Opportunity Report

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

5G

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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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Project Website: http://www.picasso-project.eu/

PICASSO Consortium Members:

inno	**inno TSD, France** – one of Europe's leading innovation management consultancy firms, specialised in helping major private and public stakeholders design and implement R&D and innovation projects. https://www.inno-tsd.fr/en
tu technische universität dortmund	**TECHNISCHE UNIVERSITÄT DORTMUND, Germany** – a leading German technically oriented research university with strong research groups in big data, communications, smart grids, e-mobility and cyber-physical systems. http://www.tu-dortmund.de
THHINK WIRELESS TECHNOLOGIES LTD	**THHINK WIRELESS TECHNOLOGIES LIMITED, United Kingdom** - an ICT company founded in 2009 after more than a decade of research and development in wireless and energy harvesting technologies. http://www.thhink.com/
ATC ATHENS TECHNOLOGY CENTER	**ATC SA, Greece** - an SME and Technology Centre in the field of ICT participating in 3 ICT European Technology Platforms: NESSI (Steering Committee member), NEM (member) and NETWORLD2020 (member), and founding member of European Big Data Value Association. http://www.atc.gr

APRE Agency for the Promotion of European Research	**AGENZIA PER LA PROMOZIONE DELLA RICERCA EUROPEA, Italy** – a non-profit research organisation, grouping together more than 100 members, including public and private research centres, industries, industrial associations, chambers of commerce, science parks and more than 50 universities, with the main objective to promote the participation in national and European RTD programmes. http://www.apre.it/
Honeywell	**HONEYWELL INTERNATIONAL INC, United States** – a multinational company and global leader that invents and manufactures technologies to address some of the world's toughest challenges initiated by revolutionary macrotrends in science, technology and society. The company's products and solutions are focused on energy and the environment, safety and security, and efficiency and productivity. http://honeywell.com/
GNKS Consult	**GNKS CONSULT BV, Netherlands** - conducting strategic and policy research and evaluation, building on excellence in understanding of the impact of the emerging Global Networked Knowledge Society http://www.gnksconsult.com/
TECHNISCHE UNIVERSITÄT DRESDEN	**TECHNISCHE UNIVERSITÄT DRESDEN, Germany** - a full-scale university with 14 faculties, covering a wide range of fields in science and engineering, humanities, social sciences and medicine. https://tu-dresden.de/
FIU FLORIDA INTERNATIONAL UNIVERSITY	**FLORIDA INTERNATIONAL UNIVERSITY, United States** - The Miami-Florida Jean Monnet Center of Excellence, (MFJMCE), a member of the global network of EU-sponsored Jean Monnet centers, has the mission to promote teaching, research and outreach activities relating to the EU. http://www.fiu.edu/; https://miamieuc.fiu.edu/
Technological Leadership Institute	**UNIVERSITY OF MINNESOTA, United States** – The Technological Leadership Institute bridges the gap between business and engineering. TLI's mission is to develop local and global leaders for technology enterprises. https://tli.umn.edu/

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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

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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:

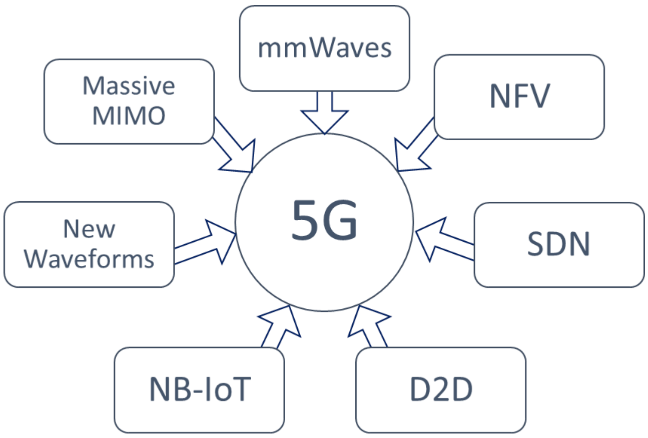

Figure 1: 5G Key Enabling Technologies.

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).

[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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