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ADWICE

Advanced Wireless Technologies
for Clever Engineering

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Document title:

Long-term Research Plan

The **ADWICE Research Projects "Smart Infrastructure for a Connected World"** aim to provide solutions for future challenges in a massively interconnected world. They address EU objectives in areas including Healthcare, Smart Cities, and Smart Factories. They recognize that the *connectivity of technical systems* will lead to a large potential for strong and sustainable innovation in the EU and, in particular, for the Moravian industry.

Achieving ubiquitous and seamless connectivity requires the advancement of wireless-based technologies enabling sophisticated networked solutions. These technologies are based on low-cost, small, connected processing and sensor devices, which form cyber-physical systems. Accordingly, the topics addressed by the ADWICE Research Projects include smart sensor systems, networked signal processing, vehicular and high-mobility communications, cybersecurity, antenna and circuit design, and cyber-physical systems with situational awareness. Advances in these areas will be achieved through close interaction of researchers based at Brno University of Technology and at TU Wien, and exploiting strong synergies among the various projects.

The ADWICE Research Projects are the core of research innovation in the ADWICE proposal. Seven high-level academics from TU Wien will take on the scientific lead for seven research groups within the SIX Research Centre at Brno University of Technology and guide the researchers at all levels – from Master student to senior level – in order to convert the existing research activities into first-class innovations within their new research directions.

ADWICE Research Projects “Smart Infrastructure for a Connected World”

1. Motivation

According to the European Strategy and Policy Analysis System (ESPAS) 2015 report [ESP15], the EU is facing several challenges by 2030. The five most important global trends were identified as:

1. The population is growing older and richer with a growing middle class and widening inequalities.
2. Economic weight and political power are shifting to Asia. Sustained development of the world economy is becoming more vulnerable to challenges and to weaknesses in the globalization process.
3. A revolution in technologies and their applications transforms societies in almost every aspect. Digitization is the invader and radical, disruptive change is the consequence.
4. Managing scarcity of resources becomes an increasing challenge, with rising energy consumption and shifting patterns of production.
5. The interdependence of countries, now a fact of global life, is not matched by strengthening global governance. The world order becomes more fragile and unpredictable.

In particular for the EU, the following technical and research-related means were defined to promote a society of change and innovation:

1. *A true digital revolution.*

   The EU and its member states need to catch up with the international top actors to regain some leadership in technical and industrial innovation, especially in the fast-growing digital sector of the economy. Enabling operators to deliver top-level research and enter the market more easily will be the key. Individuals will need to adopt new patterns of consumption, work and communication. At the EU level, completion of the digital single market will be essential to enable the EU to achieve higher growth without debt and to reduce current unemployment levels.

2. *Building a European research and innovation area.*

   Despite EU programmes, fragmentation of research and development (R&D) both in the public and in the private sector leads to inefficiency, lack of critical mass and multiple product standards. Mobility of scientists between academia and industry and bold initiatives are the likely keys to more streamlined investments and maximum innovation.

3. *A rethinking of education.*

   The return on investment in education must be reassessed thoroughly throughout Europe. Currently high levels of spending do not prevent growing skills mismatches, digital illiteracy and premature school dropout, resulting in the exclusion of many young or even older workers from the labor market. Inadequate linguistic training acts as a brake on labor mobility. Europe’s earlier advances in key enabling skills are sometimes being lost compared to other leading or emerging economies. New education and life-long training policies should aim at lasting excellence and wider participation in the labor force.

In our **ADWICE** approach, we attempt to address these objectives. We recognize that the *future connectivity of all technical systems* will lead to a large potential for strong and sustainable innovation in the EU and even more for the Moravian industry.

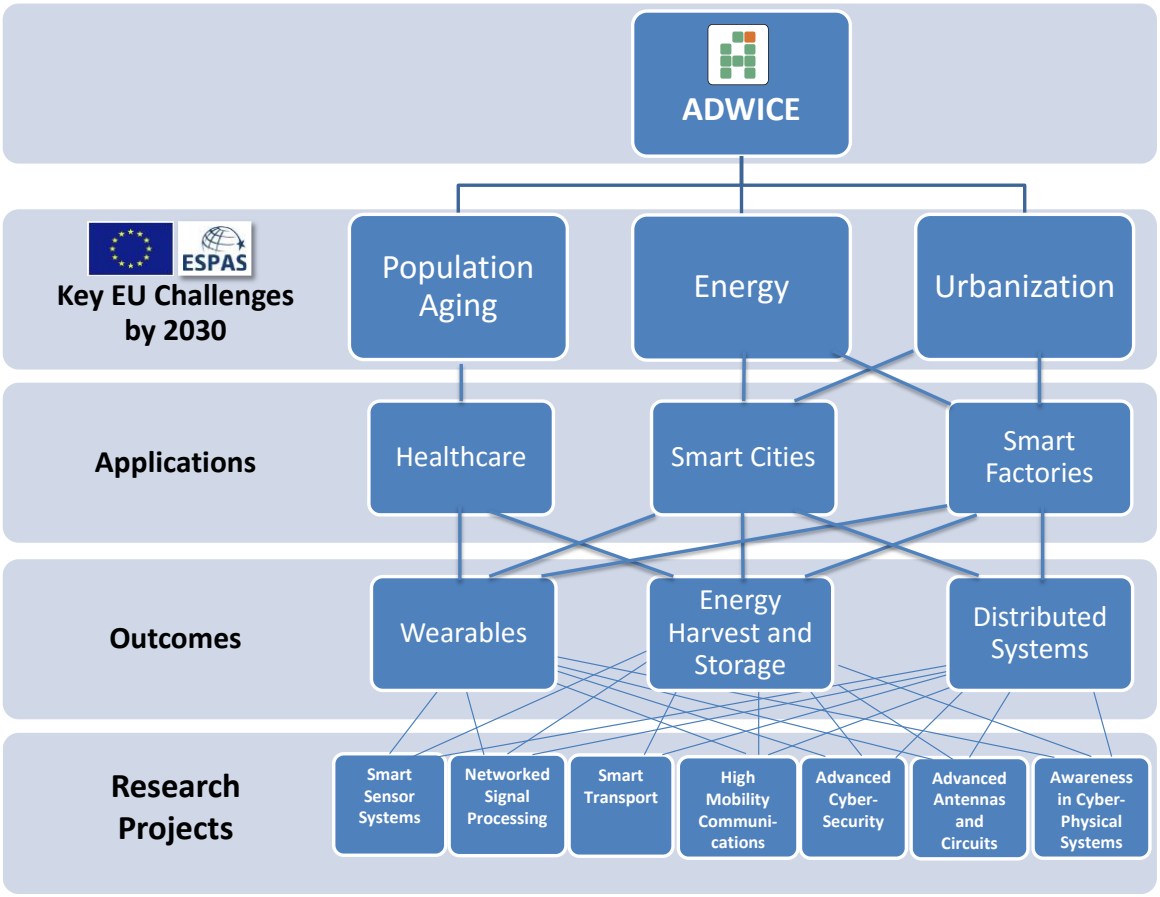

Fig. 1: Motivation and objectives of the ADWICE project in light of EU directives.

A few such activities have already started:

1. *Industry 4.0* is the idea of connecting all relevant systems and subsystems in the industrial context, forming a smart factory in order to optimize manufacturing procedures [PEN15].
2. *Smart cities* invest into more efficient public transportation [CRE14] for their future development and reduce emissions to improve the lives of their (aging) inhabitants. This can be achieved by massive communication between vehicles and infrastructure, which seems to be the only method to support the increasing trend to urbanization [UNI14].
3. *Smart homes* include communication between all relevant devices and sensors at home in order to make private places more controllable, secure, safe, and energy-efficient [CAH14].
4. *Smart grids* ensure higher dependability of energy at lower cost by intelligent regulation of energy consumption [RAD12].

All of these innovations are based on *connectivity*. They require the development of numerous low-cost, small, connected computational and sensor devices, which will form so-called cyber-physical systems (CPSs). As the technology of CPSs in terms of algorithms, sensor devices, energy efficiency, and communication is currently not ready to obtain the desired levels of performance, our goal is to achieve substantial advances in these fields. The aim of **ADWICE** is to address EU challenges in the areas of Healthcare, Smart Cities, and Smart Factories, by developing new wearable devices, devices that can harvest energy from their environment, and methods for distributed systems providing sensing, signal and data processing, computing, learning, and problem solving (see **Fig. 1**). We

therefore chose the title **"Smart Infrastructure for a Connected World"**, which is intended to summarize these research challenges. The relation of our research proposal to existing and recent EU research projects is described in Section 6.

2. The Role of the SIX Research Centre

The **ADWICE** project aims at creating a strong partnership between the *Research Centre of Sensor, Information and Communication Systems* (SIX) at Brno University of Technology and TU Wien. The SIX Research Centre was established in 2010 by the Department of Radio Electronics, the Department of Telecommunication, the Department of Microelectronics, and the Department of Physics of the Faculty of Electrical Engineering and Communication, all at Brno University of Technology. The mission of the SIX Research Centre is to support the innovation potential of companies that actively exploit communication, information and sensor technologies in different areas. The SIX Research Centre capitalizes on the background of Brno University of Technology to obtain new knowledge and create new solutions through its own fundamental research. These results are subsequently applied by the partner companies to develop new products and services.

3. The Role of the South-Moravian Innovation Centre

The *South-Moravian Innovation Centre* (JIC) was established to support innovative businesses and the commercial exploitation of research and development in the region of South Moravia. JIC also supports the cooperation of universities, research institutes, and companies to stimulate research and maximize the impact of industrial development in South Moravia.

The Region of South Moravia, the City of Brno, and major universities in Brno, including Brno University of Technology, Masaryk University, Mendel University, and the University of Veterinary and Pharmaceutical Sciences, are all members of JIC. JIC administrates two technological incubators located on the campus of Brno University of Technology, and a biotechnological incubator located on the campus of Masaryk University.

JIC supports innovative companies, students with original ideas, researchers, and inventors. JIC provides companies in incubation with funding, office facilities, consulting, contacts, promotion, and public relations as well as technology-transfer assistance. Since 2003, JIC has contributed to the starting-up of more than 50 companies, 18 of which have already successfully left the incubation state and have become independent.

The developing cooperation between JIC and the SIX Research Centre follows two directions:

- JIC supports the SIX Research Centre in the preparation of international research projects through consultancy and promotion of suitable partners (via the Enterprise Europe Network).
- JIC offers the research and measurement infrastructure of the SIX Research Centre to companies in incubation state.

JIC is responsible for the regional innovation strategy of South Moravia. Therefore, the relations between the **ADWICE** project, the SIX Centre, and JIC are of a strategic nature, aiming at the further development of the South Moravian Industry.

4. The ADWICE Research Plan

The **ADWICE** Research Plan is the core of innovation in the **ADWICE** proposal. Seven high-level academics from TU Wien (TUW) will take on the scientific lead for seven research groups (RG1–RG7)

within the SIX Research Centre at Brno University of Technology (BUT) and guide the researchers at all levels – from Master student to senior level – to convert the existing research activities into first-class innovations within their new research directions. The planned research is organized in seven projects (P1–P7). These projects, along with the respective research groups, their counterparts at TUW, and their heads at BUT and TUW, are:

P1: Smart Sensor Systems
RG1: Sensor Group (BUT) and Microsystems Technology Group (TUW)
Heads: Jaromír Hubálek (BUT) and Ulrich Schmid (TUW)

P2: Networked Signal Processing
RG2: Signal Processing Group (BUT and TUW)
Heads: Radim Burget (BUT) and Franz Hlawatsch (TUW)

P3: Smart Transport
RG3: Radio-Frequency Systems Group (BUT and TUW)
Heads: Aleš Prokeš (BUT) and Christoph Mecklenbräuker (TUW)

P4: High Mobility Communications
RG4: Mobile Communications Group (BUT and TUW)
Heads: Roman Maršálek (BUT) and Markus Rupp (TUW)

P5: Advanced Cybersecurity
RG5: Security Group (BUT and TUW)
Heads: Jan Hajný (BUT) and Tanja Zseby (TUW)

P6: Advanced Antennas and Circuits
RG6: Antenna Group (BUT) and Microwave Engineering Group (TUW)
Heads: Zbyněk Raida (BUT) and Holger Arthaber (TUW)

P7: Awareness in Cyber-Physical Systems
RG7: IoT Group (BUT) and SoC Group (TUW)
Heads: Jaroslav Koton (BUT) and Axel Jantsch (TUW)

Each of the seven RG pairs will be supported by a pair of postdoctoral researchers with international experience, one based at BUT in Brno and one based at TUW in Vienna. Each pair of postdoctoral researchers will work jointly on research topics within the proposed project themes and oversee all research activities of the respective RG, both at BUT and at TUW. By this double assignment, we expect to achieve a tight connection between the respective BUT and TUW teams as well as collaborations between the seven RGs.

The pairs of postdoctoral researchers will be research incubators, attracting funding through various funding bodies in the Czech Republic and in Austria, e.g., GACR and FWF, as well as in collaboration with companies. The latter type of research will be supported either by local schemes (TACR, FFG) or at the EU level by forming or joining cooperative research projects.

ADWICE will offer its own funding scheme to build incentives for company-related funding but also to support long-term visions. The funding rate will depend on several factors and will favor long-term research, visionary content, multi-company efforts, and small and medium-sized enterprises (SMEs).

5. Interconnection of the ADWICE Research Projects

In accordance with and motivated by their common overarching theme, **"Smart Infrastructure for a Connected World"**, the seven RGs of **ADWICE** will work tightly together, stimulate each other, and benefit from related activities. In fact, the seven research projects have strong thematic overlaps that will foster collaboration, resulting in a multidisciplinary effort. **Table 1** summarizes the contributions exchanged by the individual projects. Each column describes output of a respective project to other projects, and accordingly each row describes input to a respective project from other projects. A more detailed and comprehensive discussion of the collaborations of the **ADWICE** research projects is provided in what follows. We note that descriptions of the individual research projects can be found in Sections **Chyba! Nenalezen zdroj odkazů.** through **Chyba! Nenalezen zdroj odkazů.**.

Knowledge Provider							
Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	
	Networked sensor data processing methods	Sensor requirements for transportation		Cryptographic technologies for sensor networks	Energy-efficient antennas and circuits for sensor systems	SoC integrated processing and control for sensors	Project 1
Sensor characteristics and sensor signals		Mobile and vehicular communications	Mobile and vehicular communications; constraints		Antenna characteristics	Implementation aspects of CPSs	Project 2
Sensing transducers for wireless sensor systems	Signal processing for communication and localization		Network characteristics	Lightweight cryptographic algorithms	Antenna characteristics; input for system-level simulation	Implementation aspects of CPSs	Project 3
Sensor characteristics and sensor signals	Physical layer signal processing; network optimization	High-speed channel modeling		Lightweight cryptographic and anomaly detection algorithms	Antenna characteristics; input for system-level simulation	Implementation aspects of CPSs	Project 4
Sensor characteristics and sensor signals	Support for development of signal processing methods					Implementation aspects of CPSs	Project 5
Energy harvesting; requirements on antennas and circuits		Requirements and constraints on antennas and circuits	Antenna requirements			Implementation aspects of CPSs; antenna requirements	Project 6
Sensor characteristics and sensor signals	Distributed signal processing methods for CPSs	Case scenarios and awareness requirements	Lightweight algorithms for peer group communication	Lightweight cryptographic algorithms	Antenna characteristics		Project 7

Knowledge Recipient

Table 1: Input/output relations of the ADWICE research projects.

P1 "Smart Sensor Systems"

***Input from other projects*:** P1 will use information about networked data processing from P2 "Networked Signal Processing"; sensory requirements in the field of transportation from P3 "Smart Transport"; cryptographic technologies for assuring data confidentiality and authenticity in sensor networks from P5 "Advanced Cybersecurity"; energy-efficient antenna and circuit concepts from P6 "Advanced Antennas and Circuits"; and solutions for system-on-chip (SoC) integrated processing and control from P7 "Awareness in Cyber-Physical Systems".

***Output to other projects*:** P1 will provide information about sensor characteristics and sensor signals to P2 "Networked Signal Processing", P4 "High Mobility Communications", P5 "Advanced Cyber-security", and P7 "Awareness in Cyber-Physical Systems"; sensing transducers tailored to wireless sensor systems for transport applications to P3 "Smart Transport"; and information about power generation by energy harvesting as well as requirements and constraints regarding antennas and circuits to P6 "Advanced Antennas and Circuits".

***Synergies with other projects*:** P1 will leverage synergies with P2 "Networked Signal Processing" (topic: analysis and processing of data generated by smart sensor networks), with P3 "Smart Transport" (topic: sensing transducers for sensor networks), with P5 "Advanced Cybersecurity" (topics: security aspects of sensor systems; design and practical deployment of lightweight cryptographic protocols); with P6 "Advanced Antennas and Circuits" (topics: energy harvesting; antenna integration; novel radiofrequency-based sensing concepts); and with P7 "Awareness in Cyber-Physical Systems" (topics: energy harvesting, on-chip energy storage, and zero-power systems).

P2 "Networked Signal Processing"

***Input from other projects*:** P2 will use information about sensor characteristics and sensor signals from P1 "Smart Sensor Systems"; expertise in mobile and vehicular communications from P3 "Smart Transport" and P4 "High Mobility Communications"; information about antenna and other hard-ware characteristics from P6 "Advanced Antennas and Circuits"; and information about hardware, implementation, and application aspects of cyber-physical systems from P7 "Awareness in Cyber-Physical Systems".

***Output to other projects*:** P2 will provide information about networked data processing results to P1 "Smart Sensor Systems"; statistical and distributed signal processing techniques for vehicular communications and vehicle localization to P3 "Smart Transport"; statistical signal processing techniques for physical layer system design and dynamic network optimization to P4 "High Mobility Communications"; support for the development of signal processing techniques to P5 "Advanced Cybersecurity"; and distributed signal processing techniques for cyber-physical systems to P7 "Awareness in Cyber-Physical Systems".

***Synergies with other projects*:** P2 will leverage synergies with P1 "Smart Sensor Systems" (topic: analysis and processing of data generated by smart sensor networks), with P3 "Smart Transport" (topics: mobile networks; signal processing and communication under delay constraints; localization, tracking, and navigation), with P4 "High Mobility Communications" (topics: mobile networks; device-to-device and low-delay communication; ad-hoc networking; dynamic network optimization), with P5 "Advanced Cybersecurity" (topic: development of signal processing and machine learning techniques for detection, classification, and estimation), and with P7 "Awareness in Cyber-Physical Sys-tems" (topics: situational awareness; implementation and application of distributed signal processing and machine learning techniques in cyber-physical systems).

P3 "Smart Transport"

***Input from other projects*:** P3 will use sensing transducers tailored to wireless sensor systems for transportation from P1 "Smart Sensor Systems"; advanced statistical and distributed signal processing techniques for vehicular communications and vehicle localization from P2 "Networked Signal Processing"; information on network characteristics from P4 "High Mobility Communications"; lightweight cryptographic schemes from P5 "Advanced Cybersecurity"; information about antenna and other hardware characteristics as well as input for system-level simulation from P6 "Advanced Antennas and Circuits"; and information about hardware, implementation, and application aspects of cyber-physical systems from P7 "Awareness in Cyber-Physical Systems".

***Output to other projects*:** P3 will provide sensory requirements in the field of transportation to P1 "Smart Sensor Systems"; expertise in mobile and vehicular communications to P2 "Networked Signal Processing"; expertise in modeling high-speed channels to P4 "High Mobility Communications"; requirements and constraints regarding antennas and circuits to P6 "Advanced Antennas and Circuits"; and case scenarios and awareness requirements to P7 "Awareness in Cyber-Physical Systems".

***Synergies with other projects*:** P3 will leverage synergies with P1 "Smart Sensor Systems" (topic: sensing transducers for sensor networks); P2 "Networked Signal Processing" (topics: mobile networks; signal processing and communication under delay constraints; localization, tracking, and navigation); P5 "Advanced Cybersecurity" (topics: design and practical deployment of lightweight cryptographic protocols; combination of cryptographic protection mechanisms and efficient communication technologies for use in vehicular networks); P6 "Advanced Antennas and Circuits" (topics: antenna design and optimization; antenna coupling; nonlinear effects); and P7 "Awareness in Cyber-Physical Systems" (topics: mobile networks; localization, tracking, and navigation).

P4 "High Mobility Communications"

***Input from other projects*:** P4 will use information about sensor systems and sensor signals provided by P1 "Smart Sensor Systems". P2 "Networked Signal Processing" will contribute statistical signal processing algorithms for physical layer system design and dynamic network optimization. The system design aspects of P4 will benefit from expertise in high-speed channel models provided by P3 "Smart Transport", and from information about antenna and other hardware characteristics as well as from input for system-level simulation provided by P6 "Advanced Antennas and Circuits". P5 "Advanced Cybersecurity" will supply methods for lightweight cryptography and anomaly detection. P7 "Awareness in Cyber-Physical Systems" will contribute information about hardware, implementation, and application aspects of cyber-physical systems.

***Output to other projects*:** P4 will provide expertise in mobile and vehicular communications and realistic constraints (e.g., in the context of HetNets) to P2 "Networked Signal Processing", and information on network characteristics to P3 "Smart Transport". Information about antenna requirements will be provided to P6 "Advanced Antennas and Circuits". Finally, lightweight algorithms for peer group communications will be delivered to P7 "Awareness in Cyber-Physical Systems".

***Synergies with other projects*:** P4 will leverage synergies with P2 "Networked Signal Processing" (topics: mobile networks; device-to-device and low-delay communication; ad-hoc networking; dynamic network optimization); P5 "Advanced Cybersecurity" (topics: security aspects for traffic control and energy systems; threats to network security; physical layer approaches; attack detection; situational awareness); P6 "Advanced Antennas and Circuits" (topics: antenna design and optimization; antenna coupling; nonlinear effects); and P7 "Awareness in Cyber-Physical Systems" (topic: dynamic network configuration).

P5 "Advanced Cybersecurity"

***Input from other projects*:** P5 will support the activities of the other projects as a security and privacy protection provider. Therefore, P5 will collect the relevant requirements of the other projects, e.g., regarding use cases and boundary conditions, demanded levels of security and privacy, desired computational and storage complexity, and implementation aspects. In addition, P5 will receive information about sensor systems and sensor signals from P1 "Smart Sensor Systems"; support for the development of statistical signal processing techniques from P2 "Networked Signal Processing"; and information about hardware, implementation, and application aspects of cyber-physical systems from P7 "Awareness in Cyber-Physical Systems".

***Output to other projects*:** P5 will provide P1 "Smart Sensor Systems" with cryptographic technologies for assuring data confidentiality and authenticity in sensor networks based on constrained devices. The lightweight cryptographic schemes developed by P5 will be applied by P3 "Smart Transport" and P4 "High Mobility Communications" to transportation systems and vehicular ad-hoc networks. P4 will also use network anomaly detection methods developed by P5. Finally, P5 will contribute lightweight cryptographic algorithms for secure communication to P7 "Awareness in Cyber-Physical Systems".

***Synergies with other projects*:** P5 will leverage synergies with P1 "Smart Sensor Systems" (topic: security aspects of sensor systems); with P2 "Networked Signal Processing" (topic: development of signal processing and machine learning techniques for detection, classification, and estimation); with P3 "Smart Transport" (topic: combination of cryptographic protection mechanisms and efficient communication technologies for use in vehicular networks); and with P4 "High Mobility Communications" (topics: security aspects for traffic control and energy systems; threats to network security; physical layer approaches; attack detection; situational awareness). With P1, P3, and P7 "Awareness in Cyber-Physical Systems", we expect to collaborate on the design and practical deployment of lightweight cryptographic protocols. By exploiting these synergies, it will be possible to design and implement secure communication systems even on very constrained devices.

P6 "Advanced Antennas and Circuits"

***Input from other projects*:** P6 will take into account requirements and constraints regarding antennas and circuits from P1 "Smart Sensor Systems", P3 "Smart Transport", P4 "High Mobility Communications", and P7 "Awareness in Cyber-Physical Systems". Furthermore, P6 will benefit from expertise in power generation by energy harvesting provided by P1 and from information about hardware, implementation, and application aspects of cyber-physical systems provided by P7.

***Output to other projects*:** P6 will provide energy-efficient antenna and circuit concepts for sensor systems to P1 "Smart Sensor Systems", and information about antenna and other hardware characteristics to P2 "Networked Signal Processing", P3 "Smart Transport", P4 "High Mobility Communications", and P7 "Awareness in Cyber-Physical Systems". Results of P6 on nonlinear techniques (e.g., nonlinear coupling in beam steering and massive MIMO arrays) will provide input for system-level simulation performed in P3 and P4.

***Synergies with other projects*:** P6 will leverage synergies with P1 "Smart Sensor Systems" (topics: energy harvesting; antenna integration; novel radiofrequency-based sensing concepts) and with P3 "Smart Transport" and P4 "High Mobility Communications" (topics: antenna design and optimization; antenna coupling; nonlinear effects).

P7 "Awareness in Cyber-Physical Systems"

***Input from other projects*:** P7 will use information about sensor characteristics and sensor signals provided by P1 "Smart Sensor Systems" and information about antenna and other hardware

characteristics provided by P6 "Advanced Antennas and Circuits" within implementations of cyber-physical systems featuring a required level of awareness. Furthermore, P7 will use distributed signal processing techniques for cyber-physical systems from P2 "Networked Signal Processing", case scenarios and awareness requirements from P3 "Smart Transport", and lightweight algorithms for peer group communication and secure communication from P4 "High Mobility Communications" and P5 "Advanced Cybersecurity", respectively.

***Output to other projects*:** P7 will provide P1 "Smart Sensor Systems" with solutions for SoC integrated processing and control that are suitable for sensor nodes. Furthermore, P7 will provide information about hardware, implementation, and application aspects of cyber-physical systems to P2 "Networked Signal Processing", P3 "Smart Transport", P4 "High Mobility Communications", P5 "Advanced Cybersecurity", and P6 "Advanced Antennas and Circuits". In addition, P7 will inform P6 about its requirements and constraints regarding antennas and circuits.

***Synergies with other projects*:** The focus of P7 is on the architecture, functions, and design of individual devices, which complements the work in other projects. P7 will leverage synergies with P1 "Smart Sensor Systems" (topics: energy harvesting; on-chip energy storage; zero-power systems), P2 "Networked Signal Processing" (topics: situational awareness; implementation and application of distributed signal processing and machine learning techniques in cyber-physical systems), P3 "Smart Transport" (topics: mobile networks; localization, tracking, and navigation), P4 "High Mobility Communications" (topic: dynamic network optimization), and P5 "Advanced Cybersecurity" (topic: design and practical deployment of lightweight cryptographic protocols).

6. EU Research Projects Relevant to ADWICE

Many ongoing and recent EU projects are related to our proposal and deserve mentioning. Our approach is, however, much broader, offering a larger portfolio of expertise and featuring a longer duration (seven years) than the typical EU project. With about 70 companies behind our endeavor, we expect a much deeper impact on local industry. In the following, we describe only the most relevant EU projects.

EU Projects Relevant to ADWICE Project 1 "Smart Sensor Systems"

SMART-MEMPHIS (Smart MEMs Piezo Based Energy Harvesting with Integrated Supercapacitor and Packaging, 2012–2015, http://www.smart-memphis.eu/): This project aimed to develop a power supply based on piezo-MEMS energy harvesters, ultra-low power ASIC based electronics for power management, and a carbon-nano material based supercapacitor as energy storage. The proposed application scenarios are cardiac pacemakers and wireless sensor networks for structure health monitoring of buildings, bridges or airplanes.

On a device level, **ADWICE Project 1** will focus on different materials for energy harvesting approaches such as enhanced aluminum nitride by doping, which combines CMOS compatibility and easy process integration into existing manufacturing lines with significantly improved piezoelectric properties. For energy storage, we will employ porous standard and advanced materials such as silicon or silicon carbide for supercapacitors as long-term energy storage as well as high-permittivity dielectrics based thin film capacitors for short-term energy storage.

ENIAC-END (Models, Solutions, Methods and Tools for Energy-aware Design, 2010–2013, http://www.eniac-end.org): This project targeted the development of innovative energy-aware design solutions and electronic design automation technologies for the next generation of nanoelectronics

circuits and systems, and of related energy generation, conversion and management systems. The outputs of the project are design tools and methodologies.

In contrast, **ADWICE Project 1** will focus on energy harvesting approaches based on micro-electro-mechanical systems (MEMS) in order to enable energy self-sufficient wireless sensor systems and sensor networks. In case of access to the results of ENIAC-END, we will be able to use the appropriate tools and methodologies in our own development.

ENIAC-MERCURE (Micro- and Nanotechnologies Based on Wide Band Gap Materials for Future Communication and Sensing Systems, 2010–2013, http://www.project-mercure.com): This project developed advanced semiconductor materials to provide functionality not previously available with silicon-based micro- or nanoelectronics. It aimed at enabling future ambient intelligence systems to achieve autonomous and self-reconfigurable operations with real-time and efficient self-optimisation of performance. Key applications include the future wireless communications market, which will expand to higher frequencies. Project results include materials for MEMS/NEMS switches, piezo-acoustic resonators, and mixed technology for smart micro and gallium nitride based nanosystems.

In contrast, **ADWICE Project 1** deals with materials and technologies that are mostly based on affordable and established standard Si technologies, allowing a quick and efficient transfer of the project results to industrial partners. If appropriate, results of ENIAC-END will be used in **ADWICE Project 1**.

ENSAFE (Active and Assisted Living Programme, 2015–2018, http://www.ensafe-aal.eu/home): This project aims at supporting effective prevention and self-care strategies for elderly people by creating smarter, more accessible and more versatile links among persons, their living environment, and the support network around them. This is going to be achieved by developing elderly-oriented, network-based services aimed at fostering independent life. The project just started and its results are still unknown. It is expected that networked devices including a smartphone with built-in, wearable and environment sensors will be developed for pilot applications in services.

As the project is focused on service-based applications, we expect only a small overlap with **ADWICE Project 1**. Indeed, **ADWICE Project 1** is focused mainly on wearable technologies to solve partial issues such as unobtrusive sensors, energy harvesting and storage, low-power systems and wireless communication.

EU Projects Relevant to ADWICE Project 2 "Networked Signal Processing"

CityPulse (Real-Time IoT Stream Processing and Large-scale Data Analytics for Smart City Applications, 2013–2016, http://www.ict-citypulse.eu/page/): This project aims at creating and providing innovative smart city applications by adopting an integrated approach to the Internet of Things (IoT) and the Internet of People, and by bringing together the two disciplines of knowledge-based computing and reliability testing. The considered use-cases include parking space availability prediction, real-time 3D maps, context-aware multimodal travel planning, mobility management, and efficient public transport.

In **ADWICE Project 2**, we will develop new distributed signal processing algorithms for the IoT environment expected in 5+ years. A further focus will be unstructured big data analysis – e.g., real-time video analysis – which will open up new possibilities regarding information extraction, visualization, and automation. The IoT-related smart city applications developed by CityPulse will provide interesting application scenarios for our algorithms.

BETaaS (Building the Environment for the Things as a Service, 2012–2015, http://www.betaas.eu/): Motivated by future IoT scenarios, this project developed a platform for the execution of machine-to-

machine (M2M) applications built on top of services deployed in a "local cloud" of gateways. Scalability, security, dependability, context- and resource-awareness, and quality-of-service are embedded into the platform by design. The platform was validated through experiments targeting the smart city and home automation use cases.

Because in **ADWICE** IoT and M2M scenarios as well as scalability aspects will play an important role, we expect that we will be able to build upon and benefit from the results of BETaaS, especially regarding potential applications and basic specifications of the signal processing algorithms we plan to develop.

iKaaS (Intelligent Knowledge-as-a-Service, 2014–2017, http://ikaas.com/): This project integrates three technological fields (IoT, big data, and cloud computing) to develop a secure data storage and privacy-preserving analytics engine over heterogeneous multi-cloud environments spanning across national borders. The goal is to build privacy, security, and trust into the storage, access and analysis capabilities by design instead of plugging in data protection mechanisms at a later stage.

In **ADWICE**, a focus will be on the development of new signal processing algorithms for IoT and big data scenarios, with an emphasis on decentralized networks, scalability, and robustness. While privacy and security aspects will not be a focus of **ADWICE Project 2**, the results of iKaaS may be useful for a potential implementation of our algorithms in heterogeneous multi-cloud environments, which pose specific challenges regarding real-time processing and streaming of big data sets and an effective management of resources.

RAWFIE (Road-, Air- and Water-based Future Internet Experimentation, 2015–2016, http://www.rawfie.eu): This project introduces a platform integrating numerous test beds of unmanned vehicles for research experimentation in vehicular, aerial and maritime environments. The underlying goal is the automated, remote operation of a large number of robotic devices for assessing the performance of different technologies in IoT, networking, sensing, and mobile/autonomic application domains.

The platform developed by RAWFIE will be of interest to **ADWICE** as a basis for evaluating the performance of the distributed signal processing algorithms to be developed in **ADWICE Project 2**. Our focus on sensing, cognition, and control in application scenarios related to IoT, networks, navigation, and mobility is in line with the general approach taken by RAWFIE.

REMPARK (Personal Health Device for the Remote and Autonomous Management of Parkinson's Disease, 2011–2015, http://www.rempark.eu): This project developed a personal health system with closed loop detection, response and treatment capabilities for the management of Parkinson's disease (PD) patients. The system comprises a wearable monitoring system identifying the motor status of PD patients during ambulatory conditions, a gait guidance system, and intelligent data analysis supported by a disease management system.

The results of REMPARK will be directly relevant to **ADWICE Project 2**, whose goals include the development of multimodal signal processing methods for monitoring PD. These methods will fuse and analyze time series of different modalities (speech, visual data related to handwriting and gait) in order to objectively evaluate a patient's condition, diagnose and monitor PD, estimate disease progress, and analyze the effects of specific treatments.

EU Projects Relevant to ADWICE Project 3 "Smart Transport"

HIGHTS (High Precision Positioning for Cooperative ITS Applications, 2015–2018, www.hights.eu): This project addresses high-precision positioning by combining traditional satellite systems using on-board sensing and infrastructure-based wireless communication technologies (e.g., Wi-Fi, ITS-G5, UWB tracking, Zigbee, Bluetooth, LTE,...) to produce highly accurate positioning technologies for

cooperative information technology services (C-ITS). Precise positioning is a key enabler for cooperative adaptive cruise control (CACC) and platooning, and will provide smoother driving conditions, optimization of traffic flows, and high-precision lane detection.

ADWICE Project 3 will further develop the localization techniques developed by HIGHTS. Besides on-board sensing and wireless communication technologies, also dedicated road-side units will be employed to enable road user localization using infrastructure sensors. The fusion of data from all of these systems will further minimize the localization error and improve the reliability of localization.

TIMON (Enhanced Real Time Services for an Optimized Multimodal Mobility Relying on Cooperative Networks and Open Data, 2015–2018, http://www.timon-project.eu/): This project focuses on problems related to congestion, traffic safety and environmental challenges that could be solved if people, vehicles, infrastructure and businesses were connected into a cooperative ecosystem. The creation of such an ecosystem is a key objective of the TIMON project. This ecosystem will rely on cooperative networks and open data, and will help increase the safety, sustainability, flexibility, and efficiency of road transport systems.

ADWICE Project 3 will not directly address the high-level functionalities targeted by TIMON (driver assistance services, services for vulnerable road users, multimodal dynamic commuter services, enhanced real time traffic application programming interface (API)). Instead, it will provide a common platform that will enable the implementation of all these functions.

DEWI (Dependable Embedded Wireless Infrastructure, 2014–2017, http://www.dewiproject.eu/): This project aims at providing key solutions for wireless seamless connectivity and interoperability in smart cities and infrastructures, with a focus on everyday physical environments of citizens in buildings, cars, trains, and airplanes. The objective of DEWI is to significantly contribute to the emerging smart home and smart public space.

ADWICE Project 3 will benefit from selected results of DEWI and will supplement them by its own research. These results are related to the system architecture, processes and methods addressing interoperability and cross-domain issues in the area of wireless sensor networks and wireless communication.

ICT COST Action IC1004 (Cooperative Radio Communications for Green Smart Environments, 2012–2015, http://www.ic1004.org/): In the framework of this COST Action, the national project *Channels and Energy Efficient Concepts for Low Power Green Smart Devices* was proposed. The research work covered the following topics: vehicular channels for intra-car localization and communication, cooperative spectrum scanning, low-power radio frequency identification, and standardization of energy-efficient smart devices.

In **ADWICE**, selected topics and results of this COST national project will be further developed and implemented, particularly those related to vehicular and urban environments, radio networks, channel modeling, contribution to standardization, and physical layer cooperation and relaying.

Further, more loosely related projects include **OPTIWISE (ICT COST Action IC1101 Optical Wireless Communications – An Emerging Technology, 2011–2015, http://opticwise.uop.gr/)** and **ACOST (Advanced Communication Systems and Technologies, 2009–2012, http://www.radio.feec.vutbr.cz/acost/).**

EU Projects Relevant to ADWICE Project 4 "High Mobility Communications"

PHYDYAS (Physical Layer for Dynamic Access and Cognitive Radio, 2008–2010, http://www.ict-phydyas.org): This project developed filter bank multi-carrier (FBMC) techniques for a better utilization

of spectrum and to support dynamic access spectrum management and cognitive radio. The focus was on waveform designs that avoid a guard time or cyclic prefix and that are better confined in the frequency domain to enable minimum guard bandwidth.

The aspects addressed by PHYDYAS are of general relevance to **ADWICE**. However, as a difference from **ADWICE Project 4**, PHYDYAS did not consider robustness to high mobility.

5GNOW (5th Generation Non-orthogonal Waveforms for Asynchronous Signaling, 2012–2015, http://www.5gnow.eu): This project aimed at removing the strict synchronism and orthogonality assumptions imposed by standards such as LTE to enable a more efficient support of machine-type communications, to avoid the huge synchronization overhead of very dense heterogeneous networks, and to better support carrier aggregation over fragmented spectrum. 5GNOW developed new PHY and MAC layer concepts that are better suited to meet the upcoming needs with respect to service variety and heterogeneous transmission setups. Again, high mobility was not in the focus of the project.

In **ADWICE Project 4**, we will continue similar approaches as in PHYDIAS and 5GNOW, however with better robustness to high-mobility scenarios and using more advanced FBMC filter designs including coding to minimize interference. Our measurement facilities will allow us to assess carefully the proposed advances in real physical environments.

METIS/METIS II (Mobile and Wireless Communications Enablers for 2020, 2012–2015 and 2015–, https://www.metis2020.com/): This project aims at laying the foundation for, and creating a European consensus on, the future (5G) global mobile and wireless communications system. It provides contributions to pre-standardization and regulation processes, and ensures European leadership in mobile and wireless communications. It thus considers the overall design of 5G mobile networks, which also includes support of mobility.

Our goals in **ADWICE Project 4** include a subset of the METIS goals, but our research efforts are more focused on high mobility. METIS-II will provide the 5G collaboration framework within 5G-PPP for a common evaluation of 5G radio access network concepts and prepare concerted action towards regulatory and standardization bodies. In **ADWICE**, such standardization efforts will be followed up on as it is important for the success of the Moravian industry to be involved in standardization results early on.

MAMMOET (Massive MIMO for Efficient Transmission, 2014–2016, http://mammoet-project.eu): This project advances the development of Massive MIMO for deployment in future broadband mobile networks by using several hundreds of base station antennas that operate phase-coherently together, simultaneously serving many tens of low-complexity single-antenna terminals in the same time-frequency resource. The objectives are to provide an understanding of the statistical nature of the relevant channels, to provide algorithms for distributed and scalable processing, to investigate which hardware components are suitable, to demonstrate the high potential of Massive MIMO, and to promote its use in future 3GPP standards.

In **ADWICE**, the findings of MAMMOET will be of interest, but as the focus of **ADWICE Project 4** is high mobility, the results of MAMMOET will have only little impact on our research directions.

mmMAGIC (Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications, 2015–2017, https://5g-mmmagic.eu/): This project will develop and design new concepts for mobile radio access technology (RAT) for mm-wave band deployment. This is envisaged as a key component in the 5G multi-RAT ecosystem and will be used as a foundation for global standardization. The project will thus enable ultrafast mobile broadband services for mobile users, supporting UHD/3D streaming, immersive applications, and ultra-responsive cloud services.

For **ADWICE Project 4**, novel mm-techniques will be of interest only in indoor scenarios as the high mobility of outdoor scenarios prevents their usage.

5G-NORMA (5G Novel Radio Multiservice Adaptive Network Architecture, 2015–2018, https://5gnorma.5g-ppp.eu/): The key objective of this project is to develop a conceptually novel, adaptive, future 5G mobile network architecture. This architecture aims at unprecedented levels of network customizability, ensuring stringent performance, security, cost and energy requirements to be met, as well as providing openness for API-driven architectures.

For **ADWICE Project 4**, it will be important to follow up on proposed architectures that may lead to a standardization of the first 5G networks.

Further, more loosely related projects include **iJoin (Interworking and Joint Design of an Open Access and Backhaul Network Architecture for Small Cells Based on Cloud Networks, 2012–2015)**, **TROPIC (Distributed Computing, Storage and Radio Resource Allocation over Cooperative Femtocells, 2012–2015)**, and **MOTO (Evolving Mobile Internet with Innovative Terminal-to-Terminal Offloading Technologies, 2012–2015)**.

EU Projects Relevant to ADWICE Project 5 "Advanced Cybersecurity"

ABC4Trust (Attribute-based Credentials for Trust, 2010–2015, https://abc4trust.eu/): The goal of this project was to address the federation and interchangeability of technologies that support trustworthy yet privacy-preserving Attribute-based Credentials (ABC). So far, credentials such as digitally signed pieces of personal information or other information used to authenticate or identify a user were not designed to respect the user's privacy. They inevitably reveal the identity of the holder even though the application at hand often needs much less information, for instance only the confirmation that the holder is a teenager or is eligible for social benefits.

Using own original past results [HAJ14, HAJ14a], **ADWICE Project 5** will address the weaknesses of existing ABCs, particularly missing features for credential revocation, and develop novel schemes addressing these weaknesses.

FutureID (Shaping the Future of Electronic Identity, 2014–, http://www.futureid.eu/): This project builds a comprehensive, flexible, privacy-aware and ubiquitously usable identity management infrastructure for Europe. It integrates existing electronic identity (eID) technology, trust infrastructures, emerging federated identity management services, and modern credential technologies. It creates a user-centric system for the trustworthy and accountable management of identity claims.

ADWICE Project 5 will focus on the development of next generation user-centric authentication systems that provide stronger security based on cryptographic constructions with provable properties. Also, the aspects of secure implementation will be addressed, in particular the use of tamper-resistant hardware, such as smart-cards and security tokens.

TAMPRES (Tamper Resistant Sensor Nodes, 2010–2014, http://www.tampres.eu/): This project aimed for security of constrained devices, particularly Internet of Things (IoT) devices. Protection against side-channel analysis and integration of lightweight cryptographic technologies were addressed from the hardware perspective.

ADWICE Project 5 will use the results of TAMPRES and improve the protection against information leakage from hardware by using new machine learning methods for side-channel attacks. These results will provide better protection against simple and differential cryptanalysis of smart-cards, tokens and hardware coprocessors.

EU Projects Relevant to ADWICE Project 6 "Advanced Antennas and Circuits"

FANTASTIC-5G (Flexible Air Interface for Scalable Service Delivery within Wireless Communication Networks of the 5th Generation, 2015–, http://fantastic5g.eu): This project will develop a new multi-service air interface (AI) for below 6 GHz through a modular design. To allow the system to adapt to the anticipated heterogeneity, the pursued properties are flexibility, scalability, versatility, efficiency, and feasibility for the future. The project will develop technical AI components and integrate them into an overall AI framework where adaptation to the sources of heterogeneity will be accomplished.

ADWICE Project 6 will develop an antenna design for AI that will enable an adaptation to changing scenarios by a reconfiguration of parameters such as polarization, beam shaping, and antenna tuning.

MAPS (Millimeter Wave Massive Arrays Enabling RFID/Radar Applications on 5G Smartphones, 2014–2016, http://cordis.europa.eu/project/rcn/195713_en.html): This project considers energy- and cost-efficient services that can be supported by massive antenna arrays in base stations, access points, or smartphones. The project targets technology for accurate localization and mapping provided by a personal radar in a smartphone where a number of antennas can be implemented thanks to the millimeter waves used, and for new services in device-to-device communication.

ADWICE Project 6 will address the problem of millimeter wave identification with a new tag design using a smart adaptive antenna with beam shaping. This will result in a further improvement of the performance of mapping and localization.

MiWaveS (Beyond 2020 Heterogeneous Wireless Network with Millimeter Wave Small Cell Access and Backhauling, 2014–2016, http://www.miwaves.eu): This project aims at developing key technologies for the implementation of mm-wave wireless access and backhaul in future 5G heterogeneous cellular mobile networks. Miniature mm-wave small-cell access points will be connected to the cellular network through optical fiber or mm-wave wireless backhaul to support massive data rates for mobile users.

ADWICE Project 6 will address the problem of mobile users with agile antenna systems whose multi-dimensional reconfiguration will offer greater data speeds and higher availability of connection. Active circuits incorporated in the antenna will mitigate undesired coupling and nonlinearities in the array.

LYNCEUS (People Localization for Safe Ship Evacuation during Emergency, 2012–2015, http://cordis.europa.eu/project/rcn/103573_en.html): This project investigated and demonstrated ultra-low-power wireless body-area-network technologies for enabling unobtrusive localization and tracking of people for onboard and overboard search and rescue as well as for safe evacuation of ships during an emergency. The project aimed to revolutionize emergency management and ship evacuation through the development of real-time systems enabling early localization and rescue of people in danger onboard a ship or in the sea.

ADWICE Project 6 will build on its expertise in RFID localization to improve the performance of techniques and systems for precision position measurement and counting in emergency situations.

EU Projects Relevant to ADWICE Project 7 "Awareness in Cyber-Physical Systems"

CyPhERS (Cyber-Physical European Roadmap and Strategy, 2013–2015, http://www.cyphers.eu/): This project produced a final document describing a research agenda and recommendations for actions. This analysis emphasizes the fusion of the disciplines sensors/actuators, communication, and control and lists as one of three dimensions of complexity the “self”, meaning self-documentation, self-monitoring, self-optimization, self-healing, and self-adapting.

ADWICE Project 7 is fully in line with this analysis and will address several of the challenges highlighted in this roadmap document. CyPhERS recognized that advanced cyber-physical systems will require relatively sophisticated models of the "self" and its environment, in order to react to unforeseen situations in ways not anticipated by the system designer. To cope with increasing challenges, cyber-physical systems must be equipped with cognitive, rather than only algorithmic capabilities.

CPSoS (Cyber-Physical Systems of Systems, 2014–2016, http://www.cpsos.eu): This Support Action aims at building constituencies for a European research and innovation agenda on systems of systems. It provides a forum and an exchange platform for systems of systems related communities and ongoing projects, focusing on the challenges posed by the engineering and operation of systems in which computing and communication systems interact with large complex physical systems. Its approach is both integrative, aiming at bringing together knowledge from different communities, and application-driven.

Several key features of CPSoS – dynamic reconfiguration, continuous evolution, and the possibility of emerging behavior – are in line with the objectives of **ADWICE Project 7**. While CPSoS formulates industrial challenges and application-oriented requirements and concludes that advanced cyber-physical systems will have to be partially autonomous, dynamically reconfigurable, continuously evolving, and self-organizing, **ADWICE Project 7** will develop architectures and methods to provide and acquire these skills in a bottom-up manner from hardware circuits to sensory systems. The strong focus of **ADWICE Project 7** on efficient realizations within tight power, energy, and cost constraints will lead to enabling technology for the realization of aware cyber-physical systems.

oCPS (Platform-aware Model-driven Optimization of Cyber-Physical Systems, 2015–2019, http://cordis.europa.eu/project/rcn/198500_en.html): This Marie Skłodowska-Curie Innovative Training Network aims at enabling the design of a new generation of cost-effective, quality-driven, and reliable cyber-physical systems. Its approach is to develop model-driven design methods that capture the interaction between different models at various design layers, take into account physical constraints and processes, and introduce platform-awareness at all levels.

These goals are consistent with those of **ADWICE Project 7**, but they are broader and encompass a larger set of topics ranging from resource-constrained design methods to platform-aware control systems and distributed coordination. **ADWICE Project 7** is more focused on the concept of awareness and how it can bring benefits to various resource-constrained cyber-physical systems. The TUW part of the **ADWICE Project 7** research group is a partner of oCPS and can thus leverage the results of that project.

The activities in **ADWICE Project 7** are also in line with the current cross-cutting call **Industry 2020 in the Circular Economy** and the activities that have been agreed upon within the European Commission Division C (2015), which target mainly Factories of the Future, the Internet of Things, and Smart and Sustainable Cities [ICE20]. In all these areas, the awareness of systems is identified as one of the key issues that need to be addressed.

7. Projects

Research groups established within the ADWICE project have worked out detailed research plans predicting visionary research in their domains to be conducted in years 2017 to 2023. Each research plan has a form of a specific medium-term research project analyzing state of the art, formulating motivations, presenting goals, methodology and work plan. Competences of the teams for conducting the planned research are documented by current publications, activities in international networks, and available research infrastructure.

Since the research projects contain a detailed description of know-how of ADWICE teams, we consider them to be private ones.

8. References

[CAH14] M. Cahlin: The high-tech house, 2014. [Online] http://thehightechhouse.weebly.com/

[CRE14] Credo Business Consulting LLP and Siemens AG: The mobility opportunity: Improving public transport to drive economic growth, 2014. [Online] www.siemens.com/press/mobility-opportunity

[ESP15] Global Trends to 2030: Can the EU meet the challenges ahead? [Online] http://europa.eu/espas/pdf/espas-report-2015.pdf

[ICE20] Horizon 2020, The EU Framework Programme for Research and Innovation. [Online] http://ec.europa.eu/programmes/horizon2020/en/h2020-section/cross-cutting-activities-focus-areas
Link to the document "Cross Cutting Activities": [Online] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-focus_en.pdf

[HAJ14] J. Hajny, L. Malina, P. Dzurenda, "Privacy-PAC: Privacy-enhanced physical access control," in A*CM CCS: WPES 2014 Proceedings*, USA, 2014, pp. 1–4.

[HAJ14a] J. Hajny, L. Malina, O. Tethal, "Privacy-friendly access control based on personal attributes," in *Proceedings of IWSEC 14, Lecture Notes in Computer Science*, LNCS, Springer, 2014, pp. 1–16.

[PEN15] H. Pentek, "2015: Design Principles for Industry 4.0 Scenarios," [Online] http://www.snom.mb.tu-dortmund.de/cms/de/forschung/Arbeitsberichte/Design-Principles-for-Industrie-4_0-Scenarios.pdf

[RAD12] H. M. Rad, "Introduction to Smart Grid," Texas Tech University, 2012. [Online] http://www.ee.ucr.edu/~hamed/Smart_Grid_Topic_2_Smart_Grid.pdf

[UNI14] United Nations. World Urbanization Prospects [Highlights], 2014 revision, 2014. [Online] www.esa.un.org/unpd/wup/