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CATCHWORD

Internet of Things

Technology and Value Added

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1 Introduction

It has been next to impossible in the past months not to come across the term "Internet of Things" (IoT) one way or another. Especially the past year has seen a tremendous surge of interest in the Internet of Things. Consortia have been formed to define frameworks and standards for the IoT. Companies have started to introduce numerous IoT-based products and services. And a number of IoT-related acquisitions have been making the headlines, including, e.g., the prominent takeover of Nest by Google for $3.2 billion and the subsequent acquisitions of Dropcam by Nest and of SmartThings by Samsung. Politicians as well as practitioners increasingly acknowledge the Internet of Things as a real business opportunity, and estimates currently suggest that the IoT could grow into a market worth $7.1 trillion by 2020 (IDC 2014).

While the term Internet of Things is now more and more broadly used, there is no common definition or understanding today of what the IoT actually encompasses. The origins of the term date back more than 15 years and have been attributed to the work of the Auto-ID Labs at the Massachusetts Institute of Technology (MIT) on networked radio-frequency identification (RFID) infrastructures (Atzori et al. 2010; Mattern and Floerkemeier 2010). Since then, visions for the Internet of Things have been further developed and extended beyond the scope of RFID technologies. The International Telecommunication Union (ITU) for instance now defines the Internet of Things as "a global infrastructure for the Information Society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies" (ITU 2012). At the same time, a multitude of alternative definitions has been proposed. Some of these definitions exhibit an emphasis on the things which become connected in the IoT. Other definitions focus on Internet-related aspects of the IoT, such as Internet protocols and network technology. And a third type centers on semantic challenges in the IoT relating to, e.g., the storage, search and organization of large volumes of information (Atzori et al. 2010).

The fields of application for IoT technologies are as numerous as they are diverse, as IoT solutions are increasingly extending to virtually all areas of everyday. The most prominent areas of application include, e.g., the smart industry, where the development of intelligent production systems and connected production sites is often discussed under the heading of Industry 4.0. In the smart home or building area, intelligent thermostats and security systems are receiving a lot of attention, while smart energy applications focus on smart electricity, gas and water meters. Smart transport solutions include, e.g., vehicle fleet tracking and mobile ticketing, while in the smart health area, topics such as patients' surveillance and chronic disease management are being addressed. And in the context of

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smart city projects, solutions like the real-time monitoring of parking space availability and intelligent lighting of streets are being explored (Atzori et al. 2010; Fleisch 2010; Vermesan et al. 2014).

2 Value Creation in the Internet of Things

At its core, innovation in the Internet of Things is characterized by the combination of physical and digital components to create new products and enable novel business models. Thanks to increasingly efficient power management, broadband communication, reliable memory and advances in microprocessor technologies, it has become possible to digitalize functions and key capabilities of industrial-age products (Yoo et al. 2010). Consequently, a range of opportunities is unfolding for companies to generate incremental value in the Internet of Things. Figure 1 illustrates the logic of such value creation. It demonstrates that IoT solutions typically combine physical things with IT in the form of hardware and software. As a result, the primary thing-based physical functions of a thing can be enhanced with additional IT-based digital services, which can be accessed not only on a local basis but at a global level. For instance, the primary thing-based function of a light bulb is to provide light in a specific location. If the light bulb is however enhanced with IoT technology, it may additionally detect human presence and serve as a low-cost security system, which in the event of an intrusion activates a flashing light mode and sends an alert to the owner's smartphone. Similarly, the primary thing-based function of a bin is to provide storage capacity. But when the bin is enriched with IoT technology it may moreover measure and monitor its own weight, thus detect levels of low stock and offer an automatic replenishment service. And while the primary thing-based function of a tractor may be to tow other farm equipment, a connection of the tractor to the IoT could facilitate IT-based predictive maintenance and optimization services (Fleisch et al. 2014).

The impact which IoT technologies can have is however not limited to the value created by individual connected products. Instead, the functions of one product may be further enhanced if it is connected to related products and thus becomes part of a product system. For instance, a connected tractor may form part of a larger farm equipment system, which could include, e.g., additional tractors, harvesters, balers, or drills, and monitor the location as well as key performance indicators of the machines to optimize the overall equipment efficiency of the larger fleet. And going beyond even such product systems, the combination of multiple, previously disparate product systems, e.g., farm equipment systems, weather data systems, seed optimization and irrigation systems, may lead to systems of systems, which have the capacity to expand existing industry boundaries and shake competitive dynamics (Porter and Heppelmann 2014).

3 Technology Stack and Platforms for the Internet of Things

From a technological perspective, the implementation of a connected product typically requires the combination of multiple software and hardware components in a multilayer stack of IoT technologies. As illustrated in Fig. 2, such an IoT technology stack is usually composed of three core layers, i.e., the thing or device layer, the connectivity layer and the IoT cloud layer. At the device layer, IoT-specific hardware, such as additional sensors, actuators, or processors can be added to existing core hardware components, and embedded software can be modified or newly integrated to manage and operate the functionality of the physical thing. At the connectivity layer, communication protocols such as MQTT enable the communication between the individual thing and the cloud. And at the IoT cloud layer, device communication and management software is used to communicate with, provision, and manage the connected things, while an application platform enables

Fig. 1 IoT-product-services logic (based on Fleisch et al. 2014)

THING		+	IT (Hardware / Software)	=	Thing-based function (Physical / Local)	+	IT-based service (Digital / Global)
	Bulb		IoT stack	→	Light		Security
	Bin		IoT stack	→	Storage capacity		Automatic replenishment
	Tractor		IoT stack	→	Towing vehicle		Predictive maintenance, optimization

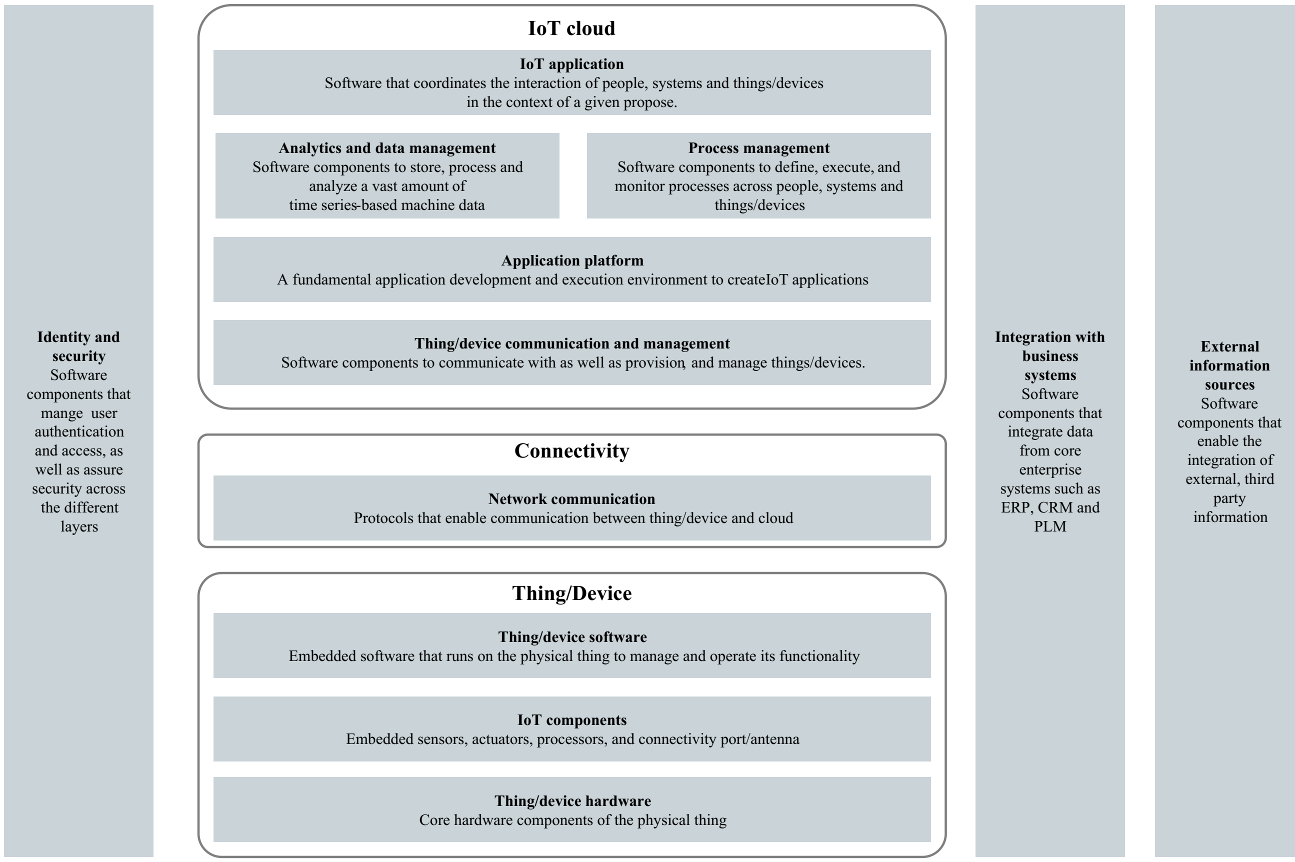

Fig. 2 IoT technology stack (based on Porter and Heppelmann 2014)

the development and execution of IoT applications. Moreover, analytics and data management software is employed to store, process, and analyze the data generated by the connected things, and process management software helps to define, execute and monitor processes across people, systems and things. Ultimately, IoT application software coordinates the interaction of people, systems and things for a given purpose. In addition, cutting across all layers, software components manage identity and security aspects, as well as the integration with business systems, e.g., for ERP or CRM, and with external information sources (Porter and Heppelmann 2014).

In the context of discussions about IoT technologies, a frequently-used concept is that of IoT platforms. In computing, the term "platform" itself is a relatively broad concept, which has, e.g., been defined as "a group of technologies that are used as a base upon which other applications, processes or technologies are developed" (Janssen 2015). Within the Internet of Things, IoT platforms are essentially software products, which offer comprehensive sets of application-independent functionalities that can be utilized to build IoT applications. The nature of individual IoT platforms therein may vary considerably as providers focus on different aspects of the IoT technology stack and correspondingly include diverse sets of functionalities in their offerings. Hence, there is no standard configuration of an IoT platform, but a multitude of IoT platforms exists, which address specific needs and areas of application. While some IoT platforms, e.g., Eclipse, are rather thing-focused and offer mainly functionality to develop and operate embedded applications on things, other IoT platforms, e.g., Xively, focus on IoT-specific functionality to complement potentially existing non-IoT platforms. And a third type of IoT platforms seeks to provide a set of functionalities which is as comprehensive as possible, going beyond core IoT technologies in an all-in-one IoT platform approach. Examples of this third type of IoT platforms currently include, e.g., ThingWorx and the Bosch IoT Suite.

4 Challenges and Future Directions

As the future for the Internet of Things is bright and expectations rising, significant challenges remain to be solved not only from a technological point of view but also from a business perspective, where the introduction of connected products raises a number of important operational as well as strategic questions. For example, at a strategic level, executives are now forced to evaluate the opportunities and threats which the emergence of the IoT might present to their companies. As a result, existing business models may have to be adapted or re-defined based on a new positioning of products in the Internet of Things, and even entire industry boundaries may need to be re-assessed as competition starts to shift and expand. At an operational level, fundamental managerial challenges are for instance likely to arise as rigorous hardware and agile software cultures start to clash not only within companies but even at early product development stages. After-sales service processes may have to be modified to meet the requirements of connected products. New marketing tools could become relevant as connected products enable a more direct or extended communication with customers. And new design principles may be required to support the development of a connected product, e.g., to enable ongoing product updates or personalization (Fleisch et al. 2014; Porter and Heppelmann 2014).

From a technological point of view, the implementation of an IoT application requires the integration of a range of information and communication technologies in the form of hardware and software, as described earlier. Some of the most important challenges which IoT innovators are currently facing in this context relate to, e.g., device level energy supply, identification and addressing, Internet scalability, security and personal privacy, as well as standardization and harmonization (Atzori et al. 2010; Mattern 2013; Vermesan et al. 2014). With regard to IoT platforms, a first important challenge for companies offering connected products or product systems will certainly lie in the choice of the IoT platform, as the respective market is young and very fragmented. A key factor will then undoubtedly be the platform providers' ability to build active ecosystems around their platforms and to provide professional and timely support to their partners as well as development communities. And finally, the support of the latest and continuously evolving standards as well as the integration of adequate end-to-end tool chains even in the embedded software domain to enhance developer productivity represent further important challenges in the development of IoT platforms (Porter and Heppelmann 2014; Schuermans and Vakulenko 2014).

For the scientific IS community, these challenges are opening up inspiring themes for future research, where key questions center around the impact of IoT-based innovation on strategy as well as corporate IT infrastructures. In the Internet of Things, digital technology becomes an integral part of strategy formulations. Therefore, received models of managing IT as a standardized commodity and aligning IT to business strategy need to be questioned and complemented by new frameworks, which view IoT technologies not only as a support function but as a core element of value creation and as a source of competitive advantage. In order to enable the implementation of such new digital innovation strategies, corporate IT infrastructures will be in need of new governance principles, tools, and processes in order to effectively and efficiently manage, coordinate, and connect the required resources within and beyond the boundaries of individual corporations (Yoo et al. 2010). Hence, a multitude of new opportunities is again emerging for IS researchers to contribute to the solution of demanding real-world challenges and create direct value for practitioners.

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