Short Paper: IoT: Challenges, Projects, Architectures

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***Abstract*—Internet of Things (IoT) is a socio-technical phenomena with the power to disrupt our society such as the Internet before. IoT promises the (inter-) connection of myriad of things proving services to humans and machines. It is expected that by 2020 tens of billions of things will be deployed worldwide. It became evident that the traditional centralized computing and analytic approach does not provide a sustainable model this new type of data. A new kind of architecture is needed as a scalable and trusted platform underpinning the expansion of IoT. The data gathered by the things will be often noisy, unstructured and real-time requiring a decentralized structure storing and analysing the vast amount of data.**

In this paper, we provide an overview of the current IoT challenges, will give a summary of funded IoT projects in Europe, USA, and China. Additionally, it will provide detailed insights into three IoT architectures stemming from such projects.

I. Introduction

IoT will become the technological innovation driving applications that have the power to change the markets across different domains. Thousands of applications can be identified in each domain and new ones appear everyday, requiring a strong interconnection among things [1]. Interconnection is not only a mere technological issue but it concerns also aspects such as privacy, standardization, legal issues, etc. This inevitably brings new challenges driving research and innovation in industry and academia over the last decade [2].

We believe that the core technological challenges, such as interconnection among heterogenous devices, very low computational and energy demand have to be overcome to pave the road for the adoption of IoT. Projects in industry and academia around the world strive to solve parts of these challenges. A fundamental importance will be the development of an open, scalable and trusted architecture.

The rest of the paper is organized as follows: Section II identifies the technological challenges of IoT and the most promising application domains. Section III provides an overview of the most important public funded projects in Europe, in the United States, and China. Three promising IoT architectures developed in public funded projects will be covered in detail in Section IV. Finally, Section V closes the paper with conclusion and outlook.

II. Applications and Challenges

Major objectives for IoT are the creation of smart environments/spaces and self-aware things. In this Section we consolidate application domains and challenges will drive the evolution of IoT systems.

A. Application Domains

We believe that IoT is application-driven, hence application requirements will boost the innovation and development of IoT. Major domains identified are: Energy, Smart City, Transportation, Smart Home, Environment, Supply Chain, and Health Care. Nevertheless, this is only an indicative collection of the most well-known uses cases, based on our research.

B. Challenges

Several research and technology challenges need to addressed towards the implementation of IoT applications as well as the potential realization of horizontal IoT platforms. The most important challenges, based on our findings, are listed below.

1) Technological Interoperability: Interoperability is significantly more challenging for the IoT as it is not (only) about connecting people with people, but about a seamless interaction between devices and people with devices. These devices can differ regarding their technological capabilities.

2) Semantic Interoperability: For full interoperability, it is necessary that the devices interpret the shared information correctly and act accordingly, which is covered by the semantic aspect of interoperability usually referred to as Information Model. Hence, improvements have to be made regarding distributed ontologies, semantic web, or semantic device discovery.

3) Security and Privacy: Data integrity, unique identification, and encryption are considered core challenges for IoT, as much of the data being acquired and communicated contain personal information. Additionally, data ownership, legal and liability issues have to be addressed accordingly. Finally, energy efficient encryption and data protection technologies have to be considered.

4) Smart Things: Ultra low power circuits and devices capable of tolerating harsh environments have to be developed. Moreover, parallel processing in low power multi-processor systems, adaptation, autonomous behavior while guaranteeing trust, privacy and security, as well as battery, energy harvesting and storage technologies are among the core challenges regarding the devices in the IoT.

5) Resilience and Reliability: In industrial environments or in emergency use cases temporary outages cannot be accepted. Hence, resilience and reliability issues in IoT need to be investigated from an overall systems view and in addition comprise aspects like availability, robustness and flexibility of

Acronym	Architecture	Technological Interoperability	Semantic Interoperability	Security Privacy	Smart Thing	Resilience Reliability
IoT-A [4]	◗	●	●	●		
Butler [5]		◗	◗	●		◗
IoT.est [6]		◗	●	◗		
RELYonIT [7]		◗		●	◗	●
IoT6 [8]		●			◗	◗
IoT Lab [9]			◗		●	◗
uTRUSTit [10]		◗		●		●
BETaaS [11]	●	●	●	●		●
iCORE [12]		●	●			◗
OPENIoT [13]	●	●	●		◗	◗
CityPulse [14]		●	●			●

TABLE I
CAPABILITIES ADDRESSED IN EU IOT PROJECTS.

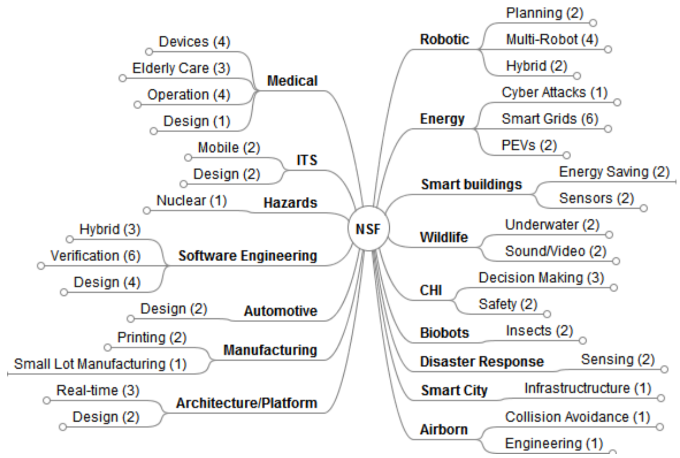

Fig. 1. Clusters of NSF CPS projects.

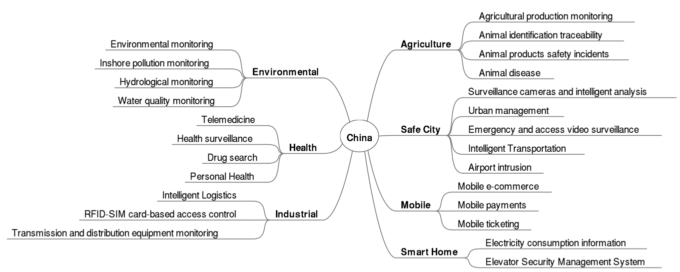

Fig. 2. Clusters of China IoT projects.

the communication and hardware to changing environmental conditions, avoidance of single points of failure, or the robustness of data processing to uncertain information.

III. PROJECTS

The IoT paradigm has been picked up by governments around the world and funding schemes have been implemented. Next we will list our findings analysing the funding schemes of the EU, USA, and China.

A. EU funded projects

The European Union has set up the European Research Cluster on the Internet of Things funding 33 projects in total [3]. Table I lists the most recognized projects and shows to what extend (full (●), partly (◗), none ( )) they address the challenges described in Section II.

A focus was given to the development of open, scalable, and reliable IoT architectures. Section IV of this paper will give a detailed view on the findings of the projects IoT-A, BETaaS, and OPENIoT regarding IoT architectures.

B. NSF funded projects

The President's Council of Advisors on Science and Technology published in December 2010 the report "Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology". It provides the base for investment into research on Cyber-Physical-Systems managed by the The National Science Foundation (NSF).

A primary focus lies on medical systems and projects in the area of software engineering. However, the clustering of all project has also identified the CPS sectors energy, smart cities and buildings, manufacturing, intelligent traffic management, and disaster and hazards.

Most projects (cf. Figure 1) emphasize on fundamental research advancing CPS in its capability, adaptability, scalability, resiliency, safety,security, and usability propelling CPS with its tightly intertwined physical processes and networked computing capabilities beyond todays simple embedded systems.

C. Chinese IoT topics

IoT is one of the major technology topics and part of the 12^{th} 5-year-plan of China. The funding is clustered among a layered schema: Perception Layer, Network Layer, Transport Layer, and Application Areas. A strong focus lies on network technology supporting IoT application. A summary of identified IoT sectors in China is depicted in Figure 2.

IV. ARCHITECTURES

A scaleable and reliable architecture will form the backbone of the future development of IoT. The architecture must cope with the new requirements of IoT and reflect the challenges listed in Section II. This Section covers the architecture reference model IoT-A, as well as two full-fledged architectures developed in the projects BETaaS and OPENIoT.

A. IoT-A

The IoT Architecture Reference Model (ARM) [15] is not an IoT architecture per se, but a set of best practices, guidelines, and a starting point to generate specific IoT architectures. It provides an architectural reference model facilitating the interoperability of IoT systems. It also provides the tools, such as resolution, look up, and discovery of things, for the actual integration into the service layer.

The ARM Process defines the steps to generate concrete IoT architectures from business goals, informing on IoT related issues in a methodology agnostic way. The covered topics include the generation of requirements and their transformation into an architecture using views and perspectives. ARM provides an exhaustive list of so-called Unified Requirements (UNIs) [16], that can be used to generate concrete requirements for a specific architecture. The UNIs are generalized requirements augmented with the views and perspectives of the respective stakeholders.

The ARM process makes use of the IoT Reference Model that introduces major IoT concepts such as devices, services, and entities and defines their relations and attributes on an abstract level that is independent from specific use cases or technologies. Following the established relations, it identifies so-called Functional Groups (FGs) for interacting with instances of the introduced concepts and introduces communication functionalities suitable for heterogenous IoT settings. Additional features introduced include trust, security, process management, service organization, and more.

B. BETaaS

Building the Environment for the Things as a Service (BETaaS) [17] defines besides the overall functionality and architecture, an actual implementation of the platform is part of the deliverables. BETaaS is a running project and some deliverables are not yet available in their final version or are even still missing completely.

BETaaS consists of a network of gateways ("local cloud of gateways") that seamlessly integrate existing heterogeneous M2M systems. To abstract from the heterogeneity of the physical layer, BETaaS defines and builds upon a baseline reference architecture called Things-as-a-Service (TaaS). The TaaS Reference Model is the foundation of the BETaaS infrastructure on which it is built. It provides architectural models for domains, information, communication, security, and functions. TaaS builds upon the IoT-A models (Sec. IV-A), tailoring and extending them to its specific needs.

C. OPENIoT

The OPENIoT research project has defined an architecture utilizing a Sensor Middleware (SM) and a Semantic Directory Service (SDS) [18]. To achieve alignment, architecture development and specification was based on the Architecture Reference Model (ARM) of IoT-A.

The *Sensor Middleware (SM)* undertakes the collection, filtering and aggregation of data streams associated to physical and virtual objects. The *Cloud Computing Infrastructure (CCI)* supports the storage of data along with their associated metadata information in a scalable and elastic manner. The *Semantic Directory Service (SDS)* supports registration management and semantic annotation for sensors and services. The *Global Scheduler (GS)* is tasked with handling requests for on-demand service deployment and the associated provisioning of access to data sets and services that may be required. The *Request Definition (RD)* element enables the dynamic specification of service requests and the *Request Presentation (RP)* element is tasked with the visualization of the results produced by an executing service.

Support for heterogeneous sensor network types and scalability to the proliferation of sensory devices is enabled by supporting a distributed deployment model for SM instances.

V. Conclusions

The current adoption of IoT will influence many application areas of our society. In this paper the major challenges that need to be tackled making IoT ubiquitous have been identified and laid out. The derived requirements are later mapped with the current research activities addressing specific parts of the challenges.

Governments around the world, most notable US, Europe, and China have put IoT as one the top priorities on their research agenda. An overview on current public funded projects in these three geographic regions has been given.

A saleable, reliable and trusted architecture is essential to allow IoT to become a world-wide business critical infrastructure. Three major projects developing IoT architectures have being identified and their results have been described.

References

[1] *Future Internet: The Internet of Things Architecture, Possible Applications and Key Challenges*, 2012. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6424332

[2] I. G. Smith, O. Vermesan, P. Friess, and A. Furness, *The Internet of Things 2012 New Horizons*, I. G. Smith, Ed., 2012. [Online]. Available: www.internet-of-things-research.eu/pdf/IERC_Cluster_Book_2012_WEB.pdf

[3] "Internet of things, pan european research and innovation vision," 2011. [Online]. Available: http://www.internet-of-things-research.eu/pdf/IERC_IoT-Pan%20European%20Research%20and%20Innovation%20Vision_2011_web.pdf

[4] M. Rossi (ed.), "IoT-A WP3 – Protocol Suite," http://www.iot-a.eu/public/public-documents/documents-1/1/1/d3.3/at_download/file, April 2012, [04 Feb. 2014].

[5] "BUTLER project description." [Online]. Available: http://www.iot-butler.eu/

[6] "IoT.est project description," 2013. [Online]. Available: http://ict-iotest.eu/iotest/

[7] "RELYonIT project description," 2013. [Online]. Available: http://www.relyonit.eu/

[8] "IoT6 project description," 2012. [Online]. Available: http://www.iot6.eu/

[9] "IOT LAb pproject description," 2013. [Online]. Available: http://www.iotlab.eu/index.php

[10] "UTRISTIT project description," 2013. [Online]. Available: http://www.utrustit.eu/

[11] "BETaaS project description," 2013. [Online]. Available: http://www.betaas.eu/

[12] "iCore project description," 2013. [Online]. Available: http://www.iot-icore.eu/

[13] "OPENIoT project description," 2013. [Online]. Available: http://www.openiot.eu/

[14] "City Pulse project description," 2013. [Online]. Available: http://www.ict-citypulse.eu/

[15] A. Bassi, M. Bauer, M. Fiedler, T. Kramp, R. Kranenburg, S. Lange, and S. Meissner, Eds., *Enabling Things to Talk*. Springer Heidelberg New York Dordrecht London, 2013.

[16] I.-A. Consortium, "Iot-a unified requirements," http://www.iot-a.eu/public/requirements/, [31 Jan. 2014].

[17] BETaaS Consortium, "Building the environment for the things as a service," http://www.betaas.eu/, 2012, [11. Feb. 2014].

[18] "OPENIoT project description," 2013. [Online]. Available: http://www.openiot.eu/