“5G is positioned to address the demands and business contexts of 2020 and beyond. It is expected to enable a fully mobile and connected society and to empower socio-economic transformations in countless ways many of which are unimagined today, including those for productivity, sustainability and well-being. The demands of a fully mobile and connected society are characterized by the tremendous growth in connectivity and density/volume of traffic, the required multi-layer densification in enabling this, and the broad range of use cases and business models expected."

5G is to provide, where needed, much greater throughput (10-100 Gbps), much lower latency (<1ms), ultra-high reliability (>99.999%), much higher connectivity density, and higher mobility range. These enhancements are to be provided along with the capability to ensure security, trust, identity, and privacy.

The building blocks of the 5G vision are multiple key technologies, some of which are briefly described in the following sections. They are based on the roadmaps and strategic documents that are described in subsequent sections, multiple white papers on the topic, on the PICASSO reports (2) and (1), and on discussions with the EG (Expert Group) members.

In order to **enhance data rates to a never seen level**, 5G needs to support **mmWave technology (frequencies above 30GHz)**. At these frequencies, high bandwidths are available but the technological difficulties rise since electromagnetic waves behave fundamentally different above 30 GHz. Combined with massive MIMO (Multiple Input Multiple Output) and beamforming, it will be possible to serve users with extremely high throughput in the order of 10-100 Gbps without greatly interfering with the quality of experience of others. This is a very large R&I topic in both, the US and the EU (US having the lead). Another technology to support higher data rates is the combined use of licensed and unlicensed spectrum, termed **Smart Blending**.

The immense diversity of requirements for future 5G use cases requires logical splits of the network. This technology is termed **Network Slicing**. Each slice of the network will make sure that the application using it receives the performance metrics it needs, not less but not more either. Networks will be built in a flexible way so that speed, capacity and coverage can be allocated in logical slices to meet the specific demands of each use case.

In the past and also nowadays, it was/is common to build networks with dedicated hardware for a specific task. E.g., network routers are a hardware unit solely usable for routing. In future networks it will be possible to **virtualize network functions** and to use low-cost multipurpose hardware to do it. Advantages of **Network Function Virtualization** (NFV) are very high flexibility, adaptability, and scalability at very little cost. In conjunction with **Software Defined Networking** (SDN), which separates the control of the network nodes from the actual data flow, NFV is a robust, fast, cheap, and yet dynamic way of transferring content across the network. Network slicing, SDN, and NFV are very important technologies developed in both, the US and the EU.

Another important technology possibly used in natural disaster events or for extending network range is **Device-to-Device Communication (D2D)**. Hereby, it would be possible for devices to communicate with each other without an underlying network infrastructure given a certain proximity of the devices. Even in catastrophic events like hurricanes, it would herewith be possibly to call emergency services for the rescue. D2D is thoroughly researched in many institutions in both, the US and the EU.

Narrowband IoT (NB-IoT) is a new low power wide area technology specifically developed for the Internet of Things (IoT), for devices that require small amounts of data, over long periods and indoor coverage. NB-IoT fills the gap between mobile and short-range wireless networks. It is designed for machine type communications, to provide connectivity for devices and applications that require low mobility and low levels of data transfer, and will therefore be critical in the development of the IoT. 3GPP standardized NB-IoT in its Release 13 for LTE Advanced Pro, which was completed in June 2016. NB-IoT will continue to evolve in future Releases towards 5G with new features, such as support for multicast and positioning.

A research topic that was identified not being thoroughly researched in neither, the US and the EU, is **long range communications** with **very large cells** at low frequencies and low/medium throughput. The goal is to enable network access from the most rural places, virtually bringing urban and rural areas closer together and providing 5G services independent of the user's location. A **combination of long range communication with**

large cells and D2D offers a lot of opportunities for 5G use cases and applications to serve the population living in rural areas. These applications are not yet identified in current 5G roadmaps.

2.3. Research and Innovation Priorities in the EU

This section summarizes the major research and innovation priorities in the EU in the area of 5G. These priorities were identified based on input by the members of the 5G Expert Group and PICASSO reports such as (2) and (1). In addition, relevant strategic documents and roadmaps were analysed. These include NGMN White Paper on 5G (6), the H2020 - Work Programme 2016-2017 on ICT (7) and the 5G-PPP White Papers on 5G Architecture and on vertical industries (8).

Overall, seven R&I priorities targeting 5G key enabling technologies were identified. Note that in the following, the item numbers do not indicate priority, but only serve to make the items easily referable.

1. **Novel air interface technologies:** This main topic covers all aspects that relate to the engineering of new transmission schemes.
    - supporting efficiently a heterogeneous set of requirements from low rate sensors to very high rate HD/3D TV and immersive services
    - supporting local and wide areas systems, heterogeneous multi-layer deployments, assuring uniform performance coverage and capacity
    - enabling usage of frequency bands between 6 and 60 GHz (mmWave) for ultra-high speed access
2. **Coordination and optimization of user access**: This topic covers the joint management of the resources in the wireless access and the backhaul/fronthaul as well as their integration with optical networks.
3. **Multi-Connectivity:** In order to fulfil the requirements of data-rate, latency, reliability, and availability, Multi-Connectivity has to be deployed in 5G networks. Multi-Connectivity describes the simultaneous connection of User Equipment (UE) to multiple base stations.

    One base station with multiple links will provide different levels of data redundancy depending on the requirements of the connection.
4. **High capacity elastic optical networks:** This topic covers the development of new optical networks to support the high data rates coming from 5G heterogeneous access networks.
    - increase of network capacity by a factor of >100
    - guarantee end-to-end optimization
    - reduce power consumption and cost per bit
5. **Software network architecture:** This topic covers all aspects of “softwarisation” of the network.
    - support of scalable, efficient, cheap, reliable networks
    - relocation of services
    - realisation of the “plug and play vision” for computing, storage, and network resources.
    - Adding new network functions like Mobile Edge Computing (MEC) to the network, providing a computing node very close to the user for very low latency applications
6. **Management and Security for virtualised networks**:
    - flexible configuration of network nodes

- network analytics tools
- security (and privacy) across multiple virtualised domains
- innovative solutions to address the increasing societal concerns regarding user privacy

7. **Technology validation and testbeds**
    - experimental testing of most promising 5G technologies in the context of key use cases involving several vertical sectors - major focus in H2020 work programme (16/17)
    - addressing standardisation roadmap (3GPP) and spectrum milestones (WRC 19)
    - Future Internet Experimentation (FIRE), addressing management and control of cognitive radio, as well as dynamic spectrum sharing in licensed and unlicensed bands
    - Some Network operators conducted first 5G trails together with vendors:
        - In July 2016, Vodafone and Huawei completed a 5G field test in Newbury that demonstrates the capabilities of a trial system operating at 70 GHz with Massive MIMO capabilities. In this test, they reached data rates of over 20 Gbps and support multiple users that receive 10 Gbps each.[1]
        - In September 2016, Deutsche Telekom and Nokia demonstrated how the ultra-high data rates promised by 5G technology can boost the viewing experience at live sports events. Nokia's 5G-ready hardware was conducted in demonstrations for free viewpoint video applications at the Berlin Olympia stadium and delivered maximum data rates of 2.3 Gbps.[2]
        - In October 2016, Nordic players Telia and Ericsson completed an outdoor test "on the first 5G trial system in Europe" in Kista, Sweden, demonstrated 5G capabilities over a live network, and included tests on speed and latency. The system used 800MHz of spectrum in the 15GHz band, with peak rates of 15Gbps per user, and a latency below 3 milliseconds.[3]
        - In January 2017, Orange announced to partner with Nokia' to test various 5G-based technologies, e.g. cloud-RAN, massive multiple input, multiple output (MIMO), network slicing, for ultra-broadband, and Internet of Things (IoT) applications. Earlier this year Orange announced it was teaming with Ericsson and PSA Group to conduct 5G tests that incorporate vehicle-to-vehicle (V2V) and vehicle-to-everything (V2X) technology for connected car applications. Initial tests will use LTE and then evolve to LTE-V and 5G. [4]

In Europe, we see that validating the research in a system context by proof-of-concepts and testbeds for multiple use cases happens in practice on many fronts. From 2018, 5G PPP - incl. EC and industry partners - targets significant investments for 5G end-to-end demonstrators, 5G & automotive trails, and 5G trials across multiple verticals using the end-to-end infrastructure. To coordinate trial actions in Europe as well as with non-EU partner countries, the 5G PPP has announced a 5G pan-EU trials roadmap in 2017 [5]. The identified cluster

[1] https://www.mobileworldlive.com/featured-content/top-three/vodafone-huawei-reach-20gbps-speed-in-5g-trial/

[2] http://www.fiercewireless.com/europe/deutsche-telekom-nokia-complete-5g-vr-trial-sports-stadium

[3] https://www.mobileworldlive.com/featured-content/home-banner/ericsson-and-telia-test-5g-in-european-first/

[4] https://www.sdxcentral.com/articles/news/orange-taps-nokias-airscale-platform-5g-trials-france/2017/01/

[5] https://5g-ppp.eu/5g-trials-roadmap/

pilots are smart city cluster, consumer and professional service cluster, industry cluster, digital health cluster and public safety & Digital divide.

On the other hand, with the perception that 5G is on its way, research interests on **beyond 5G** or even **6G** are gradually rising. At the moment, there is no clear definition on beyond 5G or 6G yet. The following topics are seen as of great interest:

8. **Very-high frequency communications beyond 100GHz, exploiting spectrum potential and pushing the limits to THz communications**
    - key technology building blocks for mmWave communications up to 300 GHz
    - visible light communications
    - radically new approaches for spectrum efficiency
9. **Advanced physical layer design.**
    - antenna processing, information theory and coding to optimize and reach Tbit/s in wireless communications
10. **Security and privacy**
    - secure hardware, software technologies and architectures
    - privacy protection mechanism technologies and architectures

2.4. Research and Innovation Priorities in the US

This section summarizes the major research and innovation priorities in the US in the area of 5G. White papers issued by 5G Americas, e.g. (9) and (10), have been studied and analysed. In the US, mainly the institutions NSF, DARPA, NIST, and the White House are responsible for the public funding of projects. These institutions and their funded projects were used to analyse the focus topics of 5G research in the US.

Overall, six R&I priorities were identified. Note that in the following, the item numbers do not indicate priority, but only serve to make the items easily referable.

1. **Novel air interface technologies:** This main topic covers two main research directions:
    - **mmWave air interface:** This topic covers all research committed to bringing multi-Gbps data rates to the user at very high frequencies. The US is the main driver of this new technology, big players are Nokia, National Instruments, Intel, and Qualcomm as well as a wide range of academic institutions. Advantages of this technology are the very high availability of spectrum (and therefore data rate), disadvantages include very high signal attenuation and very limited propagation through obstacles (e.g. walls). Various solutions are being sought to overcome blockages due to shadowing as well as penetration loss.
    - **New waveforms:** This topic includes all research focusing on transmission schemes used in 5G below 6 GHz. In 4G LTE and 5G New radio (NR), OFDM (Orthogonal Frequency Division Multiplexing) has been used or selected. However, to provide a more confined spectrum compared to OFDM (relevant for spectrum-sharing scenarios), the research interests on waveforms continue, e.g., Filter-Bank Multi-Carrier (FBMC), Universal Filtered Multi-Carrier (UFMC), Single carrier waveforms like zero-tail OFDM (ZT-OFDM) and Generalized Frequency-Division Multiplexing (GFDM). Time synchronization to retain orthogonality between different transmissions is also less of an issue then.

2. **Spectrum Management:** This topic covers all research topics related to efficiently using the available spectrum. Especially Nokia and Qualcomm conduct research in this area.

   - Shared spectrum access: The idea behind shared spectrum access is to support different RATs with the access to a certain frequency band. A primary and a secondary user is defined. The secondary user is permitted to use the spectrum whenever the primary user does not. This inherently requires base stations that are capable of spectrum sensing and agile frequency hopping (very fast switching frequencies without degrading Quality of Experience (QoE)). DARPA is heavily driving research in this area within the scope of their Spectrum Collaboration Challenge (SC2), simultaneously testing their research results in testbeds, making sure the work results can move rapidly from concept to adoption.
   - Interference between radio access nodes is the limiting factor of current wireless networks. 5G research is being conducted in the areas of inter-node coordination (Coordinated Multi-Point) and avoidance of inter-cluster interference at reasonable coordination complexity.
   - Simultaneous Transmission Reception: This topic covers the ambition to transmit and receive signals at the same frequency at the same time by means of analog hardware, and digital cancellation techniques. Interference reduction of 85dB of transmission and reception signal have already been reported (which is enough for Wifi, but not for a cellular context of much higher transmit powers). It is not yet clear to what extent the successful development of this technology would facilitate fulfilling certain 5G requirements.

3. **Ultra-low response times:** This topic covers the development of technology supporting ultra-reliable low-latency communications (URLLC). The National Science Foundation (NSF) is heavily engaged in bringing this work forward and forms bonds with the private sector (e.g., $6 million cooperation with Intel Labs) in order to achieve that.

4. **Device-to-Device and V2X Communications:** D2D communication (possible in licensed and unlicensed spectrum) in 5G has multiple use cases which are briefly mentioned in the following:

   - Extension of coverage beyond the reach of the conventional infra-structure (device-based relaying).
   - Unicast direct communication with no network infrastructure at all.
   - Information broadcast (e.g. for large event crowds) is attractive.

   Further V2X communications using infrastructure and supporting automated cars, platooning, allowing interactions between vehicles, vehicular infotainment is an ever expanding research area.

5. **OpenFlow & SDN:** The shift towards a separation of the control and data layer with control software instead of hardware (SDN) and the softwarisation/virtualization of network functions (NFV) has already been described in detail in the "Enabling Technologies" section. Especially Google and academic institutions conduct research in this domain.

6. **Testbeds and Trials:** Especially cellular providers, such as Verizon, AT&T and Sprint develop testbeds and conduct trials to confirm the practicality of research results and their realizations.

   - Verizon plans to verify that lab tests have shown transmission speeds in range of 1 Gbps, with first field trials being used to investigate propagation characteristics in 28 GHz spectrum in real world conditions. The trails shall take place in four states: Texas, Michigan, Massachusetts and New Jersey in between January and June 2017.[6] Verizon formed a 5G

[6] https://www.wirelessweek.com/news/2016/12/confirmed-verizon-applies-conduct-pre-commercial-fixed-5g-trials-4-states

Technology Forum (V5GTF) in late 2015 in cooperation with Cisco, Ericsson, Intel, LG, Nokia, Qualcomm and Samsung to create a common platform for Verizon's 28/39 GHz fixed wireless access trials. V5GTF published an early set of 5G specifications, available at http://www.5gtf.org.

- AT&T recently launched a partnership with Ericsson and Intel on a millimeter wave 5G business trial in which it will provide a 5G network to power multiple experiences – including Internet access, VPN, Unified Communications applications, and 4K video streams[7] reaching speeds of nearly 14 Gbps.
- Sprint also indicated speed up its radio network performance up to 1 Gbps by using a combination of carrier aggregation, MIMO, 256-QAM, and its new High Performance User Equipment (HPUE) technology in the 2.5 GHz spectrum.[8] According to Sprint, HPUE is mainly a device-based technology, ready to use on today's networks, and will debut in devices in early 2017. Sprint demonstrated 5G technology using the 73 GHz spectrum band to deliver claimed download speeds in excess of 2 gigabits per second and "low millisecond latency" supporting live-streaming video in 4K high-definition quality and a streaming virtual reality system. Nokia noted it was part of the Sprint 5G demonstration in Santa Clara in June 2016. In another trail in Philadelphia, Sprint used the 15 GHz spectrum band with beam switching capabilities achieving download speeds up to 4 Gbps, and run in partnership with Ericsson.[9]

In the public funding domain, the flagship action was taken by NSF via advanced wireless initiative[10]. It intends to stimulate and build US research leadership in the area of beyond 5G and contains three elements:

- Platforms for Advanced Wireless Research (PAWR): develop 4 city-scale testbeds for carrying out wireless research. It is funded and operated as a private-public partnership with NSF funding of $50 million and industry funding of $50 million. Winners of the first two cities are just announced, i.e., New York (COSMOS testbed) and Salt Lake City (POWDER-RENEW)[11].
- Fundamental research enabling advanced wireless networks: In the next 7 years, NSF will fund fundamental research carried out on the developed testbeds with 350 million $.
- Community leadership and engagement.

2.5. Vertical Sectors: Drivers and Needs

This section briefly summarizes the major drivers and needs in the vertical sectors of Automotive, Industrial Automation, eHealth, and Energy. This section is partly based on the PICASSO report (1), studies of NGMN White Paper on 5G (6) ITU-T Tech Watch report on Tactile Internet (11), 5G-PPP White Paper on Automotive, Factories of the Future, Health and Energy, (8) as well as feedback by industrial interview contacts, and on input by the 5G Expert Group.

2.5.1. Automotive and Transportation

Automated Driving has been in the media for a considerable amount of time. Multiple companies have already implemented some kind of automation to their vehicles, such as navigation services, and assisted parking. 5G

[7] https://www.wirelessweek.com/news/2016/12/t-teams-intel-mmwave-5g-business-trial

[8] https://www.wirelessweek.com/news/2016/12/sprint-looks-stretch-its-25-ghz-spectrum-further-new-hpue-technology

[9] http://www.rcrwireless.com/20160706/carriers/sprint-5g-technology-plans-ahead-curve-tag2

[10] https://www.nsf.gov/cise/advancedwireless/

[11] https://www.advancedwireless.org/

though will shape mobility in a never seen way. Both, the EU and the US do heavy research on automation of mobility.

- **Automated Driving:** Automated Driving describes the capability of a vehicle to drive automatically, i.e. without the need of a driver. Six increasing levels (0-5) of automation have been defined by US Society of Automotive Engineers (SAE) and German Association of the Automotive Industry (VDA), of which only level 5 ("Full Automation") does not require a driver at all. 5G plays multiple important roles in this development.
  - The information about infrastructure must be given to the vehicle (e.g., maps, traffic rules), i.e. data has to be downloaded from the internet (V2N).
  - The vehicle may communicate with other vehicles (V2V) and the infrastructure (V2I) to better adapt to the traffic situation (giving the vehicle a bird's eye view), leading to greater consumer satisfaction. For V2V and V2I there is no underlying network infrastructure necessary, which facilitates the installation of such services in rural areas.

- **Road safety and traffic efficiency services:** 5G will bring road safety and traffic efficiency to a whole new level. Multiple services have already been demonstrated in various EU-funded projects, such as intersection collision risk warning, approaching emergency vehicle warning, green light optimal speed advisory, traffic jam ahead warning, and road hazard warnings. V2V communication in fully automated driving will enable vehicles to drive closer together, resulting in increased road capacity and, hence, efficiency. These cars would also react a lot quicker to maneuvers, since all maneuvers are broadcast to other traffic participants beforehand.
- **Information society on the road:** With the car driving fully automated in the future, the driver (who then becomes a regular passenger) can use the travelling time for other things than operating the car. Passengers have a very high need for connectivity and with 5G this need can be satisfied, even in high-mobility scenarios. Transformations of cars to a "second office" are foreseen.
- **Predictive maintenance:** The multitude of sensors in a vehicle in the future will probably dwarf the amount of sensors in vehicles today. Having data about every aspect of the vehicle might enable a prediction of failures before they occur, reducing cost and time of the repair since the error was targeted in an early stage and it is known before it is brought to the mechanic. At the same time, obviously, safety is increased because technological errors will less often occur unforeseen.

Today, **Automated Driving is regarded as a key application** to many stakeholders in the mobile communications community. Hence, the standard Automotive use case can be seen as a mainstream application with many researchers in the public and private sector, in the US and the EU, working on it. Furthermore it is seen as one main growth driver of electric cars.

However, related applications are found in the areas of **agriculture, harvesting, and surface mining**, which have similar requirements like Automotive. These use cases are mostly located in sparsely populated rural areas.

2.5.2. Industrial Automation

Automation in industry is a key, steadily growing application field for 5G. 5G-enabled Factories-of-the-Future will become faster, more cost-efficient, and more flexible. More data from the factory floor will enable better optimization of the production process.

It is noted that the section on CPS/IoT covers this topic already.

In the future fully automated and flexible manufacturing relies on support from the 5G community, particularly regarding:

- highly reliable wireless communication to integrate mobile robots, automated guided vehicles, etc. into the closed loop control processes
- a seamless experience while using hybrid wireless and wired network technologies
- the cost-effective management of the network that unifies the connected assets of a factory

Four use case families with strict requirements towards a 5G implementation are:

Table 1: Use case families with strict requirements towards a 5G implementation.

Use case family	Impact	Requirements
Time-critical process optimization inside factory	○ Increased efficiency ○ Increased worker satisfaction ○ Increased safety/security	○ Ultra-low latency ○ Ultra-high reliability ○ Security-critical ○ High level of heterogeneity
Non time-critical in-factory communication	○ Increased efficiency ○ Increased flexibility ○ Minimized stock levels ○ Increased eco-sustainability (emissions, vibrations, noise)	○ High reliability ○ Security-critical ○ High level of heterogeneity
Remote control	○ Increased product/process quality	○ High reliability ○ Wide area coverage ○ Security-critical ○ High level of heterogeneity
Connected goods	○ Increasing sales (new products, services) ○ Improved product quality ○ Improved product/process design	○ Wide area coverage ○ Security-critical ○ High level of heterogeneity ○ High level of autonomy

Excluding “Connected goods”, all use cases have in common that only small data rates are needed, however requirements regarding latency, security, heterogeneity, and especially reliability are very high. Using wireless technology poses a large advantage to manufacturing since running cables through a factory is very expensive and inflexible. The downside of relying on wireless connections also poses a higher risk to attackers who do not have to be physically present to find an entry point to the system. Installing well-functioning security measures becomes very important in future 5G systems. In general, future manufacturing poses very challenging requirements towards 5G development.

2.5.3. Health

Healthcare accounts for about 10% of the GDP in both, the US and the EU, making up a huge market for 5G applications. However, ICT and healthcare are not necessarily sectors one would link nowadays. A few healthcare gadgets, e.g. heart rate monitors and fitness trackers, have appeared in recent years, but these contributions are very small compared to what is assumed to come. The pharmaceutical industry is expected to be one of the key drivers for this new technology.

The idea behind e-Health is a shift from the hospital-based, specialist-driven system towards a patient-centered care model. E.g., in the US, the term “precision medicine” describes a personal treatment, founding on the personal health data collected.

Three main areas of e-Health are defined:

1. The delivery of health information for health professionals and health consumers through the Internet and telecommunications.
2. Using the power of IT and e-commerce to improve public health services, e.g. through the education and training of health workers.
3. The use of e-commerce and e-business practices in health systems management.

These areas could include, e.g., the ideas of

- Wireless patient monitoring
- Mobile system access
- Smart pharmaceuticals
- Robotics, i.e., ubiquitous access
- Tele-healthcare
- Prevention

The overall vision is to bring patients and health professionals closer together. This would reduce the disparity between urban and rural healthcare and enable physical therapy and even complex surgical procedures by bringing the needed experts (who may not be available at a single location) virtually into one room. However, the ongoing fundamental transformation in this area makes it very difficult to predict the roadmap of this vertical.

On the technical side, the requirements of e-health regarding the network are very diverse, reaching from latencies <5ms (telesurgery) to no latency requirement at all (data collection). Data rate requirements are quite relaxed in this domain (below 100 Mbps). The high reliability needed in the domain (>99.999%) will be very challenging though, especially regarding high mobility use cases (e.g., helicopter rescues).

Most frequently cited issues in e-Health that must be resolved are:

- greater emphasis on interoperability
- increased coordination over e-health standardisation
- ensuring privacy
- security and safety
- how to leverage on the fast evolving ICT
- governance.

2.5.4. Energy

Efficient, reliable energy transmission and distribution are the foundations of secure energy supply. The increasing usage of renewable energy leads to distributed energy suppliers, which generate energy unsteadily and may inject the generated energy into the power grid at all of its layers. Decentralized power generation and improved grid stability are major drivers in the energy sector.

E.g., an out-of-phase injection results in “reactive power”, which cannot be used. Energy supply and demand need to be balanced in order to avoid voltage fluctuations. Today’s power grid cannot ensure a stable and thus reliable power supply when many decentralized energy suppliers inject power into the grid in an uncontrolled way. To distribute generated energy, avoid over-capacities and ensure the stability of power supply, smart grids – “intelligent” power grids – are being developed.

Essentially, a smart grid consists of two components: the power grid, including the generators and consumers; and an accompanying control grid. The smart grid knows the status of power generators, transmission lines and waypoints, as well as the current consumption and tariffs. Based on information on the status of the power grid, intelligent monitors can optimize consumers' power supply and so reduce associated costs. Washing machines and car chargers, for example, will only be activated when favorable pricing is on offer. To stabilize the smart grid, decentralized suppliers will be dynamic, activated and deactivated as required, with synchronous co-phasing of decentralized power suppliers also used to improve stability by power-factor correction.

The major benefits in the smart energy sector from 5G technologies will be:

- Making green/renewable energy useable by providing the technological framework. I.e., **managing smart grids that incorporate decentralized energy production**.
- **Exploiting the IoT and intelligent connectivity for smart grid applications.**
- **Cyber-security and safety:** Securing the smart grid against attacks is seen as a major challenge.

Although both, the benefits of smart grids and their challenges, seem to be valid on both sides of the Atlantic, the chance for collaboration in this area seems to be low. The American and European energy grid have too little in common to jointly commit on research projects in this area. We refer to the CPS/IoT section of this report for further details.

2.6. Analysis

This section summarizes some major conclusions from the assessment of the drivers and needs, research and innovation priorities as well as application areas in the EU and the US that were presented above.

1. There is a significant overlap between R&I priorities on 5G Key Technologies between the EU and the US

In general, there is a common global understanding on the 5G roadmap towards 2022. The following figure illustrates the seven key enabling technologies for 5G:

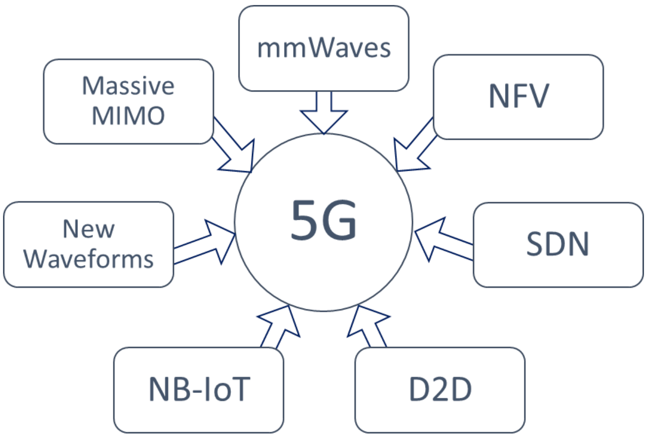

Figure 1: 5G Key Enabling Technologies.

The parts of the world most involved are EU, US, Korea, China, and Japan. Within these regions, a lot of research is conducted in the areas of mmWave communications, massive MIMO, new Waveforms, Narrowband IoT, D2D, SDN, and NFV. Depending on the region, the priority of research is shifted. For instance, in the US, the focus lies on mmWave and massive MIMO, whereas in Europe a more overarching approach on 5G system architecture considering vertical industries' requirements is pursued.

Either way, the research quality is outstanding in both regions, strengthening their competitiveness in 5G. Regarding mmWave technologies it seems the US is leading in this field. As noted in section 2.4, US-based network operators focus in their recent testbed and field trail activities on demonstrating ultra-high data rates in mmWave spectrum, using massive MIMO and carrier aggregation technologies mainly for video streaming and VR applications. However, these operators team up in their trails with globally operating EU- based system vendors, like Nokia and Ericsson; hence it is hard to distinguish, from which side of the Atlantic these innovations originating. Nevertheless, it's raising the awareness to the public and to regulatory bodies, like FCC to make more spectrum available for mobile communications services.

W.r.t. Device-to-Device (D2D) – Communication Europe seems to be more advanced than US. Since D2D is a key enabling technology for automotive applications, Europe started to engage their technological investigations with car manufactures early on. One example is the H2020 project METIS (2012-2015), where BMW as well as several EU-bases system vendors and operators were involved.

Both governments, in the EU and the US, count on public private partnerships (PPPs) to accomplish their respective goals and to drive 5G to market. The EU has started its 5G-PPP initiative in 2013, the US followed three years later[12].

Harmonization of industry standards is a key towards compatibility, economies of scale and investment protection of 5G. To achieve these goals, an international effort for global standardization is inevitable. The 3rd Generation Partnership Project (3GPP), which is the leading collaborating force in the standardization process of mobile communications is focusing on enhancing the current standards towards the 5G era. 3GPP releases 14 and 15, which are being developed and expected to be finalized by 2020, are promising to provide key requirements of 5G systems. Release 15 is also expected to be submitted to ITU as the first 5G standard. Main contributors in 3GPP are major global industry players like Nokia, Ericsson, Intel, and Qualcomm, which have research centers on both sides of the Atlantic.

Although bilateral research collaborations between EU & US partners have been already established in the last years, e.g. National Instruments' RF and Communications Lead User program[13]. The effort to form more such bonds must increase in order to facilitate the precompetitive exchange of information and to keep the leading position of 5G research worldwide.

2. 5G is regarded as key enabling technology for many vertical sectors in both EU and US, and is being verified in trails and testbeds

All of the analyzed application sectors will profit from 5G advances and collaborations. For these sectors, which focus on the *application* of 5G technology rather than its development (asking the question "How can we use 5G?" instead of "How can we make 5G happen?"), it was identified that a lot of effort is put in the construction and development of 5G testbeds, as seen in both, the EU and US. The number of testbed announcements has increased vastly over the last couple of months. There is a good distribution of the research topics and the overlap is minimal. These testbeds shall ensure that 5G technologies implemented for innovative use cases will be able to meet the objectives of vertical industries, e.g., automotive and industry automation.

3. Potential research areas have been identified for EU-US collaboration for niche markets with high societal impacts

PICASSO 5G Expert Group Members analysed 5G carefully, discussed technological challenges as well as business opportunities, and hence identified themes as potential research areas for EU-US collaboration: technologies that have niche market shares yet have strong societal impact. By strategically combining R&I capabilities on both sides, commercially viable and profitable solutions can be developed with reasonable cost on each side. The developed solutions will benefit niche markets inside the EU and US as well as similar markets in the rest of world, eventually enhancing equality of society and quality of life.

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[12] https://nsf.gov/cise/advancedwireless/

[13] http://www.ni.com/newsroom/release/national-instruments-lead-user-program-paving-the-way-for-5g-wireless/en/

4. Spectrum Harmonization

The reason why WiFi has become such a success throughout the entire planet is the prevalence of a global ISM Band (**I**ndustrial, **S**cientific, **M**edical) at 2.4-2.5 GHz. WiFi is a prime example for how global standardization together with harmonised spectrum use can enable a rapid spread of wireless technology globally.

With licensed spectrum, this is not yet the case. In 4G it is still common to buy a phone for certain geographic regions only. LTE spectrum in the US is handled differently from European spectrum, which are both different from Asian spectrum[14]; or (even worse) to buy a phone for a certain provider only, because, e.g., in the US, AT&T, Sprint and Verizon do not support common frequency bands. In this context, it would be highly advantageous to harmonize cellular frequency bands worldwide. In the context of 5G network, the use of frequency bands above 6 GHz will provide such opportunities for global harmonisations. This is also the reason that the World Radiocommunication Conference (WRC) 2019 has been considered as of strategic importance among policy makers around world.

In theory, close collaboration between US regulators, e.g., FCC, and EU regulators, e.g., European Conference of Postal and Telecommunications (CEPT), would greatly benefit the progress of global spectrum harmonisations, eventually benefiting billions of end-users all over the world. However, European and US policy makers generally practice different approaches on spectrum policies due to different ecosystems and industry structures on the EU and US sides. Most likely, FCC and CEPT will support different high band candidates for global harmonisation in the WRC 2019. Therefore, it will be challenging for EU and US policy makers to directly collaborate on spectrum harmonisation at the moment. However, this doesn't rule out possibilities to collaborate on technologies and approaches that enable different spectrum access schemes, bringing benefits to industries and users at the both sides.

[14] A good overview is shown here https://en.wikipedia.org/wiki/LTE_frequency_bands

3. Technology Themes for EU-US Collaboration

Based on the analysis in Section 2, the PICASSO 5G Expert Group has identified seven R&I topics that the EU and the US can collaborate on.

1. Connecting the Last Billion – ultra large cell with local D2D capabilities
2. mmWave technology at carrier frequencies beyond 100 GHz
3. Narrowband IoT devices for goods tracking in global supply chain management
4. Ultra-wide band RF IC at mmWave frequency
5. V2X for regional niche markets
6. Satellite communications for broadband access in oceans
7. Spectrum farming

All of these R&I themes - identified within the PICASSO 5G Expert Group - lead to significant advancements beyond state of the art technologies and will drive innovation in the wireless communications sector as well as enable new application areas in vertical industries, like media, agriculture, mining, industry automation and logistics. Those technologies have niche market and yet will produce strong societal impact once deployed. The high relevance of these themes on both sides of the Atlantic makes them promising candidates for future EU-US collaborations.

This section presents draft summaries of these themes. They will be further discussed, adapted, refined, and promoted during the remainder of the PICASSO project.

3.1. Connecting the Last Billion – Ultra Large Cell with Local D2D Capabilities

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- System concept and network design for extended range
- Signal processing for long transmission delays
- Interaction mechanisms between Device-to-Device (D2D) and Device-to-Infrastructure Communication
- Digital dividend for supporting rural areas

Why EU-US Collaboration?

System vendors like Ericsson and Nokia have great expertise in mobile network design and may use this to enhance the capabilities of their solutions. Internet pioneers like Facebook and Google have a strong interest to serve the remaining 2 billion people, which do not have any internet connection today, with their services. In Northern Scandinavia as well as in the mid-west of the US are sparsely populated areas, which can be served with this technology and once the technology is proven and mature it can be exported to emerging and developing markets in South America and Africa, respectively.

Relevance to Application Sectors

In general, this system architecture enhancement will be capable to serve all kinds in mobile internet applications. The introduction of the mobile internet in the target areas will improve education, create new businesses and jobs, and improve trading connections. The local D2D – capabilities will enable highly sophisticated applications, like precision farming and surface mining, pipeline construction and monitoring, where special requirements w.r.t. latency and reliability needs to be met.

3.2. mmWave Technology at Carrier Frequencies beyond 100 GHz

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Channel Modeling and characterization for carrier frequencies beyond 100 GHz
- System concept design for low-cost, low-power and high throughput for a reasonable range
- Design and proof-of concept of key technological building blocks, like analog frontends, power amplifiers and antennas

Why EU-US Collaboration?

As stated in Section 2.2, both EU and US researchers already have an excellent scientific position in the mmWave domain. EU-and US based companies have a successful, and well proven track record in this area and recently presented impressive multi-Gbps demonstrations at 28 and 60 GHz carrier frequencies.

It has been envisioned at the both EU and US sides that, to cope with exponentially increase data rate increase in the future, the trend of pushing carry frequency towards higher and higher frequency will continue. In order to exploit the full spectrum potential beyond 100 GHz joined forces are needed to push the envelope towards 1 Tbps. It requires a large amount of investment. Joint EU-US research will help reduced cost and bring strengthen their position in global competition.

An important aspect of this topic is spectrum regulation for these frequency bands. As of today, these frequency bands are not allocated to wireless communications. A joint approach toward achieving technological breakthroughs will be a key to unlock the commercial potentials at the carrier frequencies beyond 100 GHz.

Relevance to Application Sectors

The need for this novel mmWave technology is especially imperative in media applications requiring ultra-high data rates in public gatherings where the data rate must be shared among a large number of users e.g., in congress centers, shopping centers and stadiums. mmWave technology provides for people wishing to share the video in crowd scenarios, the video content can now also be recorded in 4K UHD quality even by a smart phone. It is expected that these UHD streaming services will raise the load on cellular networks by 2025. Augmented reality and free-viewpoint video in stadiums are examples for further applications in the media domain.

In future smart offices, it is expected that a large number of different wireless devices, ranging from computers to laptops to smart phones or tablets, will be connected with each other and with the Internet. In this scenario, mm-Wave communications can provide a huge increase of data rates. Regarding smart factory, advancements in communications are enabling new levels of factory automation for greater efficiency, flexibility, quality and safety, as well as improved maintenance, energy savings and lower production cost. Equipment manufacturers will introduce or add more sophisticated electronics in order to enhance assembly, chemical processes and other stages of manufacturing.

Furthermore, wireless fronthaul and backhaul connections for ultra-dense network deployments will have a need for such high capacity.

3.3. Narrowband IoT Devices for Goods Tracking in Global Supply Chain Management

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Ultra-Low Power Technologies, enabling 10 yrs battery lifetime
- Signal processing algorithms, e.g. narrow-band modulation, rate-less coding
- Asynchronous UE-driven mobile network access schemes
- Network slicing

Why EU-US Collaboration?

Both, EU and US have strong economic interest in sustaining leadership in the Internet of Things domain. The use cases of goods tracking in our global supply chain have a great economic value. Form a technological perspective it is favourable that leading US-based UE device producers collaborate with innovative EU- based system vendors to provide solutions for this challenge, drive the global standardization process, and hence, support the digitization of industry and trade.

Relevance to Application Sectors

The authenticity of high-quality products in B2B and B2C markets have an immense value in global trading. In other words, counterfeiting or plagiarizing of merchandise causes enormous costs, damages, and economic losses. Tagging high-quality products with Narrowband IoT devices will enable to prove the authenticity of high-quality products during their whole cycle and might support further capabilities like proper usage, handling, maintenance and tracking.

3.4. Ultra-wideband RF IC at mmWave Frequency

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Design commercial viable building blocks, e.g., local oscillator, power amplifiers and antennas
- Design commercial viable integrated solution

Why EU-US Collaboration?

To enable a hyper-connected society in the future, the usage of high frequencies with ultra-high bandwidth will be unavoidable. This is technologically challenging from the perspective of RFIC design due to physical limitations and constraints. It is a research topic and challenge that top scientists and researchers at the both EU and US sides are tackling. It is still a niche market at the moment and will be very beneficial to leverage and combine research resources and expertise at both sides of the Atlantic for a major technology breakthrough.

Relevance to Application Sectors

In fact, the technology theme “Ultra-wideband RF IC at mmWave Frequency” overlaps with the technology theme mentioned in the Subsection 3.2 “mmWave Technology at Carrier Frequencies beyond 100 GHz”. It is generally relevant to all the application sectors mentioned in Subsection 3.2 as well.

The reason for listing “Ultra-wideband RF IC at mmWave Frequency” as a separate technology theme is due to its significant technological challenge that scientists and researchers at the both EU and US could work together on.

3.5. V2X for Regional Niche Markets

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- V2X chip and software design for vehicles built in the US and sold in the EU
- V2X chip and software design for vehicles built in the EU and sold in the US

Why EU-US Collaboration?

In general, the automotive manufacture industry is highly regulated. This will be certainly reflected in the development of V2X systems. Considering the fact that the automotive industry operates at a global scale and many vehicles are built in the US and sold in the EU (or vice versa), it would be cost efficient for the EU and US industry to collaborate on the corresponding V2X system design.

Relevance to Application Sectors

Developing cost efficient V2X solutions for regional niche markets will help automotive manufacturers delivering regulation conformed V2X systems for their export products at reasonable prices. This will eventually benefit the automotive industry and customers in the both EU and US.

3.6. Satellite Communications for Bringing Broadband Access to Oceans

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Satellite communications system design for access to remote areas in the oceans
- Satellite positioning for improved precision
- Harmonised satellite communications regulations for cross-continent services

Why EU-US Collaboration?

To provide seamless connections everywhere, the EU and US have to work together on providing high data rate service for cross-continental areas over oceans, e.g., Atlantic and Arctic oceans. Communications via satellite is seen as the most sensible solution in this context. This is again a technologically challenging theme associated with high cost. Close EU and US collaboration on both technology development and policies will be essential.

Relevance to Application Sectors

It will help improve safety and reduce risks of different operations carried out in oceans. By providing broadband access to the Atlantic and Arctic oceans, many value-added services can be developed to enhance productivity and efficiency of different industries, e.g., fishing, oil and cargo. In addition, it will offer valuable tools and high rate data connection for scientific use in the ocean science research that is key for a sustainable future.

3.7. Spectrum Farming

Research and Innovation Topics

Potential topics in this area for EU-US collaboration are:

- Spectrum farming framework including spectrum access mechanisms and spectrum sharing approaches
- Link the spectrum farming framework to spectrum policy for effective 5G deployment, supporting different use/business cases, e.g., broadband, IoT and verticals.

Why EU-US Collaboration?

Radio spectrum is a scarce resource. It needs to be handled efficiently to provide a good quality of service to users. In the context of 5G networks, the spectrum will be used to serve versatile use cases as well as several vertical industries that don't belong to traditional mobile network operators (MNO)s. It requires the development of innovative spectrum access mechanisms, approaches as well as associated business models. These are challenges and new open issues that are needed to be addressed on both the EU and US sides. Even thought it might be the case that EU and US sides will choose different approaches, both sides could benefit from collaboration on enabling technologies and mapping research requirements to policy domains, helping smooth roll-out of 5G or beyond 5G in different use and business cases.

Relevance to Application Sectors

Frequency farming will provide a new paradigm for wireless access in the age of 5G and beyond 5G where different use cases and verticals other than broadband access are considered. Such a framework will improve efficiency of spectrum usage on the one hand and enable new business models on the other hand.

4. Opportunities and Barriers for EU-US Collaboration in Technology Sectors

This chapter gives a brief overview of the EU-US funding and collaboration environments in section 4.1 and summarizes barriers that may hamper EU-US collaboration in section 4.2 in all the 3 technical areas of the PICASSO project, i.e., IOT/CPS, big data and 5G. The analyses given in sections 4.1 and 4.2 were led by the IoT/CPS Expert Group with inputs from the Big Data and 5G Expert Groups. In the Section 4.3, 5G Expert Group provides recommendations of concrete collaboration opportunities in 5G that were identified as the most promising mechanisms for technological collaborations on the R&I themes presented in chapter 3.

Additional sources include inputs and pointers from numerous external experts from EU and US funding agencies, industry associations, and academia that were interviewed by the IoT/CPS Expert Group, the analyses presented in section 2, the PICASSO reports (2) and (1), materials and feedback by the EU projects *DISCOVERY* (12), *BILAT USA 2.0*, *BILAT USA 4.0, CPS Summit*, and *TAMS4CPS*, and the interactive PICASSO IoT/CPS webinar that was held on February 2, 2017.

4.1. The EU-US Funding and Collaboration Environment

4.1.1. EU and US Funding

The US R&I funding landscape is structurally very different to the EU landscape. EU-level funding is mostly centralized and is realized via major funding programmes such as *H2020*, the *ECSEL Joint Undertaking*, and *ERA-NET* (which focuses on pooling and coordinating funding of EU member states for EU joint calls) that provide EU-wide frameworks for R&I funding activities, covering all levels from fundamental over translational and applications-oriented research to knowledge transfer, innovation, and commercial deployment. In the US, the funding landscape is much more fragmented. Research and innovation is mostly funded by federal research programs that are set up by different federal agencies and that reflect directly the government's priorities and interests (3). In general, most federal agencies only fund pre-commercial research and experimentation and don't fund industry. Research funding is also available at the state level, but state funding normally focuses on specific local needs and is not usable for international collaboration.

Applications-oriented R&I funding is often provided directly by companies or industry-led associations to partnering research institutions in the form of grants, with a focus on short-term returns. Initiatives such as *H2020* or dedicated programs by US agencies usually focus on funding relatively large R&I projects, for which it usually takes months between the funding application and the start of work. On the other hand, direct funding by industry often focuses on a smaller scope and a relatively quick (e.g. within a few weeks) start of work after initial funding talks.

A major contact point in the federal US funding landscape in the areas of IT, computing, networking, and software is the *Networking and Information Technology Research and Development* (*NITRD*) Program, a multi-agency program that coordinates the funding of all federal agencies in this area. It has specific contact points that coordinate research across all agencies, such as CPS research and wireless communications incl. 5G.

The *National Science Foundation* (*NSF*) exclusively funds basic research and has a major CPS research program with more than 350 funded projects, plus funding for IoT research. The NSF has explored collaborations with the EU in the past, most successfully in the areas of environmental health and safety technology. In addition, there are several bilateral cooperation agreements with EU member states, such as the US-German IoT/CPS program, and interview partners have indicated significant interest in future programs for EU-US collaboration in the areas of IoT and CPS. The NSF will not cover EU costs, but it may cover costs for EU researchers visiting the US and vice versa. The NSF has already shown interest on collaborations on low-TRL research and is a good fit because it has a major initiative in CPS, in which energy aspects are of particular interest.

The NSF is a leader in supporting Big Data research efforts as well. These efforts are part of a larger portfolio of Data Science activities. NSF initiatives in Big Data and Data Science encompass research, cyber-infrastructure, education and training, and community building. In addition to funding the Big Data solicitation, and keeping with its focus on basic research, NSF is implementing a comprehensive, long-term strategy that includes new methods to derive knowledge from data; infrastructure to manage, curate, and serve data to communities; and new approaches to education and workforce development. “Big Data” is a new joint solicitation supported by the National Science Foundation (NSF) and the National Institutes of Health (NIH) that will advance the core scientific and technological means of managing, analysing, visualizing, and extracting useful information from large and diverse data sets. This will accelerate scientific discovery and lead to new fields of inquiry that would otherwise not be possible. NIH is particularly interested in imaging, molecular, cellular, electrophysiological, chemical, behavioural, epidemiological, clinical, and other data sets related to health and disease.

In the 5G area, the NSF coordinated the $400 million Advanced Wireless Research Initiative launched in 2016. As a first step, a Project Office for establishing the *Platforms for Advanced Wireless Research* (*PAWR*) has been created. The NSF has explored collaborations with the EU in the past, most successfully in the areas of health and safety technology. In addition, there are several bilateral cooperation agreements with EU member states, e.g. with Finland and Ireland. Potential collaboration mechanisms involving the NSF are e.g. joint workshops and mirrored calls.

The *National Institute of Standards and Technology* (*NIST*) is an important, more applications-oriented player in ICT funding (with a focus on supporting their own labs, not academia in general) and is active in a variety of technological areas and application sectors. In particular, it has a *Cyber Physical Systems Program* and a *CPS Public Working Group* that is currently developing a CPS framework (13), and its wireless networks division has a *5G & Beyond Program* and coordinates the *5G Millimeter Wave Channel Model Alliance* as well as working group developing the *Future Generation Communications R&D Roadmap*. NIST has already shown significant interest in the PICASSO work.

The parent organization of NIST, the *Department of Commerce* (*DoC*), also promotes other activities in the IoT/CPS domain. In 2016, the DoC has set as a policy priority to engage with the EU Digital Single Market initiative in the area of the free and open internet, and it also promotes activities in the telecommunications domain. The *National Telecommunications and Information Administration* (*NTIA*) of the DoC focuses on expanding broadband internet access and expanding the efficient use of spectrum, and it has recently published a “green paper” that reviews the current technological and policy landscape for the IoT and that highlights potential benefits and challenges, and possible roles for the federal government in fostering the advancement of IoT technologies in partnership with the private sector (14). In this paper, the NTIA promotes a globally connected, open, and interoperable IoT environment and recommends governmental support for US industry initiatives, greater collaboration between (private) standards organizations, the crafting of balanced policy and building coalitions, the enabling of infrastructure availability and access, and the promotion of technological advancement and market encouragement. The NTIA sees the role of government in the promotion of robust interagency coordination, public-private collaboration, and international engagement, while avoiding over-regulation that could stifle IoT innovation. International collaboration is encouraged across a range of activities and topics, including a consistent common policy approach for the IoT, cross-border data flows, privacy, and cyber-security, based on formal dialogues with top international partners on digital economy issues.

Other agencies that are potentially of interest as US partners for PICASSO collaboration mechanisms are the *Department of Energy* (*DoE*) that supports more applications-oriented research and development in areas such as clean energy, environmental cleanup, climate change, and other areas, has a strong track record in collaborations with European universities and research centers, and has shown interest in topics such as grid modernization and integrating renewables, the *Department of State* (*DoS*), the *Department of Homeland Security* (*DHS*), *Department of Defense* (*DoD*) agencies such as *DARPA*, the *Air Force Office of Scientific Research*, the *Army Research Office*, and the *Office of Naval Research*, and US foundations such as *Gordon and Betty Moore Foundation* and the *Blavatnik Family Foundation*. In addition, the *TAMS4CPS* project found that US national labs (such as Sandia) may be suitable contacts regarding funding for collaborations on more applications-oriented research.

The DoD is "placing a big bet on big data" investing approximately $250 million annually (with $60 million available for new research projects) across the military departments in a series of programs that will:

- Harness and utilize massive data in new ways and bring together sensing, perception and decision support to make truly autonomous systems that can maneuver and make decisions on their own.
- Improve situational awareness to help warfighters and analysts and provide increased support to operations. The Department is seeking a 100-fold increase in the ability of analysts to extract information from texts in any language, and a similar increase in the number of objects, activities, and events that an analyst can observe.

The *Defense Information Systems Agency* (*DISA*) offers a cloud-based set of solutions that enables the collection of large amounts of data from across the DoD Information Networks (DODIN) and provides the analytics and visualization tools to make sense of the data. The set of solutions is called *Cyber Situational Awareness Analytical Capabilities* (*CSAAC*) and is available on both *the Nonsecure Internet Protocol Router Network* (*NIPRNet*) and *Secret Internet Protocol Router Network* (*SIPRNet*). By using CSAAC, DoD network analysts and operators have a broader and more comprehensive view of DODIN activity than ever before. CSAAC enables informed decision making and enhances the overall security posture of DoD networks.

According to Deltek Principle Research Analyst Alex Rossino's new calculations, the *Defense Advanced Research Projects Agency*'s (*DARPA*'s) budget requests for big data research and development programs will grow by 39 percent in fiscal year 2016. In the past two years, DARPA's big data investments - which focus on advanced algorithms, analytics and data fusion, among other things - have spiked 69 percent, growing from just under $97 million in FY 2014 to more than $164 million in FY 2016. In addition, in 2012, DARPA initiated the 3-year $100M XDATA program to develop computational techniques and software tools for processing and analyzing massive amounts of mission-oriented information for Defence activities. Furthermore, to encourage future collaboration and innovation across the mathematic, computer science and visualization communities, DARPA open sourced the solutions for the general public.

The DoD and DARPA also support for example a spectrum collaboration challenge, where competitors are reimagining spectrum access strategies and developing new paradigms of collaborative decision-making where radio networks will autonomously collaborate and reason about how to share radio spectrum.

The *Department of Energy* will provide $25 million in funding to establish the *Scalable Data Management, Analysis and Visualization* (*SDAV*) Institute. Led by the Energy Department's Lawrence Berkeley National Laboratory, the SDAV Institute will bring together the expertise of six national laboratories and seven universities to develop new tools to help scientists manage and visualize data on the Department's supercomputers, which will further streamline the processes that lead to discoveries made by scientists using the Department's research facilities. The need for these new tools has grown as the simulations running on the Department's supercomputers have increased in size and complexity. Moreover, the DoE, with the support of partners and allies, has created the SEED Platform Collaborative to help put big data to work on one of the biggest problems in the global effort against the negative effects of climate change - the waste of energy in big buildings. The new *Standard Energy Efficiency Data* (*SEED*) Platform Collaborative creates a remarkable three-year partnership with regional and local governments to help them collect and manage data that tracks energy use in buildings, set aggressive goals for energy efficiency in them, and transform cities and regions into energy-saving leaders.

Other governmental agencies that support Big Data R&I are the *National Institutes of Health* (*NIH*) and the *US Geological Survey* (*USGS*). The NIH has announces that the world's largest set of data on human genetic variation – produced by the international 1000 Genomes Project – is now freely available on the *Amazon Web Services* (*AWS*) cloud. At 200 terabytes – the equivalent of 16 million file cabinets filled with text, or more than 30,000 standard DVDs – the current 1000 Genomes Project data set is a prime example of big data, where data sets become so massive that few researchers have the computing power to make best use of them. AWS is storing the 1000 Genomes Project as a publically available data set for free and researchers only will pay for the computing services that they use. The USGS has financed, through its John Wesley Powell Center for Analysis and Synthesis, a number of projects on Big Data in order to improve its understanding of issues such as species response to climate change, earthquake recurrence rates, and the next generation of ecological indicators. Funding was providing scientists a place and time for in-depth analysis, state-of-the-art computing capabilities, and collaborative tools invaluable for making sense of huge data sets.

Non-governmental actors play a major role in translational and application-oriented R&I, collaboration, and funding in the US and the EU, and are the main drivers in for applications-oriented ICT advancement. Non-governmental actors include multi-national companies (which have an inherently international point of view and are particularly dominant in the IoT sector), and industry-led associations and standardization bodies such as the *Industrial Internet Consortium* (*IIC*), the *International Council on Systems Engineering* (*INCOSE*), the *Smart Manufacturing Leadership Coalition* (*SMLC*), the *Object Management Group* (*OMG*), the *National Coalition for Advanced Manufacturing* (*NACFAM*), the *Conference of European Directors of Roads* (*CEDR*), and others. Our discussions with representatives from industry-led associations have shown that companies and associations are promising potential partners for future EU-US collaborations, also because they are less affected by governmental policy than federal agencies.

4.1.2. EU-US Collaboration

To our knowledge, no specific calls are currently published for foreigners' participation within H2020 (3). According to research conducted by the *BILAT USA 2.0* project, "nearly one-quarter of individual organisations' policy measures provide funds to other countries as long as the leading organisation is a U.S.-based university or other research institution. About 40% of the measures do not provide funding to non-U.S. institutions. The remaining 40% have specific pre-requisites for allowing receipt of U.S. funds by third countries".

In a recent study, the *DISCOVERY* project (12) analysed the participation rate of US partners in H2020 projects and found that out of 52 running H2020 projects with US participation (with starting dates before June 2016), only three projects focus on IoT topics, and none on CPS topics, while the majority of projects are in the scope of personal healthcare (due to an existing bilateral agreement on health R&I between the EU and the US). Two of the three IoT projects are within the scope of the *Future Internet Research & Experimentation* (*FIRE*) European initiative, which previously participated in a successful EU-US collaboration with its US counterpart, the NSF-funded *Global Environment for Networking Innovations* (*GENI*) program. The collaboration focused on the organization of joint thematic workshops and the exchange of personnel between the EU and the US.

On the EU side, there are several examples where specific programmes opened project participation, and even funding in some cases, to US partners. The *Conference of European Directors of Roads* (*CEDR*), a consortium of public national road authorities or equivalents of European countries that focuses on applications-oriented research on road transportation topics, opened a recent call for projects to US participants[15], including the possibility of receiving funding from *CEDR*. The goal of this collaboration effort was to gain access to leading research experience from the US. The ERA-NET instrument that supports public-public partnerships for joint, transnational activities between EU member states (possibly with EU-level funding contributions) recently organized a workshop with the goal of making US and Brazilian funding agencies aware of the ERA-NET work

[15] http://www.cedr.eu/download/other_public_files/research_programme/call_2016/CEDR-Call-2016-Information-Dec-2016.pdf

and to discuss collaboration opportunities[16]. Follow-up activities are planned. In addition, selected ERA-NET programmes complement EU member state funding with external initiatives, including US-based funding. An example is *the Infrastructure Innovation Programme* (*Infravation*) for road infrastructure innovation[17].

Many multi-national companies (which by definition have subsidiaries in different countries that often collaborate) and industry-led associations have a strong track record of international collaboration and are open to participating in EU-US collaboration efforts. As an example, the *Industrial Internet Consortium* (*IIC*) is a global initiative that promotes the growth of the industrial IoT by bringing together partners from around the world, coordinating ecosystem initiatives, and bridging between regional initiatives (such as *Industrie 4.0* in Germany). Particular focus is currently placed on the 27 joint testbed initiatives[18], involving partners from many different countries. These joint testbeds provide realistic industrial environments for joint pre-competitive R&I projects so that new technologies, applications, products, services, and processes from different partners can be initiated, developed, and tested. As an example, the first of these testbeds, *Track&Trace*, was established appr. 2 years ago, is located in Germany, involves partners from the EU, the US, and India, and focuses on the development and testing of future smart, hand-held tools in manufacturing, maintenance, and industrial environments.

While collaboration initiatives between governmental agencies (such as the NSF and the EC) involve only few large organizations and are usually coordinated and set up internally, establishing collaborations between many different actors (such as government agencies on one side and industry-led associations, or even single large enterprises and SMEs on the other side) may require significant coordination and support activities. An example of a non-profit organization that specializes on this kind of match-making is the *Intelligent Manufacturing Systems* (*IMS*) Global Research and Business Innovation Program[19], which is partly funded by the EC. The program aims to integrate and connect US manufacturing industries and associations with EC programmes (where EC-foreign partners must provide their own funding). They focus on two services, direct matchmaking to set up R&I projects with partners from the member states, and thematic project clustering programmes for existing projects that provide collaboration support, such as the organization of workshops for international exchange.

4.2. Barriers

This section summarizes major barriers that must be overcome to implement successful EU-US collaborations. Most of these barriers have been identified in discussions within the IoT/CPS Expert Group and personal interviews done by the IoT/CPS Expert Group with external experts. Additions were provided by the Big Data and 5G Expert Groups.

4.2.1. Structural Differences in Funding Environments

As described in section 4.1, the US R&I funding landscape is structurally very different to the EU landscape along several dimensions.

First, EU-level funding builds on centralized framework programmes that do not have a counterpart in the fragmented US landscape. There are no overarching US or EU programmes currently that focus on closing the gap between centralized EU and decentralized US funding, although programs such as *Intelligent Manufacturing Systems* (*IMS*, see previous section) provide bridging services for specific sectors. It seems

[16] https://www.b2match.eu/jpisgoglobal2016

[17] http://www.infravation.net

[18] http://www.iiconsortium.org/test-beds.htm

[19] http://www.ims.org

unlikely that such overarching programmes are viable due to differences in policy and due to the large administrative overhead that comes with the coordination of many different agencies and companies.

Second, different US funding agencies target specific technology readiness levels. The NSF focuses solely on basic research while other agencies (such as NIST, the DoE, national labs) focus on more applications-oriented translational research, and companies directly fund applications-oriented R&I. On the other hand, EU projects usually target several levels at the same time, and a single project may include basic research work, applications to realistic use cases, and even commercial deployment of novel technologies. Thus, high-level collaboration mechanisms, such as joint funding programmes or calls, are difficult to set up in a way that takes these differences into account. However, lower-level mechanisms that e.g. focus on the integration of US companies or industry-led associations for specific tasks within an EU project will be easier to accomplish.

Finally, there may be differences in the time spans between the application and the start of funding. EU projects are complex constructs that involve large consortia of partners from both, academia and industry, and it usually takes several months from the submission of an application to the start of funding. On the other hand, companies often have very specific R&I needs that can be achieved with relatively small effort, and they require a short-term return and a quick start of funding (e.g. within a few weeks) after application. However, EU projects are interesting for US companies for longer-term, more visionary R&I despite these timing differences, because these projects often run for several years, which provides planning security.

4.2.2. Administrative Overhead and Legal Barriers

International collaboration efforts always incur an administrative and bureaucratic overhead that can be a major barrier, as determined by the IoT/CPS expert group. There are many different potential mechanisms for EU-US collaboration, several of which have been successfully implemented before. The EU project *TAMS4CPS* has published proposals for such mechanisms (15), which can be separated into three different groups.

High-level, *top-down*, *heavyweight mechanisms* provide comprehensive frameworks for international collaboration. These include e.g. the **high-level multilateral agreements** between different countries (such as the 2016 Implementing Arrangement that was recently signed between the EU and the US[20]), large **thematic, targeted funding programmes** (such as the joint EC-NIH programme that supports EU-US collaboration in the health sector), and **joint calls** for R&I projects that pool funding all involved countries. High-level mechanisms usually require strong political support, and it often takes many years (estimated in interviews until 2020 when starting now) and a very large amount of work of all involved partners to set up such mechanisms.

Lower-level, *bottom-up*, *lightweight* mechanisms focus on specific collaboration aspects with smaller, targeted actions that can be set up relatively easily and quickly, and that occur a much smaller overhead than top-down programmes. These range from the **organization of joint workshops, conferences, and series of seminars** over support for the **mobility of researchers, staff exchange, fellowships to students, and training and education** and the trans-Atlantic provision of **access to research infrastructure, testbeds, and demonstrators** to (at the upper end in terms of complexity) relatively loose connections between calls for R&I projects, such as **coordinated calls** (for which both sides execute calls on a specific thematic topic that are temporally synchronized and that may support the involvement of external partners from both sides of the Atlantic, but where evaluation and funding is organized separately by each side) and **project twinning** (e.g. by implementing lightweight collaboration actions between existing R&I projects and consortia). The EC is currently planning to include coordinated calls and twinning into future work programmes as an instrument of a focused international strategy. It is e.g. planned to launch coordinated calls with Brazil, Japan and South Korea in the future (16).

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[20] http://ec.europa.eu/research/iscp/index.cfm?pg=usa

Finally, *collaboration support mechanisms* do not directly implement collaboration actions but provide support that facilitates the set-up of such actions. These include e.g. the facilitation of US participation in mainstream H2020 projects, the enhancement of framework conditions for trans-Atlantic collaboration, and the promotion of the visibility of EU/US programmes, as e.g. done in the *BILAT USA 4.0*, *PICASSO*, and *DISCOVERY* projects.

Our analysis and the interviews have conclusively shown that heavyweight mechanisms do currently not have a good chance of being successfully implemented in the IoT/CPS sector, particularly in the current political climate and if they require pooling of EU and US funding (see also below)[21]. The major reasons are the large overhead in the face of a lack of clearly visible benefits of such programmes and the fast evolution of the ICT field (and in particular of the IoT) that cannot be suitably reflected over the long time frames that are needed to set up high-level programmes.

Legal requirements are seen as major barriers for EU-US collaboration as well. In fact, many companies, for which the availability of external funding is often not an important requirement in joint R&I projects, see legal requirements as the major barrier for international collaboration. Companies are not interested in signing complex, restrictive legal documents, and initiatives that facilitate collaborations involving companies (such as the *Intelligent Manufacturing Systems* (*IMS*) program) restrict the legal requirements for partners by providing lightweight agreements and MoUs (memoranda of understanding).

It was noted by several interview partners that the need for US partners (in particular companies) to sign H2020 grant and consortium agreements has made it virtually impossible to involve commercial partners in H2020 aspects. However, this requirement has recently been removed under a new "Implementing Arrangement"[22] that was signed in October 2016 by the EU and the US. Under this new agreement, US organizations that do not receive any funding under H2020 are allowed to partake in research efforts and other relevant activities in the scope of EU projects without having to sign grant and consortium agreements, thus providing a new basis for EU-US R&I collaboration.

4.2.3. Lack of Clarity of the Benefits of EU-US Collaboration

The IoT/CPS expert group found that a major barrier to international collaboration is a lack of awareness and clarity about the benefits of EU-US collaboration activities for the participants, and a key requirement is the identification of these benefits and their communication to funding agencies, industry, and academia. This is also valid for the 5G domain. Obviously, the more administrative and bureaucratic overhead a collaboration measure creates, the larger and more convincing the benefits must be. Questions that must be answered include e.g. "Is there a skill gap which can be complemented by collaboration?", "Is there mutual economic benefit?", "What will be missed if there is no collaboration?", or "What are the common interests?" (see section 2).

Generally, collaborations within the research community are easier to justify than academic-commercial or pure commercial collaboration. The research community is inherently global and universal, and often significant advances in key areas are only possible in international collaboration efforts, e.g. by leveraging what EC academia can contribute, and vice versa. Major success stories of successful international collaboration efforts are e.g. CERN and the nuclear fusion reactor ITER. Another major benefit of EU-US research collaboration is that the expansion of the horizons of scientific human capital (e.g. of students, graduates, post-docs) is a prerequisite for successful scientific research.

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[21] Note that bilateral agreements between the US and a single EU member state are easier to implement than multilateral agreements between the US and the EU. Successful programs have e.g. been implemented between the US and Germany, the US and the UK, and the US and Ireland.

[22] http://ec.europa.eu/research/iscp/index.cfm?pg=usa

In particular, the 5G expert group considered it would be beneficial to develop technologies that have niche market shares at the moment yet have strong society impacts. By strategically combining R&I capabilities of both sides, commercially viable and profitable solutions can be developed with reasonable cost on each side. The developed solutions will benefit niche markets inside the EU and US as well as similar markets in the rest of world, eventually enhancing equality of society and quality of life.

The advancement of international standardization and the sharing of infrastructure, testbeds, and demonstrators are other key benefits of EU-US collaboration (where again CERN and ITER are good examples of successful shared infrastructure). Infrastructure and testbeds are expensive to build, thus sharing will benefit both sides, and EU-US collaborations on standardization will set the standard for the rest of the world.

In its recent survey (12), the *DISCOVERY* project asked respondents to identify the benefits that are most important for EU-US ICT collaboration. Gaining competitive advantages by an extended view of future challenges was identified as the most important benefit, followed by creating overseas relationships, sharing and gaining insights into research activities, and gaining international visibility.

4.2.4. Restrictions due to Intellectual Property Protection

Collaboration may be difficult on topics of **high near-term commercial importance**, i.e. innovation efforts that focus on products and services that may lead to large profitable businesses in the near term. Different regions are in competition, and industrial policy focuses on measures that reinforce own industry. This barrier is seen as important in all analysed application sectors, and this is also a conclusion by the *BILAT USA 4.0* project that has found a lack of bilateral funding agreements between the EU and the US in areas with immediate economic outcomes. They state that "one reason for the lack of joint funding agreements may be that there are immediate economic outcomes where the US has a competitive advantage compared to the EU in the areas of technology levels, entrepreneurship, supporting start-ups, and venture capital." (17).

It is thus arguably easier to collaborate on basic research than on applied research. An example is the *FET* (*Future and Emerging Technologies*) EC programme that focuses on basic research. Here, it is much easier to involve US partners (even including trans-Atlantic funding) than in other, more applications-oriented programmes, such as the ECSEL Joint Undertaking. One exception is the joint work on international standards and interoperability. While this is of commercial importance, it usually does not require companies to disclose information and technology that affects stand-out features of their products.

The Big Data expert group found that industrial competition between US and EU has a long tradition: It is widely accepted that EU and US are two competing regions, especially on technologically driven industries. Especially in the area of Big Data, Europe has been slow to adopt compared to the United States. More than half of worldwide revenue from big data is expected to come from the USA, and only one in twenty top big data companies is European (18). Thus, it can be very challenging for funding agencies and organisations from these regions, to collaboratively tackle research of high TRL (Technology Readiness Level) or applied research topics. However, tackling basic research subjects and topics can be an alternative.

The 5G expert group has identified this barrier as important for research topics that are already considered as study or work items in global standardization bodies, like 3GPP and IEEE. Hence, it will be easier to collaborate on fundamental research than on applied research.

4.2.5. Lack of Joint EU-US Funding Mechanisms and Policies

Generally, most of the EU funding will be used to fund EU companies and research institutes, and US funding will focus on the support of US organizations and companies. Thus, EU-US collaboration will always be a complement, or even an exception, to local and regional funding. This is not expected to change in the near future and is one of the reasons why high-level mechanisms such as joint calls or thematic, targeted funding programmes are difficult to implement (see above).

The Big Data expert group has also found that joint funding is a challenging task: As already known, US structures (both private and public) who are based in the US, have limited access to EU funding. US structures are eligible for participation in EU projects, but financial support is only available for calls where this is specified, e.g. International Cooperation calls targeting collaboration with the USA or the “Health” programme in general. Potential US participants are therefore encouraged to contact research and innovation funding organisations in the US to seek support for their participation in Horizon 2020. No jointly agreed mechanism is currently in place for co-funding Horizon 2020 research and innovation projects. On the other side, EU organisations willing to participate in US research programmes, face similar challenges, as it is almost impossible to receive funding from US agencies. Results from the newly signed EU-US agreement (signed in October 2016), which offers new opportunities for research cooperation, remain to be seen.

4.2.6. Export Control and Privacy Restrictions

Topics touching **export control issues**, **sensitive or classified data / information**, or **privacy issues** should be avoided. The EU and US national priorities, rules, and regulations are very different and will be difficult to harmonize, and generally legal and policy differences will be difficult to overcome in these areas. In particular export control issues have been identified in interviews as major blocking factors of international collaborations. Such issues must be dealt with appropriately before starting any collaboration actions.

The Big Data expert group found that data privacy is a complicated issue: The collection and manipulation of Big Data, as its proponents have been saying for several years now, can result in real-world benefits. However, it can also lead to big privacy problems (19). Both the EU and the US, have established a number of laws, policies and directives dictating the use of personal data by organisations and institutions willing to benefit from them. There are many differences between the laws regarding data privacy in the European Union and the United States, with the E.U. generally allowing more rights to the individual. With no single law providing comprehensive treatment to the issue, America takes a more ad-hoc approach to data protection, often relying on a combination of public regulation, private self-regulation, and legislation (20). Even after the US and the EU signed the EU-US Privacy Shield Framework (21), open issues remain, making it very challenging and complicated for organisations coming from these different regions to collaborate on research topics related to personal data. Moreover, the situation in EU is no homogenous across member states; e.g., Directive on Protection of Personal Data needs to be ratified and implemented by the member states, which may lead to inconsistencies.

4.2.7. Lack of Awareness and Knowledge

A lack of awareness and knowledge of EU and US actors of the other side is detrimental to collaboration. E.g., *BILAT USA 4.0* found that interested US actors may be unaware of how EU funding schemes operate (including misconceptions on how US partners can participate in H2020), and are not aware of the R&I priorities of the other side. In addition, it is often straightforward to connect to other initiatives within the US, but the EC landscape is fragmented, and the responsibilities may not be clear to US agencies.

This barrier is confirmed by an investigation of the *DISCOVERY* project (12) that identified as main barriers the lack of information on funding opportunities and programmes, the lack of knowledge about specific research areas and topics that are open to international cooperation, difficulties to understand the rules of participation in other countries, and a lack of partner search tools and methods.

Currently, several EC projects are working on solutions for these issues, including *PICASSO*, *TAMS4CPS*, *DISCOVERY*, and *BILAT USA 4.0.*

4.2.8. Lack of Interoperability and Standards

A **lack of interoperability and (device) standards** can be a barrier to collaboration. This is true for several of the application sectors and, in more detail, in (1). In addition, IoT/CPS systems were noted by our interview contacts as sometimes being highly regulated, which can stifle innovation.

4.3. Collaboration Opportunities in the 5G Domain

This section provides an overview of potential mechanisms for EU-US collaboration that was compiled based on discussions with EG members, interview results, and an analysis of the results of projects that work towards EU-US collaboration development. It is supposed to serve as an inspiration for the definition of concrete collaboration opportunities and mechanisms within PICASSO. Note that this section is at this stage highly speculative, since the success probability of future collaboration mechanisms will depend on the regulatory framework and conditions that will be enacted by the US administration.

There are different mechanisms for EU-US collaboration that can be considered, several of which have been successfully implemented before. The most promising partner for low-TRL research seems to be NSF. In general, NSF will not cover EU costs, but it may cover costs for EU researchers visiting the US or vice versa.

However, two examples for NSF-funded projects with EU member states' participation in the context of 5G have been discovered:

1) NSF and the Academy of Finland support joint US-Finland research projects on novel frameworks, architectures, protocols, methodologies, and tools for the design and analysis of robust and highly dependable wireless communication systems and networks to enable novel Internet of Things applications.

2) NSF supports US - Ireland Research and Development Partnership on spin and valley interactions in intrinsic and magnetic two dimensional transition metal dichalcogenides (2D TMDs) for novel devices. In this project, researchers from the United States, Republic of Ireland (ROI), and Northern Ireland (NI) propose to study fundamental properties, such as phase and spin coherences, inter-valley scattering, and magnetism in intrinsic and magnetically doped 2D TMDs for novel devices.

At the EU level, a joint call of EU-US collaboration on advanced wireless platform was published in the end of 2017. At the EU side, this is a coordination and support action (CSA) H2020 ICT-21-2018 with budget of 2 million euros[23] and application deadline of April 17, 2018. At the US side, with the application deadline on May 7, 2018, the call NSF US-EU Internet Core & Edge Technologies (ICE-T) [24]targets to 3 classes of rewards

- Research Collaboration (RC) for period up to 3 years
- Research Collaboration Initiation (RI) for period up to 1 years
- Research Fellowships (RF) for award period up to 1 year

where approximately 5 RC awards, 5 RI awards, and 10 RF awards with total budget of $ 2.5 million will be given including both Next Generation Internet (NGI) and Advanced Wireless Networking (AWN) areas.

Such a call certainly will open a new door and start a concrete first step for EU-US collaboration on 5G or wireless network. However, based on the analysis of PICASSO 5G expert group, several challenging aspects must be taken into account in the project planning and execution phases:

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[23] http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/ict-21-2018.html

[24] https://nsf.gov/pubs/2018/nsf18535/nsf18535.htm

- The scopes are different: The call at the EU side is clearly a CSA and focuses on testbed twinning and organising workshops while the call at the US side is most likely a research action. Although the testbeds and workshops are also mentioned at the US side, the corresponding interpretation and priorities might be very different at the US side. This implies, during the project execution phase, very likely, the EU side project has to take more administrative and coordination responsibilities than US partners and EU consortium partners have to rely on their own resources to collaborate with US partners.
- The participation structures are different: At the EU side, a consortium consisting of multiple partners from academia and industry is envisioned for carrying out the CSA. At the US side, universities are most likely the major force for the application and each of them will participate as an individual applicant. Considering the fact the call at the EU and the call at the US will be also be evaluated separately, the PICASSO 5G expert group sees the high probability of EU-US partner mismatch for collaboration.
- The twinning mechanism is unclear: From research point of view, the most important element in the call is testbed twinning, especially with PAWR, at the EU side. However, US side may or may not choose winning testbed(s) from e.g., PAWR. The up to $300000 funding for the RC winner is very marginal considering the cost of developing testbed and 3 year funding period. According to feedback gathered over the PICASSO 5G network, many US proposals only focus on research. In this context, most likely, the testbed twinning can be successful only if both EU and US partners have very strong interests and are willing to commit sufficient funding resources from outside the H2020 ICT-21-2018 and NSF ICE-T programs.

As a result, the PICASSO 5G group sees the collaboration based on H2020 ICT-21-2018 and NSF ICE-T programs to be very challenging. We suggest that once the final results are announced, EU and US partners should immediately sit together, clarify all the aspects mentioned above, develop mutual understanding and find a sensible way or structure to move forward. Otherwise, lots of conflicts and misunderstanding might rise during such a collaboration project.

In addition to challenges, the PICASSO 5G group also sees the opportunities of this concrete collaboration program. With proper communication and development strategies, this program will bring researchers at the both side of Atlantic together, improve mutual understanding and work on common goals. With the possibility of carrying out a transatlantic trial in the envisioned program, a successful story on EU-US wireless collaboration will emerge and showcase the benefit of such collaboration on the wireless research, paving the way for future collaboration, e.g., into Frameprogramme 9.

5. Conclusions and Outlook

This report outlines new **technology themes** and **collaboration opportunities and mechanisms** that have been identified as being promising for EU-US collaboration in the 5G sector. The themes and opportunities were synthesized based on a comprehensive analysis of the EU and US research and innovation priorities in the technology sectors and related application domains, the current EU and US policy environment and priorities, the EU-US funding and collaboration landscape, and technological and policy barriers for EU-US collaboration. The contents of this report have been validated and refined extensively, e.g. based on in-depth discussions and online distribution and feedback actions with a large network of international experts, analytical research by the Expert Groups, PICASSO results, and other feedback collection mechanisms such as a public consultation on the PICASSO website.

This opportunity report provides final recommendations of the PICASSO 5G Expert Group on priorities and future cooperation opportunities between the EU and the US. The in-depth analysis carried out in the report and the insight gained during the PICASSO project will serve as knowledge bases to individuals, projects as well as public and private organisations who are interested in the subject and plan to take actions in the future.

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Opportunity Report

"Towards Enhanced EU-US ICT Pre-competitive Collaboration"

Policy

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ICT Policy, Research and Innovation for a Smart Society

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Executive Summary

Policy interacts with R&I, and the three PICASSO policy domains, in two main ways: policies that are intended to advance or support R&I; and R&I activities that lead to new policies or are enabling new ways to achieve policy objectives.

This report outlines specific policy challenges for collaboration between US and EU researchers. We found that there is very fertile ground for collaboration, and it will be important to develop this further to overcome the artificial barriers created by different use of terms (e.g. 5G according to 3GPPP in Europe and "Advanced Wireless" in USA) and to harness the associated productive differences in perspective. The same applies to the 'natural experiment' created by different legislative approaches (e.g. privacy as fundamental right, or as economic right that is tradable) and instantiations of community-related concepts.

We found that the differences between US and European values, approaches and available evidence are relevant and provide an opportunity to jointly develop ICT that may serve the global market and to transfer useful aspects of digital community formation between the US and the EU. ICT is associated with a range of global industry sectors and entities; the many layers in the value chain from the chip to national and global ICT services – and beyond into the application and regulatory layers - require innovation on the fundamental technical level, the level of innovative services and the organizational and business model levels as well.

By grounding policies in a solid understanding of acting in a global market, more opportunities will arise for collaboration amongst EU and US researchers.

The PICASSO Project

The aim of the 30-months PICASSO project is (1) to reinforce EU-US collaboration in ICT research and innovation focusing on the pre-competitive research in key enabling technologies related to societal challenges - 5G Networks, Big Data, Internet of Things and Cyber Physical Systems, and (2) to support the EU-US ICT policy dialogue by contributions related to e.g. privacy, security, internet governance, interoperability, ethics.

PICASSO is oriented to industrial needs, provides a forum for ICT communities and involves 24 EU and US prominent specialists in the three technology-oriented ICT Expert Groups - 5G, Big Data, and IoT/CPS - and an ICT Policy Expert Group, working closely together to identify policy gaps in the technology domains and to take measures to stimulate the policy dialogue in these areas. A synergy between experts in ICT policies and in ICT technologies is a unique feature of PICASSO.

A number of analyses will be accomplished, as well as related publications, that will for a major part be made public and contribute to the project's outreach. Dedicated communication and dissemination material will be prepared that should support the operational work and widespread dissemination though different channels (website, social media, publications …). The outreach campaign will also include 30+ events, success stories, factsheets, info sessions, and webinars.

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List of Acronyms

3GPP	3rd Generation Partnership Program
4G	4^{th} Generation
5G	5^{th} Generation
AI	Artificial Intelligence
AIOTI	Alliance of IoT Innovation
AV	Autonomous Vehicle
AWS	Amazon Web Services
B2B	Business-to-business
B2C	Business-to-customer
BBI	Bio-based Industries
BD	Big Data
BDVA	Big Data Value Association
BDVPPP	Big Data Value Public Private Partnership
CEDR	Conference of European Directors of Roads
CERN	Conseil Européen pour la Recherche Nucléaire
CPS	Cyber-physical System
CPSoS	Cyber-physical System of Systems
CPS-VO	CPS Virtual Organization
CPU	Central Processing Unit
CS	Clean Sky
CSAAC	Cyber Situational Awareness Analytical Capabilities
D2D	Device-to-Device
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DISA	Defense Information Systems Agency
DoC	Department of Commerce
DoD	Department of Defense
DoDIN	DoD Information Networks
DoE	Department of Energy
DoS	Department of State
DoT	Department of Transportation
DSL	Digital Subscriber Line
DSM	Digital Single Market
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
EeB	Energy-efficient Buildings
EG	Expert Group
EPI	European Platform Initiative
ERA	European Research Area
EU	European Union
FBMC	Filter-Bank Multi-Carrier
FCC	Federal Communications Commission
FCH	Fuel Cells and Hydrogen
FET	Future and Emerging Technologies
FIRE	Future Internet Research & Experimentation
FoF	Factories of the Future
FP7	Framework Programme 7

FY	Financial Year
Gbps	Gigabit per second
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GENI	Global Environment for Networking Innovations
GFDM	Generalized Frequency-Division Multiplexing
GHz	Gigahertz
H2020	Horizon 2020
H2M	Human-to-machine
HD	High-definition
HMI	Human Machine Interface
HPC	High Performance Computing
HPUE	High Performance User Equipment
IA	Industry Association
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IERC	IoT European Research Cluster
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IM	Innovative Medicine
IMS	Intelligent Manufacturing Systems
INCOSE	International Council on Systems Engineering
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Rights
ISM	Industrial, Scientific, Medical
ITER	International Thermonuclear Experimental Reactor
ITS	Intelligent Traffic System
ITU	International Telecommunication Union
JTI	Joint Technology Initiative
JU	Joint Undertaking
LTE	Long Term Evolution
M2M	Machine-to-Machine
M&S	Modeling and Simulation
MEC	Mobile Edge Computing
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MoU	Memorandum of Understanding
ms	Millisecond
NACFAM	National Coalition for Advanced Manufacturing
NB-IoT	Narrowband IoT
NCP	National Contact Point
NCURA	National Council of University Research Administrators
NFV	Network Function Virtualization
NGI	Next Generation Internet
NGMN	Next Generation Mobile Networks
NIH	National Institutes of Health
NIPRNet	Nonsecure Internet Protocol Router Network
NISD	Network and Information Security Directive

NIST	National Institute of Standards and Technology
NIT	Networking and Information Technology
NITRD	Networking and Information Technology Research and Development
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
OCF	Open Connectivity Foundation
OFDM	Orthogonal Frequency Division Multiplexing
OMG	Object Management Group
PAWR	Platforms for Advanced Wireless Research
PCAST	President's Council of Advisors on Science and Technology
PPP	Public Private Partnership
PWG	Public Working Group
QoE	Quality of Experience
R&D	Research and Development
R&I	Research and Innovation
RAT	Radio Access Technology
RDI	Research, Development, Innovation
RFC	Request for Comments
SAE	Society of Automotive Engineers
SDAV	Scalable Data Management, Analysis and Visualization
SDN	Software Defined Networking
SEED	Standard Energy Efficiency Data
SIPRNet	Secret Internet Protocol Router Network
SME	Small and Medium-sized Enterprises
SMLC	Smart Manufacturing Leadership Coalition
SoS	System of Systems
SOTA	State of the Art
SPIRE	Sustainable Process Industry
SRA	Strategic Research Agenda
SSG	Senior Steering Group
Tbit	Terabit
Tbps	Terabit per Second
TRL	Technology Readiness Level
TTIP	Transatlantic Trade and Investment Partnership
TV	Television
UE	User Equipment
UHD	Ultra High Definition
URLLC	Ultra-reliable Low-latency Communications
US	United States
USGS	US Geological Survey
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-everything
V5GTF	Verizon 5G Technology Forum
VDA	Verband Der Automobilindustrie
VPN	Virtual Private Network
ZT-OFDM	Zero-tail OFDM

Table of Contents

1. Introduction

This report concentrates on policy collaboration to support further ICT R&I collaboration between EU and US researchers on issues identified to be of common interest, specifically related to 5G networks (for US: Advanced Wireless Communications); Big Data: and Internet of Things (specifically: Cyber Physical Systems). The lessons learned feed back to these specific communities through our respective PICASSO expert groups, and in addition, the insights arising are shared across the Internet Governance communities where multiple stakeholders meet, including government officials, industry, users and researchers. As described in this report, policy interacts with R&I, and the three PICASSO policy domains, in two main ways:

- **Research-based policy** – policy intended to advance or support the conduct and exploitation of research, ranging over direct R&I support modalities, demand-side instruments, complementary regulation and other interventions intended both to accelerate the solution and societal benefits of specific R&I and to strengthen the 'research base' in terms of its effectiveness, economic strength, resilience and integration with other areas; and
- **Policy-based R&I** –R&I activities that target areas of policy relevance, and R&I activities designed to inform policy by helping both to identify and clarify policy issues and by (sometimes) providing (partial) solutions to policy problems.

In both cases, it is necessary to take into account:

- The historical interaction of the EU and the US in these domains;
- The different ways in which R&I (industry & academia) and policy interact;
- The balance of societal, commercial, scientific and technology policy in driving development ("multistakeholder" nature of driving R&I);
- The extent to which the R&I policy nexus in the EU and the US develops along lines parallel to the PICASSO technology domains (5G, IoT/CPS and Big Data), societal domains (Smart Production, Smart Cities, Smart Energy, Smart Transportation) and policy areas (privacy and data protection, security and cyber-security, standardisation, and spectrum); and
- The nature and track record of EU and US engagement with other nations in these areas.

This report does not attempt to analyse, or even summarise complex linkages between policy and R&I that relate to the PICASSO technology areas (5G, IoT/CPS and Big Data) or policy areas (privacy, security, spectrum and standardisation). The work is ongoing, and in most respects, compared to the technologies and their application, policy is changing almost as rapidly (and somewhat less predictably) even if development of legal measures still take as long as they used to. Also, we were not able to provide at this point a fully-parallel discussion of the policy landscape in the EU and the US; this forms the basis of the four policy-specific reports; the first – on privacy and data protection[1] – has been completed and the second – on security – is currently under preparation. Rather, we concentrate on those areas where – based on the work of the project to date - interviews with policy analysts and actors and participants in project webinars were conducted.

The rest of this report is structured as follows: Chapter 2 presents the primary identification of opportunities – these are given in abbreviated form for ease of review and engagement, but will be expanded in a subsequent stand-alone document – in the form of an overview, in tabular form, of policy-driven R&I and R&I-driven policy areas where joint EU-US collaboration might be fruitful. This is followed by a discussion (in sections 2.2 and 2.3) of the history and comparability of ICT-related policies in the EU and the US. Chapter 3 presents a partial picture

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[1] http://www.picasso-project.eu/wp-content/uploads/2016/12/20161130-PICASSO-Policy-Paper-1-Privacy-and-Data-Protection-Final3.pdf

of the R&I priorities and frameworks of greatest policy relevance in the EU (section 3.1) and US (section 3.2). Section 3.3 discusses R&I-related policy from the EU perspective in two areas; (5G in section 3.3.2 and IoT/CPS in section 3.3.3). Potential barriers to collaboration on policy-driven R&I are further discussed in chapter 4, along with ‘external’ R&I-related policy initiatives.

2. Overview

2.1. A Summary of Challenges and Opportunities

The following table summarizes a set of policy-driven R&I and R&I-driven policy areas where joint EU-US collaboration might be fruitful. These will be more fully described after public discussion and consultation at the "Trans-Atlantic Symposium on ICT Technology and Policy" that is organized by PICASSO in June 2017 in Minneapolis[2].

Table 1: Summary of policy collaboration opportunity topics and areas.

<table>
<tr><th>Application domains:</th><th>Policy-driven R&I</th><th>R&I-driven policy</th></tr>
<tr><td colspan="3">General, cross-area</td></tr>
<tr><td colspan="3">Policy areas</td></tr>
<tr><td>Legal definitions</td><td colspan="2">Need to develop common definitions or core vocabulary to be used in specifying policies and regulations.</td></tr>
<tr><td>Removing "stovepipes" and work across sectors and domains</td><td>Research into information-sharing, joint control, etc. for safety, liability</td><td>Consistency of regulation and policy across domains.</td></tr>
<tr><td>cyber-security & privacy</td><td>• Solutions[3] to both concerns e.g. 'enhanced access.'
• Address SOTA (state of the art) paradox: most organisations believe they are compliant with the rules[4] but lack:
  ○ Concept of "state of the art";
  ○ Processes or metrics to measure alignment with SOTA;
  ○ Periodic reviews.</td><td>• Reduce 'false dichotomy' that:
  ○ security and privacy are inevitably opposed; and
  ○ privacy is a global, fundamental concern but security is national.
• EU: Secondary rules under GDPR[5] /NISD[6] may produce effective and equitable policy linkage;
• US fragmented general[7] and sector-specific[8] initiatives may accurately reflect technology and practice, stimulate R&I, business evolution;
• EU and US can learn from each other to find a better synthesis[9] than could be achieved by simply adjusting in isolation.</td></tr>
</table>

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[2] http://www.picasso-project.eu/newsevents/project-events/june-2017-symposium

[3] For different uses and domains or 'up the stack'

[4] In EU, GDPR + NISD.

[5] General Data Protection Regulation, see http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.119.01.0001.01.ENG&toc=OJ:L:2016:119:TOC

[6] Network and Information Security Directive, see http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.194.01.0001.01.ENG&toc=OJ:L:2016:194:TOC

[7] E.g. Securely Protect Yourself Against Cyber Trespass Act (phishing and spyware; 2005; dead); Cyber-security Act (2012; dead); Executive Order Improving Critical Infrastructure Cyber-security (2013; in force, but not ratified); National Strategy to Secure Cyberspace; Cyber Intelligence Sharing and Protection Act (CISPA; contested), etc.

[8] i) Health Insurance Portability and Accountability Act (HIPAA, 1996), ii) Gramm-Leach-Bliley Financial Services Modernization Act (1999); and iii) Homeland Security Act, including the Federal Information Security Management Act (FISMA 2002). ISPs and computer companies are not covered. There are proposed extensions (e.g. the Consumer Data Security and Notification Act which would strengthen GLB to mandate breach disclosure, or proposals to extend GLB to all entities handling consumer financial information (e.g. payment services).

[9] Taking into account both the impact of policy measures on future technology and the scientific, trade and policy links between the EU and the US.

<table>
<tr><th>Application domains:</th><th>Policy-driven R&I</th><th>R&I-driven policy</th></tr>
<tr><td>Roles of public, private and civil society domain entities and interests</td><td colspan="2">Interface between regulation and criminal law on one side and contract and tort law (private harm-based lawsuits[10]) on the other;
Which ‘domain’ has primacy?
Privacy: protection from whom?
IPR: Open vs proprietary
Security: national, critical infrastructure, commercial types of security; security vs. cyber-security.
Joint work to establish a consistent framework for balancing these competing perspectives
Immunity or standing for inter-domain lawsuits</td></tr>
<tr><td>Demonstration at scale and replication of solutions</td><td>Joint demonstrations to build common demand;
Pooled or shared solutions.</td><td>Ease policy harmonisation through unified technical bases;
Replicate, adapt or differentiate solutions, policy frameworks.</td></tr>
<tr><td>Trade and international application aspects of international rules</td><td colspan="2">EU: GPRD and NISD
Both require companies to ‘take into account’ and ‘have regard to’ state of the art for cyber-security;
Neither specifies technologies;
Coverage broader than US but still vague and technologically sensitive;
May lead to over- or mal-investment.
US:
Few direct, no general[11] cyber-security rules;
No specific cyber-security measures[12] (only “reasonable” levels of security);
May lead to under-investment.
Collaboration prospects: where direct economic impacts are viewed as asymmetric, collaboration is considered less attractive (quid pro quo?).</td></tr>
<tr><td>Anonymising data, encryption and processing in encrypted domains</td><td>End-to-end solutions;
Secure ‘enhanced access’ with appropriate joint controls and automated consent;
Solutions to ensure data integrity.</td><td>Rules on international (esp. bulk) access, data analysis, equipment interference, etc.;
Reciprocal access and suitable protections for non-citizens whose data may be compromised.</td></tr>
<tr><td colspan="3">Regulation areas</td></tr>
<tr><td>Data protection</td><td>Data structures;
Data processing controls;
Auditable algorithms;
Extension to complex systems.</td><td>Consistent regulations spanning data and processing;
Regulation of (and by) algorithms.</td></tr>
</table>

[10] Effectively, tort law governs implicit societal responsibilities that people have to one another, as opposed to those responsibilities laid out in contracts or defined in statute law.

[11] Sector-specific rules: Health Insurance Portability and Accountability Act (HIPAA, 1996); Gramm-Leach-Bliley Financial Services Modernization Act (1999); Homeland Security Act, including Federal Information Security Management Act (FISMA 2002). ISPs, computer companies are not covered. Proposed extensions (e.g. Consumer Data Security and Notification Act) would strengthen GLB to mandate breach disclosure, or extend GLB to all entities handling consumer financial information (e.g. payment service providers).

[12] Data Quality Act (2001) *may* let OMB impose CNI protections, but technical aspects remain open.

Application domains:	Policy-driven R&I	R&I-driven policy
Alternatives to regulation	• Self and co-regulation with industry-based international lead; • Structured[13] international standards; • Market-based alternatives (e.g. compliance trading); • Pool regulatory information to improve policy, reduce distorting differences; • Trade linkages (TTIP, Privacy Shield successor(s)); and • Multistakeholder agreements recognising and inciting global good practice[14].	
Cyber-security and privacy	• Specific technical loopholes and provisions in GDPR, etc.; • Technical feasibility of compliance in layered, self-organised, autonomous etc. systems; • Develop privacy and security sensitivity taxonomies for tools, applications and services; • Better ID and security solutions[15].	• Research to clarify provisions, impacts of NISD and its national approximation e.g.: ○ Regtech for Critical National Infrastructure operators[16], designated services[17] and related entities[18]) to report breaches and take other actions; ○ Require "good behaviour" from ICT developers and users[19]
Safety certification of systems	R&I to[20]: • Determine types and limits of safety performance; • Measure and control stochastic behaviour; • Safety taxonomy.	• Regulatory incentive and informational approaches; • Intermediaries, contract menus; • Third-party liabilities.
General regulatory areas transformed by Internet	Regtech solutions: • Compliance reporting; • Automated adherence.	• Consumer protection; • Personal data protection; • Intellectual property law.
Sharing good practice regulations[21]	Develop policy-compliant solutions (both for ICT policy and for sectoral policies that relate to ICT) to attain critical mass and advance SOTA	
Harmonisation of regulations in specific areas		
Smart energy	General recommendation, not much technology specificity except for noting potential for economies of scale all along energy value chain: • Allow stakeholders to make grid investments in EU and US.	

[13] Encourage compliance by wide applicability, foreclose race to bottom; structure may mirror Trade Agreements.

[14] See for instance the Good Practice Policies of the IGF Dynamic Coalition on the Internet of Things at http://www.iot-dynamic-coalition.org/wp-content/wp-content/uploads/sites/3/2016/07/IoT%20Good%20Practice%20Paper%202016.pdf

[15] E.g. replace passwords, develop appropriate encryption and implement differential privacy.

[16] Energy, transport, health and banking.

[17] Online marketplaces, online search engines and cloud computing.

[18] Cloud providers, internet exchanges, online marketplaces.

[19] Based on definition that reflects current and new technologies, application areas and behaviour – an example is banning use of default passwords for IoT consumer devices.

[20] This does not refer to technological R&I per se (discussed elsewhere in this document) but to technological alternatives or complements to policy rules, standards and/or regulations.

[21] E.g. for smart metering and tariffs to manage system load capacity.

<table>
<tr><th>Application domains:</th><th>Policy-driven R&I</th><th>R&I-driven policy</th></tr>
<tr><td>Smart transportation</td><td>A substantial amount of collaborative policy-driven R&I is already going on.</td><td>Adoption of green technologies;
Improved efficiency of electric cars;
Align charging station policies[22];
Regulatory provision[23] for automatic train control systems;
Resolve autonomous vehicle (AV) regulatory issues[24];
Conduct/share AV pilot experiences at global level;
Resolve regulatory issues[25] to allow autonomous aircraft to operate safely in civil airspace.</td></tr>
<tr><td colspan="3">Standardisation</td></tr>
<tr><td>Interoperability standards and harmonisation for ‘smart’ domains (energy, production, transportation, cities, production)</td><td>R&I efforts to jointly comply with different national requirements, procurement processes, etc. providing input to RFC processes.</td><td>Generic opportunities:
Participate in standardisation;
Reflect standards in regulations.</td></tr>
<tr><td>Smart city functionality standards</td><td>Collect and (bench)learn from practices;
Ethical and safe crowd management.</td><td>Legal status for Smart Cities and supporting entities;
New structures for (international) critical service providers and strategic technology partners.</td></tr>
<tr><td>Wireless standards for car infrastructures (V2V, V2I, …)</td><td colspan="2">Common, localisable regulatory and administrative structure for AV network managers;
Standards-based rules for H2M and M2M communication;
Legal recognition for standardised smart contracts.</td></tr>
<tr><td>Standards for air traffic management</td><td colspan="2">EU-US link with regard to drones mainly reflects:
Equipment market opening (hardware, services and information harvesting);
Interoperability with general Air Traffic Control systems;
Key policy issue is certification via standards or otherwise;
Rules for where and how drones can be used.</td></tr>
<tr><td colspan="3">5G</td></tr>
<tr><td>Promote collaboration between the 5G PPP in Europe and the Advanced Wireless Research Initiative in the US</td><td>Technology solutions for dealing with different spectrum requirements and limitations</td><td>Funding;
Coordinate deployments/pilots;
Standardisation;
Spectrum allocation[26].</td></tr>
</table>

[22] Subsidies, technological compatibility.

[23] Accepting international standards, suppliers, R&I and testing results.

[24] Safety, energy use, privacy, economic development, impacts on related sectors, insurance, etc.

[25] Training liability, operational regulation, guidelines and rules, ATC, privacy, noise, etc. policy.

[26] Esp. for managing global policy issues (competition, privacy, etc.).

Application domains:	Policy-driven R&I	R&I-driven policy
Global spectrum harmonisation	• Enable single devices to use many parts of the spectrum; • Dynamic band selection based on local spectrum use policy and on location, application combination.	• Agree spectrum mapping for range of consumer and industry purposes; • Adapt spectrum licensing to fit new uses, power, interference etc.; • Modify spectrum allocation procedures (auction, trading) to serve 5G requirements.
Standardisation	Market driven • Reflect technological realities; • Stimulate R&I; • Remove or reduce market distortions; • Lower sectoral and use boundaries.	• Ensure functioning of markets for ICT products and services; • Build on initiatives led by large companies[27] such as NGMN 5G[28]; • Reflect standards in regulations and procurement.
Big Data		

There are very strong Big Data policy initiatives on both sides of the Atlantic	• Build privacy protection into data use (protect against personal data abuse);
	• Data quality, provenance checks;
	• Solutions and standards that allow auditing, monitoring and evaluation of data processing to verify privacy, confidentiality, integrity;
	• Technical and operational approaches to algorithm creation, use and linkage to ensure and/or demonstrate regulatory compliance.
		• Move privacy rules from protecting against *use* of personal data to protecting against abuse of persons by means of data processing;
		• Trade-compatible data mobility rules to address current technical, economic and policy issues, esp.
		  ○ Data processing for science, government and commerce;
		  ○ Extraterritoriality.

Regulation is a key enabler for global adoption of data-intensive services[29]	• Enable and facilitate control of data localisation or tracking;
	• Explore automating location-specific data processing.
		• Common legal (treaty) bases for national regulations (e.g. rights of the person, commercial activities);
		• Reciprocal legislation protecting the rights of the individual;
		• Negotiated harmonisation and subsidiarity structure for
		  ○ Addressing current, future issues;
		  ○ Balancing rights with regulatory and policy concerns.

[27] E.g. NTT Docomo, Samsung, Ericsson, T-Mobile and Verizon.

[28] See https://www.ngmn.org/5g-white-paper.html.

[29] This was recognised in e.g. Safe Harbour and Privacy Shield, though national differences and regulatory burden considerations have undermined this.

<table>
<tr><th>Application domains:</th><th>Policy-driven R&I</th><th>R&I-driven policy</th></tr>
<tr><td>Cloud computing [30] implications</td><td>Explore ability of technological, managerial and commercial solutions to:
Comply with letter/spirit of law;
Open path to better ways to attain general and specific policy objectives?</td><td>NISD covers e.g. cloud mining, other Big Data Analytics functions;
Need to reconsider legal structures -
ethereum and similar distributed computing platforms and services delivered over them;
Providers (ostensibly covered) who may not be local or attributable.</td></tr>
<tr><td>Blockchain implications[31]</td><td>Develop effective applications for specific purposes[32];
(Learning from practice).</td><td>Application-driven regulatory issues:
Cryptocurrencies - anti-money laundering, terrorist financing and other financial regulations;
Smart contracts - contract law;
Token crowd sales - securities regulation.</td></tr>
<tr><th colspan="3">IoT/CPS</th></tr>
<tr><td colspan="3">Policy</td></tr>
<tr><td colspan="3">Engineering trustable, reliable, evolvable and affordable cyber-physical systems requires huge efforts; joining forces will help to advance more quickly and thus meet societal challenges.</td></tr>
<tr><td>Combining the CPS and IoT worlds.</td><td></td><td>Consistent regulatory treatment;
Common rules for aggregating, decentralising and partitioning regulatory responsibilities and entitlements.</td></tr>
<tr><td>Guidance, good practice on implementing smart functionalities</td><td>Establish global good practice framework;
Establish taxonomy for privacy/safety/security sensitivity.</td><td>Guidance-based:
Comply, demonstrate equivalent performance or explain;
Apply to identification, monitoring and enforcement of “good practice”
Where proportionate and justified – even cross-border;
Breach reporting legislation;
Consumer protection, Service Level Agreements.</td></tr>
<tr><td colspan="3">Regulation</td></tr>
<tr><td>Safety certification</td><td>At device and/or system level:
Technical indicators;
Verification means;
Safety-by-design.</td><td>Legal standing of guidance;
Standards-based safety regulation;
Ex ante licensing and type approval;
Common or harmonised ex post (conduct or outcome) sanctions.</td></tr>
</table>

[30] NIS Directive definition: “digital service that enables access to a scalable and elastic pool of shareable computing resources.” Also: "cloud computing services span a *wide range of activities* that can be delivered according to *different models*."

[31] Big Data is (in large part) concerned with analysis of unstructured data, so the access structures and data quality certification aspects of Blockchain, the analytic applications of data mining and the data collection implications of distributed ledger technologies (selection effects in the record) make this a Big Data topic.

[32] Applications for purposes refers to e.g. cryptocurrencies, distributed ledgers for banking records and interfirm coordination, smart contracts, regtech applications, and blockchain business models in retail, transport, manufacturing, etc.

Application domains:	Policy-driven R&I	R&I-driven policy

Privacy[33] .	• At device and/or system level:
	  ○ Technical indicators;
	  ○ Verification means;
	  ○ Privacy-by-design;
	• Privacy as service business models and processes;
	• Correct or route around design deficiencies to pre-empt or reduce requirements for coercive regulations[34];
	• Security standards and privacy protections matching information sensitivity[35];
	• Format consistency of security protections[36];
	• Technical implementation of data use, purpose, amount and time limits.
		• Foresight-based policy – take strategic account of data privacy and sharing regulatory impact on the development of CPS and IoT;
		• Harmonise regulation across technical, application, policy areas;
		• Industry-led[37] regulatory recommendations, guidelines;
		• Adjust consent rules to cope with lack of user interface on many IoT devices and intransparent automatic interaction among connected devices, which make it hard to meet legal requirements.

[33] Applications rely on collecting and utilising data from a myriad of sensors.

[34] E.g. lack of user interface/visibility/control; invisibility of most M2M interactions.

[35] This is a generic regulatory requirement (also embedding burden reduction mandates) that implies technological detection and response to changing or differentiated sensitivity.

[36] To protect private information against: loss; theft; corruption; and unauthorized access, disclosure, copying, use, or modification, *regardless of the format in which it is held*.

[37] E.g. BITAG (http://www.bitag.org/documents/BITAG_Report_-_Internet_of_Things_(IoT)_Security_and_Privacy_Recommendations.pdf)

Application domains:	Policy-driven R&I	R&I-driven policy
Security and cyber-security	• At device and/or system level: ○ Technical indicators; ○ Verification means; ○ Security-by-design; • Security as a service business models and processes; • Match security requirements to ○ Information, functional sensitivity, ○ Data amount, distribution, format and method of storage ○ CPS architecture and control. • Physical, organisational and/or technological controls; • Shared, policy-focused research into attribution and incentives; • Model (and simulate) potentially harmful interactions among devices, develop device- or system-level safeguard[38]s; • Develop and implement monitoring and patching measures for devices in systems context.	• Innovation-friendly, coherent regulatory rules and procedures; • Reward security-conscious products with certification; • Promote adoption and legal standing of cyber insurance; • Facilitate or accommodate industrial sharing of threat, incident information; • Recognise voluntary good practice development, adoption; • Agree and adopt responsibility[39] and accountability arrangements for data and functions moving across system, organisational, purpose, national etc. boundaries; • Proportionate and conformant (common) monitoring, reporting and dispute resolution mechanisms esp. for cross-border issues; • Develop legal framework[40] for class action lawsuits on privacy, data and security breaches; • Address four linked rising challenges: ○ Risk of harm; ○ Sensitivity to privacy or performance problems; ○ More – and more complex – vulnerabilities and difficulty of patching; ○ Vulnerabilities created by third parties (knowingly or not).
Regulation to support market access	Blockchain[41]/tracking	Policy research needed: • Markets hard to measure and analyse; • market access regulation subject to many restrictions ranging from Trade Agreements to jurisdiction issues; • Complex counterfactual.
Interoperability standards	• Open standards; • Intelligent matching/adaptability.	Compliance with good practice standards

[38] For example, autonomous vehicle policy require this kind of R&I to establish what needs to be regulated and in what way this should be done. It requires collaboration because the value chain stretches from designers and manufacturers in one country to drivers in another.

[39] This includes DDOS and related issues – see e.g. https://www.schneier.com/blog/archives/2016/11/regulation_of_t.html.

[40] For example, it may not be practical for developers comprehensively to test all possible device interactions for compatibility issues. If an IoT device causes harm through decisions or actions made or coordinated with other devices, actual and efficient liability may be hard to determine. Establishing 'fault' for incorrect dosing from a medication pump is harder if the pump adjusts dosage after communicating with other connected devices to obtain health and environmental data – particularly if communication problems may have occurred. Fault for a traffic accident may be complicated by reactions of an AV to communications from other AVs, devices carried by pedestrians or networked sensors. Existing negligence, product liability and privacy laws provide some – but not complete guidance. In regulatory law, this is complicated by the differences between civil and common-law means of detecting and responding to change. In tort law, these uncertainties will encourage plaintiffs' counsel to seek new ways to place liability for damages caused by IoT devices.

[41] Operational (sensor and actuator) data in distributed interacting systems of things can usefully be placed in and processed via distributed ledgers.

2.2. Approaches to ICT Policy Issues in the EU and the US: Some Similarities and Differences

2.2.1. A Bit of History

The EU and the US have taken different approaches to ICT policy issues. One part of this concerns the underlying policy stance. At least until the implementation of the Digital Single Market Strategy (1), the EU sought to encourage the development of underlying infrastructures and the service and application markets created on top of them through demand-pull and removal of ‘bottleneck’ barriers to competition (though not the bottlenecks themselves). To do this, policy sought to drive down prices for DSL-based Internet services by forcing network providers to open their facilities at discounted prices to new entrants. But this had the (apparent) effect of limiting both maintenance and new technology investment incentives for providers, and restraining the growth of EU cable Internet, fibre-optic and high-speed mobile broadband networks. From the regulatory standpoint, this amounted to ‘utility-type’ control of large essential facility providers that tried, with varying degrees of success, to force competition in the ‘upper layers’ of the market.

The US pursued a similar strategy with respect to voice telephony, but intentionally exempted Internet services, in effect leaving fixed and mobile broadband Internet access markets to develop largely on their own. As a result, the US has seen much higher (nearly a trillion and a half dollars by 2015) private investment in cable, mobile, fibre, and next-generation copper/fibre hybrid services. This helped contribute to the development of innovative Internet-based businesses; 11 of the top 15 Internet businesses, most started in the last decade, are US-based, with the rest coming from China. None are from Europe. On the other hand, US markets remain largely foreclosed, with relatively little competition in broadband service provision, and consequent higher prices.

The DSM sought to reform the EU stance by embracing competition; critics of the US light-touch approach have urged the EU to ‘avoid the mistakes’ of US Policy (2). The new strategy led not only to considerable advances in many areas[42] but also to a tighter linkage across different aspects of policy. However, progress towards ubiquitous availability, affordability, uptake and quality remains patchy; this uneven development is itself a drawback, since it leads to uneven playing fields for rural and urban enterprises, small and large enterprises, different services or technological approaches to service delivery (meaning that the market will not always go to the ‘best’ technology or firm) and to asymmetries among Member States. These types of digital divide can, as is well-known, harden into other divides. From the European perspective, this type of inefficient inequality is considered a serious policy problem.

In the US, the potential to limit competitors’ access over networks drove high levels of investment (3); the inevitable pushback led to a certain amount of net neutrality and other forms of open network regulation. The US also achieved fairly high availability and adoption of ‘regular’ broadband (though not of high-speed broadband) (4), but retains high levels of concentration (though some argue that potential competition in slower broadband and possible emergent competition in gigabit broadband may drive a degree of efficiency). As a further consequence, the US lags Europe in terms of affordability, especially for faster broadband (3).

2.2.2. The Difficulty of Meaningful Comparisons

But it should be stressed that there is little general agreement as to whether (or in which ways) the EU and the US are ‘doing better’; different metrics are associated with different ways of defining and stating overarching

[42] See e.g. Digital Single market Scoreboard data (e.g. https://ec.europa.eu/digital-single-market/digital-scoreboard).

policy objectives. Available official statistics do not promote easy comparisons, and as a result, the scope and nature of policy interventions differ. This policy 'status contest' seems strongly to influence policy directions. To do this area justice would mean looking at the influence of industry on policy and the way R&I policy interacts with other 'owners' of the relevant policy space, but that goes beyond the scope of the current exercise. It what follows, we merely note that the EU and the US *tend* to attach different priority to such policy performance metrics as inequality (of opportunity or outcome), competition vs. profitability, co-operation vs. collusion, international openness vs. protectionism and the pace of innovation.

2.3. Differences and Co-operation

These differences both inhibit and create opportunities for mutually-beneficial co-operation. They inhibit them to the extent that

- EU and US public administrations see policy only in nationally (political or economic) competitive terms;
- Public administrations try to pick and support 'national champions' in global playing fields;
- 'Not invented here' parochialism on both sides of the Atlantic prevents conduct of R&I by teams representing the best minds, the fullest possible sharing and analysis of evidence or the best possible application of the fruits of R&I; or
- Differences in perspective lead to fragmentation and poor results arising from a lack of critical mass lead to the abandonment of promising areas for collaboration.

Differences of perspective can enhance cooperation if they:

- Suggest useful alternative ways of formulating or tackling problems;
- Allow the EU and the US collectively to influence policy on a global front or where collective R&I policy can influence technological or market development;
- Spark novel contacts such as partnerships among researchers, and between research, industry and government (the 'strength of weak ties' effect (5));
- Create a positive feedback competition leading to faster or better results by avoiding lock-in and minimising the chance of blind alleys; and
- Promote a diversity of disciplines, methods and perspectives leading to deeper understanding.

Note that the end result may be convergence to a common approach (in research or in application) or a complementarity (e.g. the development of use-specific standards as well as use-neutral ones, or the development of policies that reflect international differences or comparative advantage together with those that are harmonised in areas where the benefits outweigh the drawbacks. This arises directly from differentiated R&I collaboration, which allows us to distinguish those areas that require harmonisation from those that require differentiation in ways that reflect the ultimate ways in which technologies will be developed rather than the mechanisms of interoperability on the purely technological plane.

3. Policy Priorities in the EU and the US

Associated with each of the identified technologies are a range of policy areas; these go beyond the overarching areas identified in PICASSO, but are worth identifying because policy initiatives are on one hand not technology-specific while technological advances can not only address multiple policy issues but also change the trade-offs to be considered by policy-makers and the degree to which policy may be shaped by R&I (and thus, given the greater ease with which technology crosses national boundaries (compared to policy) the potential alignment of policies.

For 5G, the two main policy areas are:

- Spectrum - a priority for policymakers to set the stage for 5G is allocation of high-band millimeter wave spectrum. Here the US FCC has set a strong precedent: in 2015 the Commission proposed rules as to how best to put high-band spectrum to use and has proposed an order to open up a significant amount of high-band spectrum[43]. For its part, the EU has made spectrum an explicit part of both the 5G Action Plan and the Proposed Electronic Communications Code.
- Infrastructure - high-band spectrum, or any small-cell densification will require significant investment in infrastructure—both for siting the antenna equipment and for backhaul. The US again is relying on industry, while the EU foresees substantial co-funding.
- It should be noted that 5G in the 3GPP sense, not to be confused with various marketing claims and proprietary 5G-like schemes currently being deployed in the United States. The work on "Advanced Wireless" currently done in the US comes closest, and goes beyond the 3GPP 5G in some aspects.

For IoT/CPS, the priorities are more diffuse, but include such elements as:

- Governance of complex and diverse masses of connected devices;
- Secure and accurate identification of devices and their systemic compatibility;
- Privacy, trust, security and performance of complex systems of interacting devices and subsystems;
- Algorithmic regulation in the context of cyberphysical systems; and
- Legal and regulatory issues and policies arising from these phenomena.

We do not cover Big Data in the same way, in part because industry and academia are well in advance of government in this area and in part because the linkage to policy domains beyond the scope of this project is stronger for that area.

3.1. EU Priorities

3.1.1. Overarching Research Programme – Horizon 2020

The Horizon 2020 programme has identified a number of strategic priorities tied closely to the technology, societal and policy application areas identified by PICASSO. They are not divided exactly along the same lines, but the linkages are clear. The overall programme is structured around three priority areas: excellent science; industrial leadership; and societal challenges. These in turn define three 'pillars' of the overall programme. This is shown in graphical form in Figure 1.

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[43] 3.85 gigahertz of licensed, flexible use spectrum and 7 gigahertz of unlicensed spectrum. Six hundred megahertz will be reserved for experimental spectrum-sharing models.

More specifically, the Excellent Science pillar is linked to science, R&I and education policy; the Industrial leadership priority is linked to industrial policy (investment in key technology areas and measures to increase private sector investment), SME support measures and (to a lesser extent) policies to improve competition and remove market distortions in technology-based sectors. The societal challenges priority area is linked to climate, environment, energy, transport and similar policy areas, to multidisciplinary approaches (including those that strengthen links between science and policy) and to improving the evidence base for these policies by tests, demonstrators and scale-up activities.

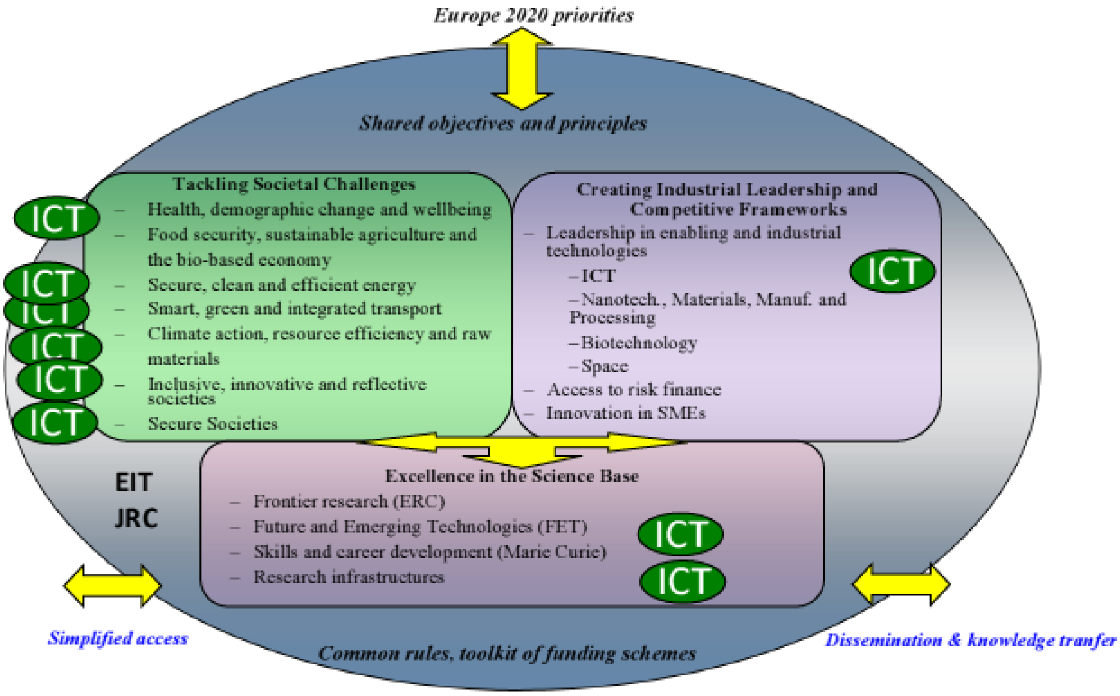

Figure 1: Horizon 2020 ICT-related priority areas[44].

Progress is not limited to direct project funding, but includes a range of partnerships:

- Public private partnerships, through Joint Technology Initiatives or other formal structures (Art. 187) and through contractual agreements that provide inputs to work programmes (on the basis of clear commitments from private partners).
    - The Joint Technology Initiatives (usually institutional PPPs run as Joint Undertakings between industry and the EU) involve a range of different structures and funding mixes. The first batch of JTIs included several of relevance particularly in the IoT/CPS area – ARTEMIS (Embedded Systems), ENIAC (Nanoelectronics) and EpoSS (Smart Systems Integration) – which have been merged into the ECSEL Joint Undertaking (Electronic Components and Systems for European Leadership). Each JTI implements a common Strategic Research Agenda (SRA) and defines its own Work Programme, and runs its own support arrangements (Calls, project selection, negotiation of Grant Agreements, reporting etc.). The current crop includes:

[44] European Commission (2016) "A Guide to ICT-related activities in WP2016-7" at: https://ec.europa.eu/programmes/horizon2020/sites/horizon2020/files/Guide%20to%20ICT-related%20activities%20in%20WP2016-17%20A4%20v8.pdf.

    - Innovative Medicine 2 (IMI) to develop next generation vaccines, medicines and treatments, such as new antibiotics;
    - Clean Sky 2 (CS2) to develop cleaner, quieter aircraft with significantly less CO_2 emissions;
    - Fuel Cells and Hydrogen 2 (FCH) to develop and demonstrate clean and efficient fuel cell and hydrogen technologies for stationary and mobile applications;
    - Biobased Industries (BBI) to use renewable natural resources and innovative technologies for greener everyday products;
    - Electronic Components and Systems for European Leadership (ECSEL) to boost Europe's electronics manufacturing capabilities. ECSEL combines the Joint Technology Initiatives (JTI) ARTEMIS - Embedded Systems, ENIAC - Nanoelectronics and EpoSS;
    - Shift2Rail (S2R) to develop better trains and railway infrastructure; and
    - SESAR to develop the new generation European air traffic management system.
  - The funding for contractual PPPs comes equally from the private and public sectors, and is awarded through open H2020 Calls administered by the EU. Include (those of most relevance in bold):
    - Factories of the Future (FoF) to strengthen European manufacturing industry's international competitiveness, increasing the small and medium-sized enterprise base by development and integration of innovative technologies;
    - Energy-efficient Buildings (EeB) to support the European construction sector by exploring innovative methods and technologies to drastically cut energy consumption and CO_2 emissions of buildings via energy-efficient systems and materials for new buildings and refurbishment and retrofitting of existing buildings;
    - Green Vehicle to promote R&I in technologies for renewable and sustainable use and safety and transport planning;
    - Sustainable Process Industry (SPIRE) to foster a sustainable process industry by enhancing manufacturing resource and energy efficiency;
    - Photonics to realise the potential of photonics to contribute across sectors and products;
    - Robotics to enhance industrial competiveness and tackle such societal challenges as demographic change, health and welfare, food, mobility, safety and security;
    - **5G Infrastructure to support development, deployment and use of 5G networks for the Internet of the future to provide advanced ICT services for all sectors and users;**
    - High Performance Computing (HPC) to underpin European economic growth European science; and
    - **Big Data to combine public and private research in order to develop pioneering concepts in the fields of energy, manufacturing and health.**
    - [A prior PPP on Future Internet] was discontinued last year.

Many of these initiatives are linked to PICASSO priorities. For example, the 5G priorities explicitly incorporate:

- Technological challenges such as the traffic increases expected from IoT and other M2M communications and objectives like capacity/efficiency improvements, increased service/content centricity, virtualisation & cloud transition, AI (cognitive and context-aware processing), improved manageability (including via complexity-related channels like self-organisation and –optimisation), cross-layer optimisation, increased flexibility, smart environments, sensor and sensor-actuator networks and M2M; and

- Societal and policy impetus from 'Smart' systems (Cities, Transportation, Energy and Grids) to meet challenges of (*inter alia*) urbanisation, urban sprawl, changes in population density, mobility and diversity (age, income education, ethnicity, etc.), increased information supply, demand and processing power, evolving and increasingly plastic social networks, increased (cause for) concern about privacy, security, environmental impact, energy efficiency, food security, healthcare and education (inter alia).

The 5G public-private partnership (launched in 2014 with starting EU funding of €700 million and founder members drawn from the largest European corporate players in the area – Ericsson, Orange, NSN, SES and Alcatel-Lucent. The current membership[45] stands at 27 industrial members, 13 research partners and 10 SME members and 15 Associate Members, including e.g. standards organisations. This PPP is very active in the global 5G Infrastructure Association, which has a range of policy-orientated Working Groups aligned with the H2020 Pillars and EU policy:

Figure 2: Policy-related working groups of the 5G Infrastructure Association.

3.1.2. Innovation Policy – IoT/CPS

The EU is seeking to support innovation in the IoT domain by using public funding to adjust the balance of research in the direction of open and easy accessible IoT platforms. One concrete expression of this is the recently-launched "IoT European Platform Initiative (IoT-EPI)[46]" which is aimed at building "a vibrant and sustainable IoT ecosystem in Europe." This platform will be linked to the inter-industry Alliance for Internet of

[45] A full listing can be found at: https://5g-ppp.eu/our-members/.
[46] http://iot-epi.eu/

Things innovation (AIOTI) (see Section 3.3.3), which in turn builds on the work of the IoT European Research Cluster (IERC)[47] – a grouping of FP7 and national IoT projects and initiatives.

The European Union also participates in international research and policy discussions in order to advance the technology. International calls for joint proposals are foreseen under the Horizon 2020 programme.

International public-private collaboration is also progressing via the Industrial Internet Coalition[48], which is "a global, member-supported, organization that promotes the accelerated growth of the Industrial Internet of Things by coordinating ecosystem initiatives to securely connect, control and integrate assets and systems of assets with people, processes and data using common architectures, interoperability and open standards to deliver transformational business and societal outcomes across industries and public infrastructure."

3.2. US Priorities

The US is keen to preserve its position in relation to 4G, relying on a permissive and industry-led approach[49].

3.3. Research-driven Policy in Two Technology Areas

3.3.1. Schema

In this section, we survey some aspects of policy-relevant research that provide fruitful scope for collaboration in two specific areas; 5G and IoT/CPS. This discussion should be seen as supplementing the suggestions and opportunities identified in Table 1. They can be divided roughly according to whether:

- Policy is directed at technological, economic or societal levels (objectives and instruments);
- The two regions have parallel (but largely separated) policy mechanisms and issues – for instance, telecommunications is largely localised and regulated primarily at Member State (MS) or EU level in the EU (though increasingly harmonised), but is nationally more uniform and primarily regulated at Federal level in the US. This can be further subdivided according to whether conduct is regulated at EU or US Federal level or at MS/state level;
- The two areas have overlapping policy issues (e.g. privacy and security, which are shared because the systems to which they are connected and the flows of data and interactions are global in scope); and
- The policy issues are linked to (or sharper in) specific application areas that are shared (e.g. finance) or complementary, e.g. health, where delivery is local but inputs (e.g. pharmaceuticals) are increasingly global.

Where the policy issues in the two regions can be separated, they may be

- Convergent – e.g. where dominant technologies or approaches will prevail in both areas;
- Divergent – where solutions and institutional arrangements follow different equilibrium paths (including regulation and other policies)

[47] http://www.internet-of-things-research.eu/

[48] http://www.iiconsortium.org/index.htm

[49] See e.g. the remarks of Michael O'Rielly, FCC Commissioner, to Hogan Lovells' Technology Forum: "The 5G Triangle" at: https://apps.fcc.gov/edocs_public/attachmatch/DOC-339558A1.pdf.

- Localised – where differences in development reflect ‘environmental’ or settled differences in local conditions
- Complementary – where the interactions between the two regions on the policy or technology planes reflect comparative advantages (e.g. in hard or soft innovation)

3.3.2. EU Policy in the 5G Domain

Overall, it appears (at the moment) that the EU and the US both recognise the importance of 5G and are eager to encourage both infrastructure and exploitation, though in very different ways (as, indeed, was the case with 4G). While policy remains fluid, some broad outlines can be seen.

As regards 5G, the EU has concrete plans and initiatives (both via the 5G PPP described above and other actions foreseen in the 5G Action Plan[50] and the closely-associated industry-developed 5G Manifesto[51]), that extend and builds on the R&I underpinnings established by the 5G PPP, especially in the direction of a European market for 5G. This includes in particular

- The proposed Directive for a European Electronic Communications Code[52], which seeks to support the deployment and take-up of 5G networks, notably as regards assignment of radio spectrum, investment incentives and favourable framework conditions;
- Recently adopted open Internet rules that provide legal certainty to the deployment of 5G applications.
- Aligning roadmaps, timetables and priorities for coordinated 5G deployment across all EU Member States, with i) a timetable involving preliminary trials, national deployment roadmaps, at least one major "5Genabled" city per country by the end of 2020 and uninterrupted 5G coverage in all urban areas and major terrestrial transport paths by 2025 and ii) 5G national roadmaps that coordinate fibre and cell deployment;
- Making provisional spectrum bands available for 5G ahead of the 2019 World Radio Communication Conference (WRC-19), to be complemented by additional bands as quickly as possible, and work towards a recommended approach for the authorisation of the specific 5G spectrum bands above 6 GHz;
- Promoting early deployment in major urban areas and along major transport paths and pan-European multi-stakeholder trials to accelerate progress from technological innovation into full business solutions.
- Implementation of an industry-led venture fund in support of 5G-based innovation including plans for key technological experiments and demonstrations starting in 2017 and detailed roadmaps for advanced pre-commercial trials in 2018 in key sectors; and
- Collective action to develop and promote global standards.

[50] See: https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan.

[51] “5G Manifesto for timely deployment of 5G in Europe” at: http://telecoms.com/wp-content/blogs.dir/1/files/2016/07/5GManifestofortimelydeploymentof5GinEurope.pdf.

[52] See https://ec.europa.eu/digital-single-market/en/news/proposed-directive-establishing-european-electronic-communications-code, both for the proposed Directive and for the detailed Impact Assessment, which identifies and assesses problems connected with 5G, IoT/CPS and Big Data, and seeks to assess the impacts of specific elements of the Code, especially in relation to the specific objectives of ubiquitous very high capacity connectivity (in the Single Market), competition and wide user choice and simplification and harmonisation of the regulatory environment.

- This is to be backed up by demand-side measures (Member States are supposed to consider using the 5G infrastructure to deliver communications for public safety and security) a targeted public-private venture capital financing initiative (combining EU funds and governance with EIB and industry).

By contrast, the US approach appears to be more laissez-faire, relying on making available large blocks of spectrum for experimentation and supporting industry-led standards and deployment initiatives[53].

However, there are as yet few concrete steps to harmonise policy involving the US and the EU; at the moment, the global picture appears somewhat fragmented[54].

3.3.3. EU Policy on the Internet of Things/CPS

Starting in 2015, the EU has launched a series of policy measures to accelerate IoT development and take-up.

In March 2015, a dedicated association, the Alliance for Internet of Things Innovation[55] (AIOTI) was launched by the European Commission support EC-industry joint action to establish a competitive European IoT market and foster the creation of new business models. Today AIOTI is the largest European IoT Association.

The May 2015 adoption of the Digital Single Market (DSM) Strategy[56] contained specific objectives for the Internet of Things; in particular to avoid fragmentation and to foster interoperability. This was further clarified in an April 2016 staff working document "[57]Advancing the Internet of Things in Europe". This document is part of the "Digitising European Industry (DEI)" initiative[58]; it outlines the EU's IoT vision based on three pillars:

- a thriving IoT ecosystem;
- A human-centred IoT approach; and
- A single market for IoT.

Potential obstacles that could be addressed by collaborative R&I include the growing need for e.g.:

- Capacity to handle large diversity and volumes of connected devices;
- Secure identification[59] the ability to discover devices that can be plugged into IoT systems;
- Acceptable and effective ways to tackle privacy, trust, security and performance issues surrounding complex systems of separate (but interacting) things;
- Understanding of the functions, interactions and impacts of algorithms used to process data and to take actions within the context of cyberphysical systems;
- Methods for regulating the systemic behaviour of networks of algorithms (as well as devices); and

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[53] See e.g. http://www.5gtf.org/.

[54] See e.g. the presentation by Werner Mohr (Chair of the Board of 5GPPP) at the Global 5G Event, Rome, Italy, November 9, 2016: https://5g-ppp.eu/wp-content/uploads/2016/11/Opening-2_Werner-Mohr.pdf.

[55] https://ec.europa.eu/digital-single-market/en/alliance-internet-things-innovation-aioti.

[56] http://ec.europa.eu/priorities/digital-single-market/.

[57] Staff Working Document: "Advancing the Internet of Things in Europe", accompanying the document "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Digitising European Industry - Reaping the full benefits of a Digital Single Market COM(2016) 180" available at: http://eur-lex.europa.eu/legal-content/TXT/?uri=CELEX:52016SC0110.

[58] This initiative emphasises cyber-physical systems to a greater degree and also deals with cloud computing, big data and data analytics, robotics and 3D printing – see https://ec.europa.eu/digital-single-market/en/digitising-european-industry.

[59] Numbering and identification issues were partially being addressed in conjunction with the 2016 Review of the EU telecommunications rules and is being further developed as part of the measures proposed under the rubric of “Connectivity for a European Gigabit Society” (https://ec.europa.eu/digital-single-market/en/connectivity-european-gigabit-society), the European Data Economy initiative (https://ec.europa.eu/digital-single-market/en/building-european-data-economy)

- Ways to handle legal, regulatory and policy issues arising from these R&I-based developments.

4. Barriers to Policy-driven R&I Collaboration

In principle, the policy relevance of R&I activity does not create any extra barriers to international collaboration, provided the policy issues themselves are sufficiently broad or shared. This is just as well; existing barriers are steep enough already in joint undertaking of publicly-funded R&I. Purely private-sector or third-sector activities are generally less sensitive to the extent that the participating entities are already international in scope or partnerships; existing barriers are less bound up with considerations of national interest than with more easily-definable commercial or career interests (e.g. IP formation, ownership and exploitation, market access and power, etc.). These can be priced and contracted for, providing framework conditions (e.g. relating to patents) can be aligned.

Within specific domains, however, policy considerations can create more direct barriers; as noted in the Policy Thematic Papers, privacy and data protection are approached in very different ways and existing attempts to harmonise the legal requirements in order to address privacy and data protection concerns in relation to international flows of data have stalled and may be in danger of reversal[60]. It may be that this uncertainty militates against shared R&I activity, leads to a situation where technological solutions are required to reconcile the different approaches in different countries, or fragments research in the two regions. In particular, as regards Big Data and IoT/CPS initiatives, it may be appropriate to develop solutions that provide some of the benefits of data flows without attendant risks.

Similar considerations apply to security and cyber-security, with potential additional classification complications, not exclusively focused on "securing" access and data, but including security measures intended to facilitate surveillance and (police) investigations.

Other issues are related to "terms of art", such as 5G. In Europe, this is taken in the 3GPPP sense, broadly, whereas the term is in use in the USA as marketing concept by telecom companies in the narrower sense. EU work on 5G compares more to US work on "Advanced Wireless" – and here, collaboration remains attractive.

In terms of funding, there are explicit arrangements under Horizon 2020 for international collaboration (e.g. by launching parallel projects, or through having US entities participate in EU projects using US funding), but these do not fully cover US-EU R&I collaboration. More precisely, Horizon 2020 is open to participation from across the world, provided European researchers include international partners when preparing proposals. Therefore US researchers, enterprises and institutions can join with European partners jointly to develop knowledge and data and to participate in or even to lead scientific teams and networks.

Of course, participation and funding are different matters. The EU will fund the participation of partners from developing countries[61], it does not automatically fund the partners from industrialised countries such as USA. US researchers should bring their own funding – either from the participating institutions or US funding agencies.

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[60] The Art 29 WP has expressed its doubts about the US-EU Privacy Shield (see http://ec.europa.eu/justice/data-protection/article-29/press-material/press-release/art29_press_material/2016/20160726_wp29_wp_statement_eu_us_privacy_shield_en.pdf) and the recent US Executive Order on "Enhancing Public Safety in the Interior of the United States" includes the statement that "Agencies shall, to the extent consistent with applicable law, ensure that their privacy policies exclude persons who are not United States citizens or lawful permanent residents from the protections of the Privacy Act regarding personally identifiable information." The picture is complicated by the EU-US "Umbrella Agreement" which seeks to protect personal data transferred for law enforcement purposes between the EU and U.S. under existing international agreements involving the EU and U.S. The Agreement's privacy protections apply to many earlier agreements such as the Passenger Name Records Agreement, various Mutual Legal Assistance Treaties ("MLATs"), and the now defunct Safe Harbour framework. Redress was ensured by US passage of the Judicial Redress Act in February 2016; on January 17 2017, the US Attorney General made clear that the protection included citizens of all EU Member States other than Denmark and the United Kingdom (which were expected to be included in the definition soon). It is not wholly clear whether this is nullified by the Executive Order, or whether the EU remains protected by Section 14 of the Executive Order which requires agencies to act in a manner "consistent with applicable law." If this situation changes, the EU may withdraw its assent to the Privacy Shield, or decline to extend it beyond the current 'probationary' period.

[61] Specifically, the EU will fund researchers (and institutions) from 16 a*ssociated countries* (Iceland, Norway, Albania, Bosnia and Herzegovina, the Former Yugoslav Republic of Macedonia, Montenegro, Serbia, Turkey, Israel, Moldova, Switzerland, Faroe Islands,

However, there is currently no jointly agreed mechanism is currently in place for co-funding Horizon 2020 research and innovation projects, although US participants in projects under the Horizon 2020 Health, Demographic Change and Wellbeing Societal Challenge are automatically eligible for funding and European researchers are also eligible for funding in US NIH projects. It is conceivable that similar reciprocity arrangements could be negotiated with respect to other pillars of the H2020 programme and US counterpart programmes or agencies[62].

Ukraine, Tunisia, Georgia and Armenia) and 130 *developing countries*. Additionally, researchers from anywhere in the world can be funded to work in Europe through the European Research Council or the Marie Skłodowska-Curie actions.

[62] See e.g. European Commission (2012) "Enhancing and focusing EU international cooperation in research and innovation: A strategic approach" Communication COM(2012) 497 final at:

https://ec.europa.eu/research/iscp/pdf/policy/com_2012_497_communication_from_commission_to_inst_en.pdf.

5. Conclusions and Outlook

This report outlines specific policy challenges for collaboration between US and EU researchers. We found that there is very fertile ground for collaboration, and it will be important to develop this further to overcome the artificial barriers created by different use of terms (e.g. 5G according to 3GPPP in Europe and “Advanced Wireless” in USA) and to harness the associated productive differences in perspective. The same applies to the ‘natural experiment’ created by different legislative approaches (e.g. privacy as fundamental right, or as economic right that is tradable) and instantiations of community-related concepts.

We found that the differences between US and European values, approaches and available evidence are relevant and provide an opportunity to jointly develop ICT that may serve the global market and to transfer useful aspects of digital community formation between the US and the EU. ICT is associated with a range of global industry sectors and entities; the many layers in the value chain from the chip to national and global ICT services – and beyond into the application and regulatory layers - require innovation on the fundamental technical level, the level of innovative services and the organizational and business model levels as well.

By grounding policies in a solid understanding of acting in a global market, more opportunities will arise for collaboration amongst EU and US researchers.

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