Bridging IoT Islands: The symbIoTe Project

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***Abstract*—The rapidly increasing interest that the Internet of Things (IoT) has received both in academia and industry over the past few years has already resulted in a huge number of IoT platforms which, however, typically are conceived as individual vertically integrated systems without supporting inter-platform collaboration and interaction. In this paper, we present the techno-economic approach of the EU project symbIoTe (Symbiosis of smart objects across IoT environments) which aims at designing a sustainable IoT ecosystem that will enable the inclusion of existing individual IoT platforms ("islands") into federative structures via the use of a novel set of inter-system interfaces. The objective of symbIoTe is thereby to accomplish the two key criteria for the successful evolution of large ecosystems, i.e., backward compatibility and incremental deployability. In other words, the symbIoTe interfaces are designed to serve as stable evolutionary kernels which will enable diversity and dynamics, both in the space of applications and IoT platforms. Furthermore, we expect the symbIoTe interfaces and their corresponding logic to also play an important role in the next generation of the Internet of Things which will be comprised of *things as actors* in addition to the small devices addressed in the present *things as sensors/actuators* paradigm.**

Keywords—Internet of Things; IoT; interoperability; federation; systems evolution.

I. INTRODUCTION

While the idea of an Internet of Things (IoT), as the networking-related side of Weiser's famous vision for the "Computer of the 21st Century" [1], has been around already for almost two decades, only a few years ago IoT has started gaining substantial attention in industry and academia, while today this topic is experiencing a dramatic boom [2]. Despite of this immense popularity, there is still no unified view on the fundamental notion of IoT within the respective research communities: From an interconnection-driven perspective, IoT boils down to enabling efficient communication with a large set of small devices (typically sensors and actuators) suffering from three types of basic restrictions, i.e., limited computation power, limited battery autonomy and limited communication capabilities. In contrast, from a cyber-physical perspective, the paradigm of IoT may also be understood as a productive system of things that serve as autonomous actors, which, however, is still in its infancy. Hence, while we expect ultimately both these paradigms to converge, in this paper we will focus rather on the first, i.e., interconnection-driven approach.

As already pointed out in [3], at present we are witnessing a highly fragmented landscape of partly specialized vertical IoT solutions that typically focus on specific application domains. As a consequence, today there is a huge number of IoT platforms in industry and academia which, however, currently mostly function as individual vertically integrated systems without supporting inter-platform collaboration and interaction. In other words, these "IoT islands" do not constitute at all a proper "Internet of Things", therefore a number of research projects currently aim at interconnecting these silo-type platforms in order to allow for the creation of a true IoT ecosystem where the IoT platforms and their resources may interact and collaborate in a seamless way.

In order to design such a cross-domain IoT system which is able to "bridge" those IoT islands, we relate to Dovrolis' key insight that any system which is experiencing a dynamic evolution requires a stable evolutionary kernel [4]. As an immediate consequence, this results in the indispensable need for open and to the best extent possible time-invariant interfaces on all levels. Consider in analogy, for instance, the evolution of different railroad networks whose success would not have been possible without predominantly keeping the gauge, i.e., track width, constant starting from their beginnings in the 1820ies, whereas all other system components (i.e., signaling, traction, etc.) have changed significantly since (cf. [5]). Following this line of thought, we postulate that inter-system Application Programming Interfaces (APIs) fulfill this vital purpose and hence provide the stable evolutionary kernel for the long-term future of the envisioned IoT.

In order to address this key challenge, the EU Horizon 2020 project symbIoTe currently develops a flexible interoperability framework which will not only enable the cooperation between vertical IoT platforms, but also support the exchange of resources with the help of IoT-platform federations and, last but not least, allow independent developers to create cross-domain and cross-platform applications.

II. THE SYMBIOTE PROJECT: CONCEPT AND ARCHITECTURE

With respect to the two major prerequisites for the evolutionary ecosystem development postulated by Dovrolis in [4], symbIoTe fulfills both these criteria as follows:

- **Backward compatibility:**

In order to enable an abstraction which is both sufficiently generic and specific enough for the targeted application, symbIoTe aims at defining its abstraction APIs individually for particular application domains, as in this way the detailed requirements of an application domain can reliably be taken into account. symbIoTe assumes that existing IoT platforms will implement these high-level domain-specific APIs (see Fig. 1), which will enable the utilization of all underlying platforms' capabilities such that full backward compatibility with the existing systems is assured.

- **Incremental Deployability:**
  The implementation and offering of these symbIoTe APIs comes along with immediate benefits both for platform providers and application developers, as they both may substantially extend their market reach by offering standardized interfaces. In the resulting two-sided market, platform (cf. [6]) providers gain a far larger number of applications while developers can generically add new platforms to their application's portfolio in terms of sensors and actuators.

To this end, symbIoTe distinguishes between four different cumulative compliance levels as follows:

- **Level 1 compliance:**
  In order to facilitate application development, which currently is characterized by the fact that developers are facing many different IoT-platform specific interfaces, thus rendering the reuse of implementations difficult if not impossible, symbIoTe will enable a new generation of applications that are built in a platform-independent manner and capable of interacting with a plethora of symbIoTe-enabled platforms through uniform interfaces.

- **Level 2 compliance:**
  On a second level, which cumulatively encompasses also Level 1, a platform is enabled to collaborate with a peer platform for the mutual benefit of both, through sharing, bartering and/or trading of resources. For instance, consider two platforms with spatially overlapping resources that are mutually substitutable in terms of their functionalities. Then, Level 2 compliance allows avoiding premature resource depletion and thus creates a win-win situation for all parties.

- **Level 3/4 compliance:**
  The two remaining compliance levels are related to interoperable cooperating gateways and devices. Here, we have to distinguish nomadic resources with intermittent connectivity and mobile sensors which are online throughout. For both cases, symbIoTe will enable device handover between gateways, translating to roaming in case that the gateways belong to different platforms. In this way, devices are no longer in danger of being locked-in to specific platforms which results in a market of perfect competition [7], thus fostering market proliferation of the developed technology. Moreover, due to the peer-to-peer wireless nature of Level 3/4 interfaces, they may – if designed well – ultimately serve as foundation and as stable evolutionary kernels also for the future world of the Internet of *things as actors*.

The resulting high-level overall architecture of symbIoTe is depicted in Fig. 1, and the corresponding compliance levels are depicted in Fig. 2, cf. [8] for further details.

III. USE CASES

In order to validate our approach of domain-specific high-level APIs, a total of five use cases will be pursued which are targeting typical everyday situations both in- and outdoor, and which, as a whole, provide a comprehensive range of IoT applications that are currently run and managed as isolated systems instead of exhibiting interoperability. Summarizing briefly, the symbIoTe use cases include:

- **Smart mobility and ecological urban routing:**
  Based on air quality monitoring through various platforms, including in-situ stations, wearable sensors and mobile devices, as well as further input concerning, e.g., road traffic information, parking space situation etc., the ecologically most preferable route will be calculated and offered to motorists, cyclists and pedestrians.

- **Smart residence:**
  As particular examples of smart spaces, here local resources and dynamic service composition will be used for accessing and managing functions across any available device in homes and offices, as well as for sharing resources like processing power, storage or wireless spectrum with collocated platforms.

- **Smart campus:**
  In this use case, collaboration services based on indoor navigation will be developed for university campuses, and offered also to visiting students whose smart phone becomes a visiting device in a foreign campus smart space.

- **Smart stadium:**
  Here, the goal is to link physical and virtual worlds for the sake of creating a unique experience for the visitors of a sports event or a cultural performance taking place in a stadium or other type of open air arena.

- **Smart yachting:**
  Our last use case addresses mainly the exchange of information between yachts and ports or port authorities, including preparations for refitting and maintenance of the boats.

Altogether, these five use cases will showcase a broad range of symbIoTe specific features, including platform interoperability within an application domain (smart mobility, smart stadium), interoperability of collocated deployments in smart spaces (smart residence) as well as IoT platform federations (smart campus) and the integration of multiple control platforms (smart yachting). Additionally, also the potential of business models will be demonstrated from several perspectives; here, it is especially interesting to consider resource bartering based on the exchange of certain forms of vouchers (including Service Level Agreements, authorization tokens, etc.) as a simple means of making resources of one platform available to other platforms without the need of managing explicit financial remuneration, while of course also various forms of trading (for instance forward and reverse auctions) are considered.

IV. SUMMARY AND OUTLOOK

The transition of IoT-based systems from academic concepts to practical real-world implementations currently lies in the focus of major industry stakeholders all over the world. In order to facilitate this process and to assure its sustainability, the EU Horizon 2020 project symbIoTe specifies APIs which will (a) enable system interoperability for a large spectrum of application domains, and (b) serve as stable evolutionary kernels in the future development of IoT ecosystems. From a techno-economic perspective, we believe that based on the stability and openness of symbIoTe, large parts of the value chain can be kept within the local IoT ecosystem by establishing truly federative relationships between the individual actors. Our techno-economic considerations are especially important in the context of the European ICT landscape, as it has so far proven to be very difficult to retain added value creation in the area of Internet search, social media, cloud solutions, etc., on the continent. In fact, there are even intrinsically federative service like, e.g., e-mail [9], which are currently experiencing *de facto* centralization by large global Internet technology companies. Setting here a clear counterpoint, the symbIoTe system will demonstrate its practicability based on the implementation of the five mentioned use cases and thus underline the importance of open and long-term stable interfaces for the establishment of sustainable techno-economic ecosystems.

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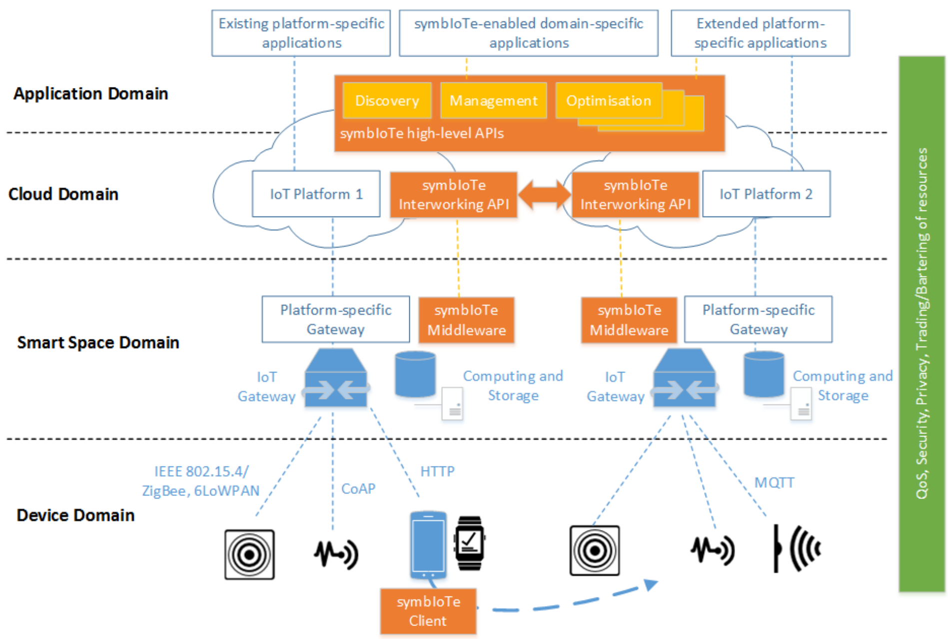

Fig. 1. symbIoTe architecture.

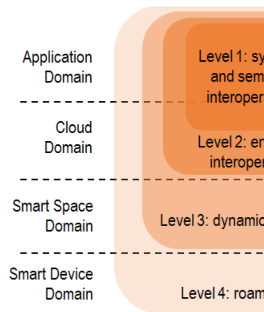

Fig. 2. symbIoTe complia