Internet of Things Evolution: A European Perspective

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Since 2009, the European Union (EU), through the IoT European Research Cluster (IERC), publishes Strategic Research Agendas (SRA) with short, medium and long term forecasts of development and research topics about the Internet of Things (IoT). The aim of this paper is to study the SRAs published since 2009 and, based on an extensive analysis and review, to make an identification of the relevant topics in the realm of IoT, in order to understand their evolution over time. This study involves the SRAs of 2009, 2011, 2014, 2015, 2016 and 2017. We are particularly interested in understanding the IoT technology development efforts over this period of almost a decade and the research areas that have already been explored, as well as those that have not received attention yet. In simple words, we aim to conclude about the dynamics of the IoT field in Europe and its probable evolution path.

Keywords: *Internet of Things, European Union, Strategic Research Agenda, IoT European Research Cluster, Alliance for Internet of Things Innovation.*

1. INTRODUCTION

The IoT European Research Cluster (IERC) is bringing together EU-funded projects with the purpose of defining a common vision and the IoT technology and development research challenges at the European level in view of global development. Since 2009, IERC publishes Strategic Research Agendas (SRA) with short, medium and long term forecasts of development and research topics about the Internet of Things (IoT) [1]. In the year of 2015, the EU established the Alliance of Internet of Things Innovation (AIOTI) as the entity responsible for defining policies and stimulus programs focusing specifically on identifying and removing obstacles, promoting fast learning, deployment and replication of Innovation in real scale experimentation in Europe [2]. This alliance includes the IERC in the Work Group 01 (WG 01) - the IoT Research Work Group. The WG 01 mission includes activities with the focus on defining an EU vision of IoT technology development and research challenges. IERC was established in 2007 and addresses the large potential of IoT-based capabilities in Europe and coordinates the convergence of ongoing activities.

The SRAs were published in the last years and have suffered constant updates. The first SRA was released in 2009 and IERC has published updates in 2011, 2014, 2015, 2016 and 2017. Since each SRA has many topics and objectives, it is not possible to describe them in detail but it is possible to define the changes/updates that they suffered in terms of dimension and give some explanations about the appearance of new topics and/or the disappearance of others.

The creation of the SRAs by the IERC through the years allowed the identification of a group of areas that are needed to successfully implement IoT in Europe, in both the short term and the long term. Since some of these areas weren't successfully implemented in the SRA they were intended initially, they have been postponed.

The purpose of this paper is to study the SRAs published in the years of 2009 [3], 2011 [4], 2014 [5], 2015 [6], 2016 [2] and 2017 [7]. Based on a detailed literature review, we aim to make an identification of the relevant topics in the realm of IoT, in order to understand their evolution over time. We are particularly interested in understanding the IoT technology development efforts and the research areas that have already been explored, as well as those that have not yet received sufficient attention.

Regarding the structure of this paper, in sections 2 and 3 very brief definitions of the IoT concept and the AIOTI organization are presented. In the following, in section 4 the various SRAs already published by IERC are described. In this section, the topics related to the area of technological development as well as the topics related to the research area are mentioned. Due to the extension of the goals of each topic, it is not possible to detail them; however, the number of changes / evolutions that they have suffered is presented and discussed. In section 5, the comparison between the different SRAs is carried out, identifying the topics that are interesting to both academic and research communities. Section 6 contains the conclusions.

2. INTERNET OF THINGS

Although IoT is a recent buzzword, it was nicknamed this way in the late 1990s. However, the concept was developed many years earlier, in the early 1980s, by a group of programmers at Carnegie Melon University

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who modified a Coca Cola machine by linking it to the Internet. The basic idea was to obtain information on the availability of the drink and also the time that the bottle spent inside the machine, to ensure that the beverage was chilled and thus prevent people from making the trip in vain [8]. It is a simple example, but it explains the concept.

Kevin Ashton is recognised as having used the term “Internet of Things” for the first time, in a 1999 presentation to a group of Procter & Gamble managers, trying to convince them about the benefits of connecting RFID, used in the P&G's supply chain, to the Internet [9]. According to Ashton, most of the roughly 50 petabytes of data available on the Internet were first captured and/or created by humans – by typing, taking a digital picture, scanning a bar code, etc. The problem is, humans are not so good at capturing data about events happening in the real world. Computers and all sorts of processing devices are much more able, fast and accurate in doing so.

In simple words, IoT might be defined as a global network infrastructure, connecting computing devices with sensing and/or actuating capabilities, collecting and exchanging data over the Internet, which is characterized by “smart” and self-configuring capabilities.

With IoT, everyday things that, in the past, had not much to do with the Internet are now becoming interconnected, providing 'smart services' to consumers of many industries. Indeed, many widely used products and services have become 'smarter' thanks to IoT. Nowadays, maybe the most well known examples to the general public come from the area of smart home technologies, in which IoT solutions are allowing us to save energy at home while providing more comfort in our daily lives. However, there are many other applications of IoT in several industries, such as healthcare, agriculture, tourism, transportation, and manufacturing, just to name a few. In the near future, IoT has the potential to influence every aspect of our lives with technologies such as smart homes, smart cities, smart manufacturing, smart traffic, smart transportation, and so on.

On the organizational field, the incorporation of IoT in the operational processes allows higher levels of flexibility, efficiency, innovation and responsiveness, providing a better support to the constantly evolving business requirements. Additionally, IoT generates large amounts of data, which might be used by organizations to create value. In this context, Big Data technologies can be used with Machine Learning, Artificial Intelligence, Data Mining, Analytics and other advanced technologies and methods, to help organizations in decision making, to identify operational weaknesses and to make business improvements.

Regarding Industry 4.0, also known as Industry IOT (IIoT), the seamlessly interconnection of devices installed in the production (shop floor) and logistic chain allows the autonomous interaction of production lines and logistic centers, increasing the efficiency of the value chain [10,11].

The IERC definition states that IoT is “A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual ‘things’ have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network” [4].

3. THE ALLIANCE FOR INTERNET OF THINGS INNOVATION

The AIOTI was formally launched on the 26th of March 2015. In the past, the Alliance has successfully contributed to the convergence and interoperability of IoT standards, as well as to Digitizing European Industry policy. To achieve the remainder of its mission the Alliance plans to engage with building IoT Innovation Ecosystems from the ground up, and to establish communication channels with startup ecosystems, early adopter communities, European regions, global IoT initiatives and new potential markets [12].

The AIOTI is divided in the following groups: Management Board (MB), General Assembly (GA), Work Groups (WG) and Steering Groups (SG). There are thirteen Work Groups, divided in four horizontal and nine vertical groups (see **Error! Reference source not found.**):

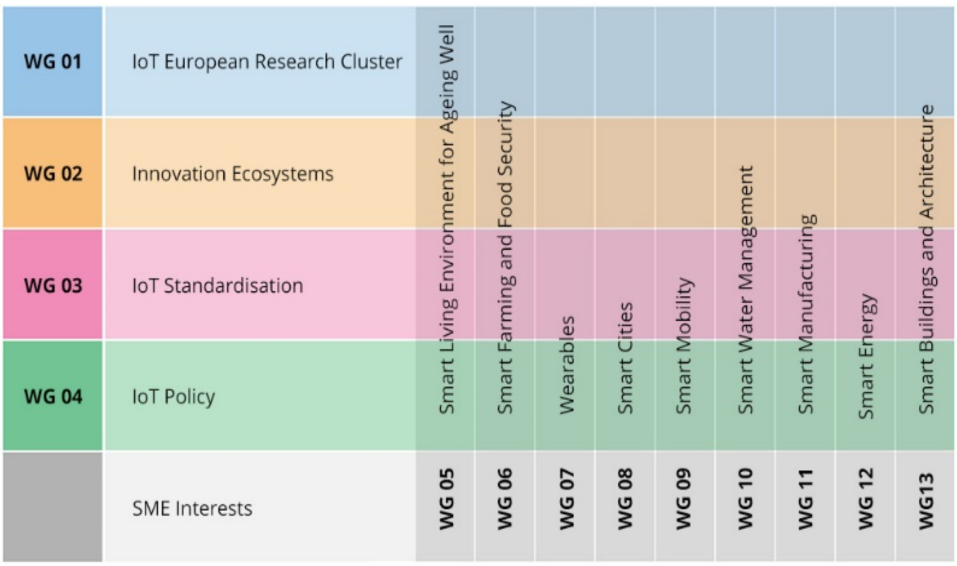

Figure 1. AIOTI Work Groups (from [12])

- **WG 01 – IoT European Research Cluster**, the IERC compares EU-funded innovation research and development programs, with the aim of defining a common vision of IoT technology and addressing European research challenges;
- **WG 02 – Innovation Ecosystems**, this WG aims at designing actions to develop innovation ecosystems by stimulating startups, encouraging the use of open IoT platforms, enabling Large Scale Pilots, and linking large and small companies through open innovation;
- **WG 03 – IoT Standardization**, this WG identifies and, where appropriate, makes recommendations to address existing IoT standards, analyses gaps in standardization, and develops strategies and use cases aiming for (1) consolidation of architectural frameworks, reference architectures, and architectural styles in the IoT space, (2) interoperability and (3) personal data & personal data protection to the various categories of stakeholders in the IoT space;
- **WG 04 – IoT Policy**, this WG identifies, and, where appropriate, makes recommendations to address existing and potential barriers that prevent or hamper the take-up of IoT in the context of the Digital Single Market;
- **WG 05 – Smart Living Environment for Ageing Well**, the topic for this WG refers to smart homes and smart living environments that can support vulnerable people, such as, but not limited to elderly or disabled people, in staying active, independent and out of institutional care settings, also leading to reduced costs for care systems and better quality of life for vulnerable categories of citizens. The WG deliverables include white papers, recommendation reports and innovative use cases susceptible to improve the quality of life of elderly people using the latest IoT technologies;
- **WG 06 – Smart Farming and Food Security**, the topic of this WG refers to IoT scenarios/use cases that allow monitoring and control of the plant and animal products life cycle "from farm to fork";
- **WG 07 – Wearables**, the topic for this WG refers to IoT solutions that integrate key technologies (nano, organic, sensing, actuating, communication, visualization, low power computing, and embedded software) into intelligent systems to bring new functionalities into clothes, other fabrics, patches, watches and other body-mounted devices. The WG focuses its work on healthcare, well-being, safety, security and infotainment applications;
- **WG 08 – Smart Cities**, the topic for this WG refers to IoT solutions used by a city in order to enhance performance, safety and wellbeing, to reduce costs and resource consumption, and to engage more effectively and actively with its citizens. Key 'smart city' sectors may include transport, energy, healthcare, lighting, water, waste and other city related sectors;
- **WG 09 – Smart Mobility**, the topic for this WG refers to IoT solutions that allow for increased multi-modal mobility, more efficient traffic management, a dynamic road infrastructure, automated road tolling, usage based insurance and improved policy making through the analysis of road usage data provided by smart vehicles including autonomous and connected cars;
- **WG 10 – Smart Water Management**, the topic for this WG refers to IoT solutions that improve water management efficiency by monitoring and controlling surface water retention, flooding, etc.;
- **WG 11 – Smart Manufacturing**, the topic for this WG refers to IoT solutions that bring together information, technology and human ingenious to achieve a rapid revolution in the development and application of manufacturing intelligence to every aspect of business;
- **WG 12 – Smart Energy**, the topic for this WG refers to IoT solutions deployed by various companies along the value chain (i.e. IoT technology providers, energy companies (in generation, supply, grid and market participants, traders, aggregators, etc.) to allow the performance optimization of their energy asset portfolios (Renewables plants, Grid Substations, Control Rooms, Prosumer Demand Responsive Loads and EV Charging infrastructures);
- **WG 13 – Smart Building and Architecture**, the topic of this WG is the IoT technologies and solutions deployed in buildings and districts of buildings to improve life of the occupant by addressing and optimizing elements such as comfort, light, temperature, air quality, water, nourishment, fitness, and energy usage.

Each WG has a Chair and a Co-Chair, nominated and elected among the WG's members. Every WG elects one representative for the SG. The SG members are the WG Chairs. They are assigned for a period of two years, to a maximum of six years (three periods). The EU Commission is a special member of the SG.

4. EUROPEAN RESEARCH CLUSTER ON THE INTERNET OF THINGS – SRAS

The European Union (EU) started the IERC due to the need to unite projects funded by the EU in the IoT area. The IERCs main purpose is to define a common vision as well as the technologies for IoT [1]. Nevertheless, IERC goals are more embracing because it aims to create and develop a unified vision of all the research on IoT in Europe, as well as a cooperation strategy with non-European entities in the IoT field.

The IERC has made available the so-called Strategic Research Agendas (SRAs) to achieve its goals. These SRAs aim to select evolution paths for IoT and divide the area into "Research" and "Development". In this context, fifteen (15) IoT development technology topics have emerged throughout the several SRAs [2-4,5,6]:

- **Identification Technology** – it includes all technology to allow the identification, and authentication to be operated at large scale, namely management of unique identifiers for physical objects and devices;
- **IoT Architecture Technology** – it includes a definition of an architecture to maximise interope-

rability among heterogeneous systems and distributed resources including providers and consumers of information and services;

- **Communication Technology** - it includes the development of communication technology with low power consumption, reduced size, and more integrated (e.g. on chip antennas);
- **Network Technology** – it includes the network infrastructure to support the IoT architecture to integrate wired and wireless technologies in a transparent and seamless way;
- **Software, Service and Algorithms** - it includes the interoperability layer to harmonize the access to the different devices with a common language and procedure;
- **Hardware Devices** – it includes hardware and parallel processing in ultra-low power multi-processor system on chip that handle situations not predictable at design time with the capability of self adaptiveness and self-organization;
- **Data and Signal Processing Technology** – it includes the cyber physical devices to be web enabled, i.e., transform the things/objects to be smart, i.e., to increase communication and cognitive capabilities;
- **Discovery and Search Engine Technologies** – it includes some kind of search engines to discover resources like sensors, actuators and services. Thus, it is possible to know the resources capabilities (e.g., type of sensor/actuator/services offered), their location and/or the information they can provide (e.g., indexed by the unique IDs of objects, transactions etc.);
- **Power and Energy Technologies** – it includes all devices that need some power source to work, such as active communication and object condition monitoring. Thus, it is relevant to develop, for instance, miniature high-capacity energy storage technologies;
- **Security, Privacy & Trust Technologies** – it includes security challenges and techniques across multiple policies to ensure an easy and safe user control, because users have to trust that when they use the IoT there are no risks to their security and privacy;
- **Material Technology** – it includes the development and use of new materials (like diamond, carbon nanotubes, conducting polymers, graphene, etc.) to improve/build new semiconductor capable to support high temperatures;
- **Standardization** – it includes the use of standards to converge to a common reference model, reference architecture for the future networks, future internet and IoT and integration of legacy systems and networks;
- **IoT Infrastructure** – it includes the foundations of IoT solutions and it intends to integrate different applications, providers, and infrastructures;
- **IoT Applications** – it includes solutions and standards to embrace several IoT applications, for instance, IoT food/water production and tracing, IoT in manufacturing industry, IoT in industrial lifelong service and maintenance, IoT devices with strong processing and analytics capabilities. In resume, applications capable of handling heterogeneous high capability data collection and processing infrastructures;
- **Interoperability** – it includes dynamic and adaptable interoperability for technical and semantic areas, such as open platform for IoT.

In addition to the fifteen (15) IoT development technology topics mentioned above, the following six topics also appear in the IERC IoT research agenda, making a total of twenty one (21) research topics [1]:

- **IoT Architecture** – it includes research about extranets, i.e., Extranet of Things (EoT). The EoT represents partner to partner applications, basic interoperability of billions-of-things;
- **SOA Software Services for IoT** – it includes composed IoT services, i.e., IoT services composed of other services, single domain, single administrative entity;
- **Hardware Systems, Circuits and Architectures** – it includes hardware systems with multi-protocol front-ends and improvements in: communication range; transmission speeds; distributed control and databases; multi-band, multi-mode wireless sensor architectures; smart systems on tags with sensing and actuating capabilities (temperature, pressure, humidity, display, keypads, actuators, etc.); ultra-low power chipsets to increase operational range (passive tags) and increased energy life (semi passive, active tags, etc.); ultra-low cost chips with security; and collision free air to air protocol;
- **Societal Responsibility** – it includes the identification of societal trends, these trends are grouped as: health and wellness, transport and mobility, security and safety, energy and environment, communication and e-society;
- **Governance (Legal Aspects)** – it includes legal framework for transparency of IoT bodies and organizations by adoption of clear European norms/standards regarding privacy and security for IoT;
- **Economic** – It includes the study of business cases and value chains for IoT, in terms of the emergence of IoT in different industrial sectors.

The SRAs were published in the last years and they have suffered constant updates. The first SRA was released in 2009 and more have been issued in 2011, 2014, 2015, 2016 and 2017. These SRAs aim to select research and development fields as paths for the future. Since each SRA has numerous topics and objectives, it is not possible to describe them here in detail, but it is possible to define the changes/updates that they suffered in terms of dimension.

4.1 SRA 2009

This was the first SRA to be issued by the IERC, two years after the creation of the work team that started work in the initial IoT concept. In this first SRA a survey of the areas in which IoT is or may be present was accomplished, while identifying the areas that deserve greater attention by the practitioners and research community [3].

The 2009 SRA became the foundation for the remaining SRAs that were published in the following years. The SRA identifies several topics divided into two areas: what needs to be included in "Development" at the technological level; and what needs to be included in "Research" in order to address existing needs.

In the IoT "Development" area, more precisely at the technological level, the 2009 SRA identifies twelve topics, namely [3]: (1) Identification Technology, (2) IoT Architecture Technology, (3) Communication Technology, (4) Network Technology, (5) Software and Algorithms, (6) Hardware Devices, (7) Data and Signal Processing Technology, (8) Discovery and Search Engine Technologies, (9) Power and Energy Technologies, (10) Security, Privacy & Trust Technologies, (11) Material Technology and (12) Standardization.

In the "Research" area the 2009 SRA identifies fifteen topics, namely [3]: (1) Identification Technology, (2) IoT Architecture, (3) SOA Software Services for IoT, (4) IoT Architecture Technology, (5) Communication Technology; (6) Network Technology; (7) Software and Algorithms, (8) Hardware Devices, (9) Hardware Systems, Circuits and Architectures, (10) Data and Signal Processing Technology, (11) Discovery and Search Engine Technologies, (12) Power and Energy Technologies, (13) Security, Privacy & Trust Technologies, (14) Material Technology, (15) Standardization.

These topics are divided chronologically by four temporal periods: the first is the time period before 2010, the second is in an interval of years between 2010 and 2015, the third period is in another interval of years between 2015 and 2020 and finally the last period corresponds the years beyond 2020. This SRA is the only one that has incorporated the time period before 2010, so this time period is not considered in this study.

4.2 SRA 2011

The SRA 2011 [4] continues the work carried out by the previous SRA, published only two years before. However, the time periods applied in the SRA 2011 were adjusted to the date. Therefore, the first period corresponds to the years from 2011 to 2015, the second from 2015 to 2020 and finally the third time period is beyond 2020.

In this SRA [4] most of the topics have remained unchanged. However, three topics have undergone changes, one in "Development" at the technological level, the topic (6) Hardware Devices has incorporated the addition of another goal for the interval from 2011 to 2015. This goal consisted in the integration of NFC (Near Field Communication) in mobile phones and Sensors.

The other two topics were in the "Research" area. For the interval from 2011 to 2015 the topic (1) Identification Technology has incorporated a new goal (Convergence of IP and IDs and addressing scheme) and the topic (6) Network Technology has incorporated another goal (incorporating systems based on RFID sensors). Only three new goals were added in all the time periods present in the SRA 2011, as might be seen in Figures 2 and 3.

4.3 SRA 2014

The SRA 2014 [5] introduces some differences in relation to the previous SRAs, mainly due to the development and research in IoT being more mature. Once again, the temporal periods used in this SRA have been adjusted to the date it was published.

As the knowledge about the IoT filed increases, new topics have emerged. More specifically, in this SRA, there are eight new topics that are divided as follows: three new topics for "Development" (see Figure 2), and five new topics for "Research" (see Figure 4).

Summarising, in the "Development" area the topic (1) Identification Technology had seven goals in 2012 and now has six. Topic (2) IoT Architecture Technology changed from eight to six goals. Topic (3) Communication Technology augmented from seven to eight goals. Topic (4) Network Technology diminished from eight to seven goals. Topic (5) Software and Algorithms changed from twelve to thirteen goals. Topic (6) Hardware reduced from nine to five goals. Topic (7) Data and Signal Processing Technology changed from four to three goals. Topic (8) Discovery and Search Engine Technology changed from five to four goals. Topic (9) Power and Energy Storage Technology changed from nine to seven goals. Topic (10) Security, Privacy and Trust Technology reduced from fourteen to ten goals. Topic (11) Material Technology changed from five to four goals. Topic (12) Standardization decreased from seven to five goals. Topic (13) IoT Infrastructure changed from seven to six goals. Topic (14) IoT Applications increased from four to eight goals. The new topic (15) Interoperability has five goals.

In the "Research" area the topic (1) Identification Technology had seven goals in 2012 and now has six. Topic (2) IoT Architecture change from two to one goal. Topic (3) SOA Software Services for IoT reduced from six to four goals. Topic (4) IoT Architecture Technology change from thirteen to twelve goals. Topic (5) Communication Technology augment from eight to eleven goals. Topic (6) Network Technology change from fourteen to thirteen goals. Topic (7) Software and Algorithms maintain the same fourteen goals. Topic (8) Hardware Devices reduce from twenty-three to seventeen goals. Topic (9) Hardware Systems, Circuits and Architectures reduced from twenty to fourteen goals. Topic (10) Data and Signal Processing Technology maintain the same five goals. Topic (11) Discovery and Search Engine Technology maintain the same seven goals. Topic (12) Power and Energy Storage Technology reduce from ten to six goals. Topic (13) Security, Privacy and Trust Technology reduced from twenty to sixteen goals. Topic (14) Material Technology change from seven to four goals. Topic (15) Standardization has zero goals, so this topic is no long be considered. Topic (16) IoT Infrastructure change from six to five goals. Topic (17) IoT Applications increase from five to nine goals. Topic (18) Societal Responsibility has zero goals, so this topic is no long be considered. Topic (19) Governance (Legal Aspects) maintains the same three goals. Topic (20) Economic change from one to two goals. Finally, the new topic (21) Interoperability has three goals

To recapitulate, in addition to the new topics, in the SRA 2014 a total of one hundred forty-three new goals distributed across different areas and topics were added, in addition to being distributed over different time periods.

4.4 SRA 2015

The SRA 2015 [6] includes only two time periods, one is the time period 2015-2020 and the other is beyond 2020. There are very few changes in this SRA compared to the previous SRA. In the "Development" area, three topics have suffered changes in the number of goals, see Figure 2. In the "Research" area, four topics differ from the previous version, see Figure 4.

4.5 SRA 2016

The SRA 2016 [2] brought relevant changes in the number of goals for both "Development" and "Research" areas. The topic Material Technology has now zero goals in both areas, "Development" – topic 11, see Figure 2, and "Research" – topic 14. The same occurs to topic 15 (Standardization) in "Research" area, see Figure 4.

In the "Development" area, in the time period of 2016-2020, four topics increase the number of goals: one in the topic (2) IoT Architecture Technology, one in topic (5) Software and Algorithms, two in topic (3) Communication Technology and three in topic (14) IoT Applications. For the time period beyond 2020, five topics increase the number of goals, topic (1) Identification Technology has a new goal, topic (3) has one new goal, topic (10) Security, Privacy and Trust Technology has three new goals, topic (14) has ten new goals and topic (15) Interoperability has one more goal.

In the "Research" area, to the time period of 2016-2020, eight topics change their number of goals: five new goals to topic (3) SOA Software Services for IoT, reduction from twelve to ten goals in topic (7) Software and Algorithms, two more goals in topic (8) Hardware Devices, one more goal in topic (9) Hardware Systems, Circuits and Architectures, two more goals in topic (10) Data and Signal Processing Technology, reduction of one goal in topic (17) IoT Applications, increase of two goals in topic (19) Governance (Legal Aspects), and one more goal in topic (20) Economic

4.6 SRA 2017

In comparison to the previous SRAs, the 2017 SRA suffered major changes regarding structure, as the topics were not organized anymore in the same way. The SRA 2017 simply proposes a list of major open research challenges for the future of IoT, such as [7]:

- IoT architectures considering the requirements of distributed intelligence at the edge, cognition, AI, context awareness, tactile applications, heterogeneous devices, end-to-end security, privacy and reliability;
- IoT systems architectures integrated with network architecture forming a knowledge-centric network for IoT;
- Intelligence and context awareness at the IoT edge, using advanced distributed predictive analytics;
- IoT applications that anticipate human and machine behaviours for social support;
- Tactile IoT applications and supportive technologies;
- Augmented reality and virtual reality IoT applications;
- Autonomics in IoT towards the Internet of Autonomous Things (IoAT);
- Inclusion of robotics in the IoT towards the Internet of Robotic Things (IoRT);
- Artificial Intelligence (IA) and Machine Learning (ML) mechanisms for automating IoT processes;
- Distributed IoT systems using securely interconnected and synchronized mobile edge IoT clouds;
- Stronger distributed and end-to-end holistic security solutions for IoT, addressing also key aspects of remotely controlling IoT devices;
- Stronger privacy solutions, considering the new General Data Protection Regulation for protecting the users' personal data from unauthorized access, employing protective measures as closer to the user as possible;
- Cross-layer optimization of networking, analytics, security, communication and intelligence;
- IoT-specific heterogeneous networking technologies that consider the diverse requirements of IoT applications, mobile IoT devices, delay tolerant networks, energy consumption, bidirectional communication interfaces that dynamically change characteristics to adapt to application needs, dynamic spectrum access for wireless devices, and multi-radio IoT devices;
- Adaptation of software defined radio and software defined networking technologies in the IoT.

Such as in the previous SRAs, IERC describes the major changes that occurs in the IoT technologies and Applications. The Research Cluster proposes a set of IoT Use Cases and Applications [7]:

- **Wearables** – the technological innovations are pushing wearables into IoT applications for instance: health care, education, smart cities and smart vehicles;
- **Smart Health, Wellness and Ageing Well** – to enable the health professionals to spend more time on direct patient contact and treatment [13]; The Internet of Health (IoH) will allow the citizens to be more involved with their healthcare by accessing to medical records, tracking the vitals signals with wearables devices, getting diagnostics results, and monitoring health habits with web-based applications on smart mobile devices;
- **Smart Buildings and Architecture** – the Internet of Building (IoB) and Building Internet of Things (BIoT) appears to improve life of the building

occupants, this implies many aspects including light comfort, temperature, air quality, security, having access to services, adapting the behavior to the needs of the occupants. There is also a direct economic interest to do it as it is recognized that productivity level is connected to the comfort level, as well the reduction of power energy consumption. The different ingredients of IoT, such as connectivity, control, cloud computing, data analytics, can all contribute to make smarter buildings (offices, industrial, residential, tertiary, hotels, hospitals, etc.) more efficient;

- **Smart Energy** – the development of Internet of Energy (IoE) concept as network infrastructure based on standard and interoperable communication to control an intelligent and flexible power grid to react to power fluctuations in terms of consumption and production;
- **Smart Mobility and Transport** – the Internet of Vehicles (IoV) connected with IoE, for providing services in an increasingly electrified future mobility industry. The emergence of autonomous vehicles (SAE level 5, full automation) in different use case scenarios, using local and distributed information and intelligence is based on real-time reliable platforms managing mixed mission and safety critical vehicle services, advanced sensors/ actuators, navigation and cognitive decision-making technology, interconnectivity between vehicles (V2V) and vehicle to infrastructure (V2I) communication.

5. DISCUSSION OF SRAS EVOLUTION

Regarding the "Development" area, all topics and number of goals are presented in Figure 2. In this figure, it is possible to observe the evolution of the goals that each topic underwent throughout the various SRAs. The first line represents all the topics published, the columns represent the fifteen topics and the lines represent the five SRAs (2009, 2011, 2014, 2015 and 2016) with the various time periods. Each cell on the table contains a numeral that represents the number of goals that each topic had in each SRA (depending on the time period). A hyphen (-) means that the topic was not covered in the specific SRA and time period.

Regarding the IoT Technology "Development" area (see Figure 2), the topic 14 (IoT Applications) has to be highlighted because this topic has only been included in the SRA 2014, starting with seven goals, evolving to twelve goals in the SRA 2015. In the SRA 2016 this topic raised to twenty-one goals, which is the highest value in the SRA.

There are two other topics with high importance: topic 3 (Communication Technology) with a growth from eight goals in the SRA 2014 to eleven goals in the SRA 2016 and topic 10 (Security, Privacy and Trust Technology), which presented ten goals in the SRA 2014, evolving to thirteen goals in the 2016 SRA. Topic 5 (Software and Algorithms) has a persistently high number of goals in all SRAs (12/13 goals). The other topics have an almost constant number of goals in the five SRAs.

Figure 3 represents graphically the evolution of each topic of the IoT Technology "Development" Area, from the SRA 2009 to the SRA 2016, beyond 2020.

Regarding the IoT "Research" area, Figure 4 contains all the data concerning the number of goals for every topic in each of the SRAs, during the defined periods.

Comparing the SRA 2009 to the SRA 2011 one verifies that the SRA 2011 reflects a greater concern in defining some topics that were not defined in the SRA 2009, as is the case of topic 6 (Network Technology) that was adapted to the reality of the area of IoT [3,4].

SRAs	Topic	Identification Technology 1	IoT Architecture Technology 2	Communication Technology 3	Network Technology 4	Software and Algorithms 5	Hardware Devices 6	Data and Signal Processing Technology 7	Discovery and Search Engine Technology 8	Power and Energy Technologies 9	Security, Privacy & Trust Technologies 10	Material Technology 11	Standardization 12	IoT Infrastructure 13	IoT Applications 14	Interoperability 15
SRA 2009	Before 2010	3	3	1	1	6	5	3	2	6	2	2	2	-	-	-
	2010-2015	3	4	5	5	4	3	2	2	3	3	3	3	-	-	-
	2015-2020	3	2	1	1	3	2	1	1	4	3	1	1	-	-	-
	Beyond 2020	1	2	1	2	5	1	1	2	2	1	-	1	-	-	-
SRA 2011	2011-2015	3	4	5	5	4	4	2	2	3	3	3	3	-	-	-
	2015-2020	3	2	1	1	3	2	1	1	4	3	1	1	-	-	-
	Beyond 2020	1	2	1	2	5	1	1	2	2	1	-	1	-	-	-
SRA 2014	2015-2020	5	4	6	4	6	4	2	2	5	8	2	4	4	6	4
	Beyond 2020	1	2	2	3	6	1	1	2	2	2	2	1	2	1	1
SRA 2015	2015-2020	5	5	6	4	6	4	2	2	5	8	2	4	4	6	4
	Beyond 2020	2	2	2	3	6	1	1	2	2	2	2	1	2	6	1
SRA 2016	2016-2020	5	5	8	4	7	4	2	2	5	8	-	4	4	9	4
	Beyond 2020	3	2	3	3	6	1	1	2	2	5	-	1	2	12	2

Figure 2. IoT Technology "Development" Area – SRAs comparison

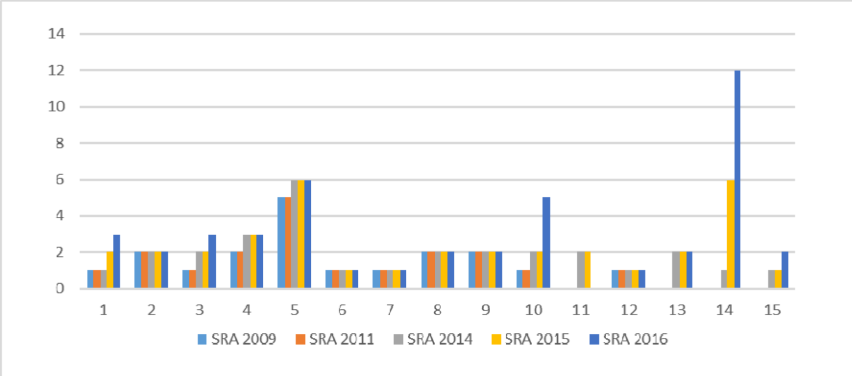

Figure 3. IoT Technology "Development" Area Evolution – Beyond 2020

SRAs	Topic	Identification Technology 1	IoT Architecture 2	SOA Software Services for IoT 3	IoT Architecture Technology 4	Communication Technology 5	Network Technology 6	Software and Algorithms 7	Hardware Devices 8	Hardware Systems, Circuits and Architectures 9	Data and Signal Processing Technology 10	Discovery and Search Engine Technologies 11	Power and Energy Technology 12	Security, Privacy & Trust Technology 13	Material Technology 14	Standardization 15	IoT Infrastructure 16	IoT Applications 17	Governance (Legal Aspects) 18	Economic 19	Interoperability 20
SRA 2009	Before 2010	2	1	1	6	1	4	6	12	6	4	3	5	1	2	4	-	-	-	-	-
	2010-2015	4	1	1	7	4	6	8	12	10	2	4	6	2	5	3	-	-	-	-	-
	2015-2020	1	1	1	5	3	3	4	9	6	2	2	3	4	1	2	-	-	-	-	-
	Beyond 2020	1	-	-	1	1	4	2	2	2	1	1	1	1	-	2	-	-	-	-	-
SRA 2011	2011-2015	5	1	1	7	4	7	8	12	10	2	4	6	2	5	3	-	-	-	-	-
	2015-2020	1	1	1	5	3	3	4	9	6	2	2	3	4	1	2	-	-	-	-	-
	Beyond 2020	1	-	-	1	1	4	2	2	2	1	1	1	1	-	2	-	-	-	-	-
SRA 2014	2015-2020	5	1	3	8	10	8	12	15	12	4	6	5	13	3	-	4	7	2	2	2
	Beyond 2020	1	-	1	4	1	5	2	2	2	1	1	1	3	1	-	1	2	1	-	1
SRA 2015	2015-2020	5	1	3	7	10	8	12	15	12	6	6	5	13	3	4	4	6	2	2	2
	Beyond 2020	1	-	1	4	1	5	2	2	2	2	1	1	3	1	1	1	2	1	1	1
SRA 2016	2016-2020	5	1	8	8	10	8	10	17	13	6	6	5	13	-	-	4	6	4	3	2
	Beyond 2020	1	3	2	4	2	5	6	3	2	1	3	1	5	-	-	3	6	2	3	1

Figure 4. IoT "Research" Area – SRAs comparison

Comparing now the SRA 2011 and SRA 2014, one can conclude that the SRA 2014 presents five new topics. When analysing the topics that are being added we can verify the existence of the first concerns regarding the impact of the implementation of IoT in the society, e.g., topics like 17 (IoT Applications), 18 (Governance (Legal Aspects)) and 19 (Economic). Through the observation of the goals that appear in this SRA, one concludes that the goals are related to two subjects, namely: processes, with the creation of infrastructures/ standards that allow the integration of IoT; and the use in an industrial environment with sensors.

Related to topic 13 (Security, Privacy and Trust Technology), there is a higher number of goals that focus on privacy techniques to remain anonymous, techniques that ensure users' privacy as well as their data, new methods for assessing trust in devices and data and methods to ensure platform and data security. However, in the SRA 2014 there is a situation that needs to be emphasized, which consists in the suppression of the topic 15 (Standardization), which appears again in the SRA 2015. This is justified by the redefinition and new placement of its goals to other topics [4,5] (Figure 4).

Regarding the comparison between years 2011 and 2014, the latter is already focused on the time period from 2015 to 2020. In this comparison, the number of goals that were delayed between the SRA 2011 and SRA 2014 are highlighted. In the SRA 2014 a total of one hundred and twenty-two goals (122) were identified. These goals are spread over nineteen topics for the time period between 2015 and 2020, with forty-seven of these goals being carried over from the previous time period (because they were not fulfilled in a timely manner) and twenty-eight new goals have emerged. Two topics stand out: topic 17 (IoT Applications), which includes mobile applications for IoT; and topic 5 (Communications Technology) which includes the new networks, as is the case of 5G referenced in the goals of the SRA 2014.

Lastly, the comparison between the SRA 2014 and SRA 2016 is carried out. The first highlight is that the number of goals increased from one hundred forty eight (148) to one hundred eighty-two (182), which represents a growth of thirty-four goals. This happens essentially in the time period of beyond 2020. Generally, all topics increased the number of goals for all time periods, but in the time period of beyond 2020 the number of goals increased from thirty in SRA 2014 to fifty-three in SRA

2016, which represents an increase rate of 77%. However, the topic 14 (Material Technology) was suppressed. It is concluded that the SRA 2016 presents a higher number of goals when comparing with the previous SRAs as a result of the higher number of goals for almost all topics in the time period of beyond 2020 [2,5]. These issues may be observed in Figure 4.

Figure 5 represents graphically the evolution of each topic of the IoT "Research" Area, from the SRA 2009 to the SRA 2016, beyond 2020.

Figure 6 compares the numerical representation of goals in all topics of both areas "Development" and "Research" in IoT. The interpretation of Figure 6 is similar to Figures 2 and 4. Every topic is associated with two values. The first value corresponds to the IoT "Development" area, the second value relates to the IoT "Research" area.

Regarding "Research", this study allow us to conclude that there are many relevant topics for those who want to research in the IoT field. Obviously, regarding the "Development" area, it is considered that the market already responds and will continue to respond to the needs of IoT.

In the IoT "Research" area, the topic 15/20 (Interoperability) is one of the most important, because "things" need protocols to communicate (3/5 – Communication Technology) with other "things" by using (4/6 - Network Technology).

To accomplish that there is a need for a (-/2 - IoT Architecture). In this IoT ecosystem there is also the need for providing services (-/3 - SOA Software Services for IoT). These services are delivered by (14/17 - IoT Applications). These applications will be executed on (6/8 - Hardware devices) in a secure way (10/13 - Security, Privacy & Trust Technologies) and should return value (-/19 Economic). We consider that these topics may be relevant to research, especially in the actual state of maturity of IoT.

The topic (-/18 - Governance (legal aspects)) could also be considered but, as was mentioned above, IoT has not yet reached the level of maturity necessary to consider these kind of topics.

In the SRA 2017, these topics are not directly identified, as in previous SRAs, but the relevance of research and development in those topics remains the same or has increased.

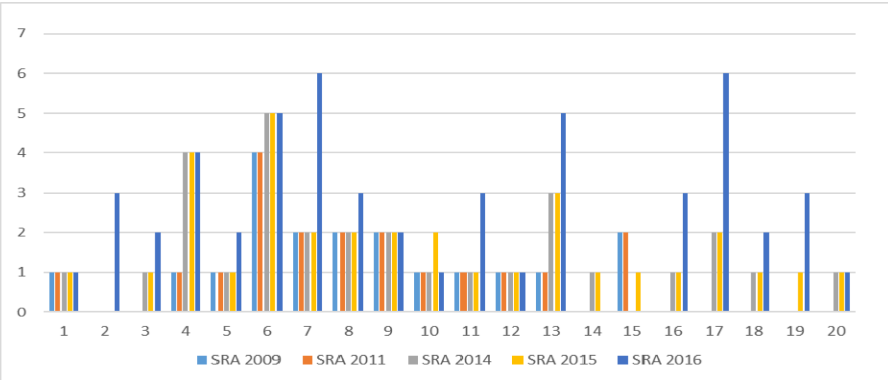

Figure 5. IoT "Research" Area Evolution – Beyond 2020

SRAs \ Topic		Identification Technology 1/1	IoT Architecture -/2	SOA Software Services for IoT -/3	IoT Architecture Technology 2/4	Communication Technology 3/5	Network Technology 4/6	Software and Algorithms 5/7	Hardware Devices 6/8	Hardware Systems, Circuits and Architectures -/9	Data and Signal Processing Technology 7/10	Discovery and Search Engine Technology 8/11	Power and Energy Technologies 9/12	Security, Privacy & Trust Technologies 10/13	Material Technology 11/14	Standardization 12/15	IoT Infrastructure 13/16	IoT Applications 14/17	Governance (Legal Aspects) -/18	Economic -/19	Interoperability 15/20
2009 SRA	Before 2010	3/2	-/1	-/1	3/6	1/1	1/4	6/6	5/12	-/6	3/4	2/3	6/5	2/1	2/2	2/4	-/-	-/-	-/-	-/-	-/-
	2010-2015	3/4	-/1	-/1	4/7	5/4	5/6	4/8	3/12	-/10	2/2	2/4	3/6	3/2	3/5	3/3	-/-	-/-	-/-	-/-	-/-
	2015-2020	3/1	-/1	-/1	2/5	1/3	1/3	3/4	2/9	-/6	1/2	1/2	4/3	3/4	1/1	1/2	-/-	-/-	-/-	-/-	-/-
	Beyond 2020	1/1	-/-	-/-	2/1	1/1	2/4	5/2	1/2	-/2	1/1	2/1	2/1	1/1	-/-	1/2	-/-	-/-	-/-	-/-	-/-
2011 SRA	2011-2015	3/5	-/1	-/1	4/7	5/4	5/7	4/8	4/12	-/10	2/2	2/4	3/6	3/2	3/5	3/3	-/-	-/-	-/-	-/-	-/-
	2015-2020	3/1	-/1	-/1	2/5	1/3	1/3	3/4	2/9	-/6	1/2	1/2	4/3	3/4	1/1	1/2	-/-	-/-	-/-	-/-	-/-
	Beyond 2020	1/1	-/-	-/-	2/1	1/1	2/4	5/2	1/2	-/2	1/1	2/1	2/1	1/1	-/-	1/2	-/-	-/-	-/-	-/-	-/-
2014 SRA	2015-2020	5/5	-/1	-/3	4/8	6/10	4/8	6/12	4/15	-/12	2/4	2/6	5/5	8/13	2/3	4/-	4/4	6/7	-/2	-/2	4/2
	Beyond 2020	1/1	-/-	-/1	2/4	2/1	3/5	6/2	1/2	-/2	1/1	2/1	2/1	2/3	2/1	1/-	2/1	1/2	-/1	-/-	1/1
2015 SRA	2015-2020	5/5	-/1	-/3	5/7	6/10	4/8	6/12	4/15	-/12	2/6	2/6	5/5	8/13	2/3	4/4	4/4	6/6	-/2	-/2	4/2
	Beyond 2020	2/1	-/-	-/1	2/4	2/1	3/5	6/2	1/2	-/2	1/2	2/1	2/1	2/3	2/1	1/1	2/1	6/2	-/1	-/1	1/1
2016 SRA	2016-2020	5/5	-/1	-/8	4/8	8/10	4/8	7/10	4/17	-/13	2/6	2/6	5/5	8/13	-/-	4/-	4/4	9/6	-/4	-/3	4/2
	Beyond 2020	3/1	-/3	-/2	2/4	3/2	3/5	6/6	1/3	-/2	1/2	2/1	2/1	5/5	-/-	1/-	2/3	12/6	-/2	-/3	2/1

Figure 6. "Development and Research" Areas – SRAs comparison

6. CONCLUSIONS

The analysis of the evolution of the SRAs published by IERC allowed us to understand the dynamics of the IoT field in Europe or, at least, in the European Union (EU). From this study, we might conclude that IoT is a very hot topic, not only in the "Research" area, but also in the "Development" area.

Of course, the evolution path of a new technology like IoT involves some setbacks. Indeed, when comparing the various SRAs, it is possible to verify that in some years it was not always possible to reach all the goals proposed for the various topics, thus postponing some of them to later times.

In the same line of thought, it is possible to verify that, in relation to some topics, the number of goals to achieve have increased systematically from SRA to SRA, which shows their importance. On the other hand, it is a fact that some topics, both in the IoT "Research" and "Development" areas, have decreased in importance or have been completely withdrawn.

Recently, taking into account the importance given to IoT Applications in the SRA 2017, one may expect substantial efforts in order to create frameworks that allow the implementation of IoT in any type of real environment.

The SRAs evolution is based on the results of development and research projects involving the cooperation between EU and other countries, while overseen by IERC. In this context, AIOTI is expected to develop the most dynamic European Internet of Things ecosystem and to become a global influencer on IoT technology.

Regarding the future, this quantitative study can no longer be further performed, because the SRA 2017 has initiated a different structure, which is not compatible with the former SRAs. Therefore, in the future, we are thinking about conducting qualitative studies involving the subsequent SRAs.

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ЕВОЛУЦИЈА ИНТЕРНЕТА-СТВАРИ: ЈЕДНА ПЕРСПЕКТИВА ЕВРОПЕ

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Од 2009. године, Европска унија (ЕУ), кроз Европски истраживачки кластер ИС (Интернет-Ствари) (ЕИКИС), објављује Агенду Стратешких Истраживања (АСИ) са краткорочним, средњорочним и дугорочним прогнозама развоја и истраживачких тема о Интернету-Ствари (ИС). Циљ овог рада је да се проуче АСИ објављених од 2009. године и, на основу опсежне анализе и прегледа, да се идентификују релевантне теме у домену интернета ствари, како би се разумела њихова еволуција током времена. Ова студија укључује АСИ-е 2009, 2011, 2014, 2015, 2016 и 2017. Посебно смо заинтересовани за разумевање напора у развоју технологије интернета ствари у овом периоду од скоро једне деценије и области истраживања које су већ истражене, као и оних које још нису добиле одговарајућу пажњу. Једноставним речима, циљ је да закључимо о динамици домена интернета ствари у Европи и о њеном вероватном путу еволуције.