1 An Architectural Approach Towards the Future Internet of Things

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Abstract Many of the initial developments towards the Internet of Things have focused on the combination of Auto-ID and networked infrastructures in business-to-business logistics and product life cycle applications. However, a future Internet of Things can provide a broader vision and also enable everyone to access and contribute rich information about things and locations. The success of social networks to share experience and personalised insights shows also great potential for integration with business-centric applications. The integration and interoperability with mainstream business software platforms can be enhanced and extended by real-time analytics, business intelligence and agent-based autonomous services. Information sharing may be rewarded through incentives, thus transforming the Internet of Things from a cost-focused experiment to a revenue-generating infrastructure to enable trading of enriched information and accelerate business innovation. Mash-ups and end-user programming will enable people to contribute to the Internet of Things with data, presentation and functionality. Things-generated physical world content and events from Auto-ID, sensors, actuators or meshed networks will be aggregated and combined with information from virtual worlds, such as business databases and Web 2.0 applications, and processed based on new business intelligence concepts. Direct action on the physical world will be supported through machine-interfaces and introduction of agile strategies. This chapter aims to provide a concept for a future architecture of the Internet of Things, including a definition, a review of developments, a list of key requirements and a technical design for possible implementation of the future Internet of Things. As open issues, the evaluation of usability by stakeholders in user-centric as well as business-centric scenarios is discussed and the need for quantifying costs and benefits for businesses, consumers, society and the environment is emphasised. Finally, guidelines are derived, for use by researchers as well as practitioners.

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1.1 Introduction, Background and Initial Visions

The term *Internet of Things* first came to attention when the Auto-ID Center launched their initial vision of the EPC network for automatically identifying and tracing the flow of goods in supply-chains, in Chicago in September 2003 (EPC Symposium 2003). Whereas the first mention of 'Internet of Things' appears in an Auto-ID Center paper about the Electronic Product Code by David Brock in 2001 (Brock 2001), increasing numbers of researchers and practitioners have followed this vision, as it is documented by books, conferences and symposia having Internet of Things in their titles.

The Internet of Things is a concept in which the virtual world of information technology integrates seamlessly with the real world of things. The real world becomes more accessible through computers and networked devices in business as well as everyday scenarios. With access to fine-grained information, management can start to move freely from macro to micro levels and will be able to measure, plan and act accordingly. However, the Internet of Things is more than a business tool for managing business processes more efficiently and more effectively – it will also enable a more convenient way of life.

Since the founders of the Auto-ID Center coined the term 'Internet of Things' (Santucci 2010), it has widely been used by researchers and practitioners to describe the combination of the real world with the virtual world of information technology (Fleisch and Mattern 2005, Bullinger and ten Hompel 2007, Floerkemeier et al. 2008) by means of automatic identification technologies, real-time locating systems, sensors and actuators.

Thanks to the recent advances of miniaturisation and the falling costs for RFID, sensor networks, NFC, wireless communication, technologies and applications, the Internet of Things suddenly became relevant for industry and end-users. Detection of the physical status of things through sensors, together with collection and processing of detailed data, allows immediate response to changes in the real world. This fully interactive and responsive network yields immense potential for citizens, consumers and business.

RFID is increasingly being deployed in applications across supply chains with readers that are distributed across factories, warehouses, and retail stores. Sensor technology is also being adopted in manufacturing and logistics in order to control processes and the quality of goods. In traditional RFID applications, such as access control and production automation, tags moved in closed-loop processes, and the RFID data was consumed only by a single client system. Accordingly, there was little need for exchange of data across organisational boundaries. In the same way that monolithic business information systems of the past have evolved into highly networked systems that use the Internet extensively, open-loop RFID applications in networked environments represent a challenge that various stakeholders from industry are facing and partly solving.

Accessing real-time information through Information and Communication Technology (ICT) usage in the 'anytime, anywhere' manner, as suggested by the paradigm of the Internet of Things, calls for open, scalable, secure and standardised infrastructures which do not fully exist today. These have been developed and continue to be developed for example in working groups within the EPCglobal community in order to gather user requirements and business cases to develop open global technical standards for improved visibility. Similarly, members of the Open Geospatial Consortium (OGC) are building a framework of open standards for exploiting Web-connected sensors and sensor systems of all types, including flood gauges, air pollution monitors, stress gauges on bridges, mobile heart monitors, webcams and satellite-borne earth imaging devices. Today’s technology-centric instead of user-centric developments are some of the problems that hinder a broader and faster adoption. The arrival of NFC and RFID technology in the consumer market (e.g., Nabaztag.com, Touchatag.com) together with the availability of mobile Internet (e.g., Apple iPhone, HTC Touch) and scalable information sharing infrastructures (e.g., Twitter.com) opens an enormous space for end-user innovation and user-centric developments. People and things are getting closer. An open and holistic approach of a network of products and people has yet to be developed.

Most existing RFID-installations in production and logistics today can be considered as an Intranet of Things or Extranet of Things. Traditional communication means, such as EDIFACT, are used to communicate with a limited number of preferred partners. These early approaches need to be extended to support open Internet architectures.

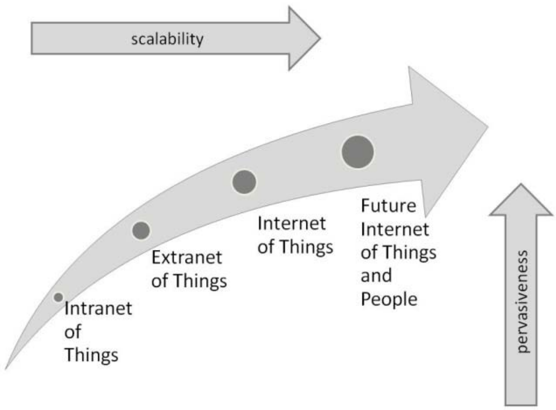

Fig. 1.1 A Phased Approach from the Intranet of Things to a Future Vision on the Internet of Things

Figure 1.1 shows a phased approach from the current Intranet / Extranet of Things to a future Internet of Things and People. While pervasiveness increases through new applications and wider adoption, the scalability requirements of the Internet of Things have to be met.

Additionally, a solid business case and flexible mechanisms for balancing costs and benefits are missing in many of today's early implementations. The usability needs to be improved by providing flexible but simple devices and services to connect things and people. The Internet of Things can benefit from the latest developments and functionalities commonly referred to as Web 2.0 through provision of new intuitive user-centred and individually configurable and self-adapting smart products and services for the benefit of businesses and society. Whereas the successful examples of Web 2.0, such as Facebook or Twitter, connect people with data, this is achieved by proprietary Application Programming Interfaces (APIs) that do not provide powerful data-sharing models capable of Business-to-Business (B2B) requirements, such as data management and analysis.

This chapter will focus on providing an overview of the Internet of Things and its future requirements. In section 1.2 we will provide a definition of the Internet of Things. Section 1.3 will provide a broad review of development projects and initiatives, whereas in section 1.4 we will highlight ten key requirements for the future Internet of Things. Section 1.5 will explain a holistic architectural approach and, finally, in section 1.6 we will provide a conclusion and a further outlook towards future developments.

1.2 Definitions and Functional Requirements

The term Internet of Things is not well defined and has been used and misused as a buzzword in scientific research as well as marketing and sales strategies. Until today it remains difficult to come up with a clear definition of the Internet of Things. One definition has recently been formulated in the Strategic Research Agenda of the Cluster of European Research Projects on the Internet of Things (CERP-IoT 2009):

> "Internet of Things (IoT) is an integrated part of Future Internet and could be defined as 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. In the IoT, 'things' are expected to become active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information 'sensed' about the environment, while reacting autonomously to the 'real/physical world' events and influencing it by running processes that trigger actions and create services with or without direct human intervention. Interfaces in the form of services facilitate interactions with these 'smart things' over the Internet, query and change their state and any information associated with them, taking into account security and privacy issues."

While this definition lists the possible technical components of the Internet of Things, it still has three major shortcomings. Firstly, it lists components that have been mentioned before in relation to other visions such as pervasive or ubiquitous computing and therefore it is difficult to distinguish from these concepts. Secondly, it misses wider consideration of current developments and user-interactions in the Internet commonly referred to as Web 2.0. Similar to the relationship between the World Wide Web (WWW) and the Internet, the addition of Web 2.0 functionality may be seen as a user-centric extension to the Internet of Things rather than an integral part of it. However, whereas the development of the Internet began more than thirty years before the realisation of the WWW in the early 1990s, the Internet of Things is already being influenced by Web 2.0 functionality right from the beginning. Both technology developments have been happening in parallel rather than consecutively. Thirdly, it does not provide a reason why or how the Internet of Things will be a self-sustainable and successful concept for the future. Self-sustainability encompasses viability, including a dynamic global network infrastructure with self-configuring capabilities based on standards and interoperable communication protocols as well as openness for future extensions, ideas, and technologies. Economic success may never have been a part of a definition for the Internet or other technical network infrastructures. Nevertheless, we consider it a valid consideration within a holistic definition approach as economic success and adoption is just as important as technical sustainability in a forward-looking statement.

For the purposes of differentiation it may be best to consider what the Internet of Things is not – or at least not exclusively. A corresponding blog discussion has been started by Tomas Sánchez López (Sánchez López 2010). He considers that the Internet of Things is not only:

- *ubiquitous / pervasive computing*, which does not imply the usage of objects nor does it require a global Internet infrastructure
- the *Internet Protocol (IP)*, as many objects in the Internet of Things will not be able to run an Internet Protocol
- a *communication technology*, as this represents only a partial functional requirement in the Internet of Things similar to the role of communication technology in the Internet
- an *embedded device*, as RFID tags or Wireless Sensor Networks (WSN) may be part of the Internet of Things, but stand-alone they miss the back-end information infrastructures and in the case of WSN the standards to relate to ‘things’
- the *application*, just as Google or Facebook could not be used in the early 90’s to describe the possibilities offered by Internet or WWW

With these negations in mind it is easier to differentiate the Internet of Things. Consequently, this implies that most publications claiming to address the Internet of Things are not really covering the real essence of the Internet of Things. We suggest two more negations. The Internet of Things is *not the Internet of People* (although we believe that the Internet of People will link to the Internet of Things) and it is *not the Intranet or Extranet of Things*. Therefore, applications that provide only access to a small group of stakeholders (e.g., few companies) should not be considered to represent the full scope of the Internet of Things. However, all fields of research that have been mentioned above overlap partially with the Internet of Things (Figure 1.2).

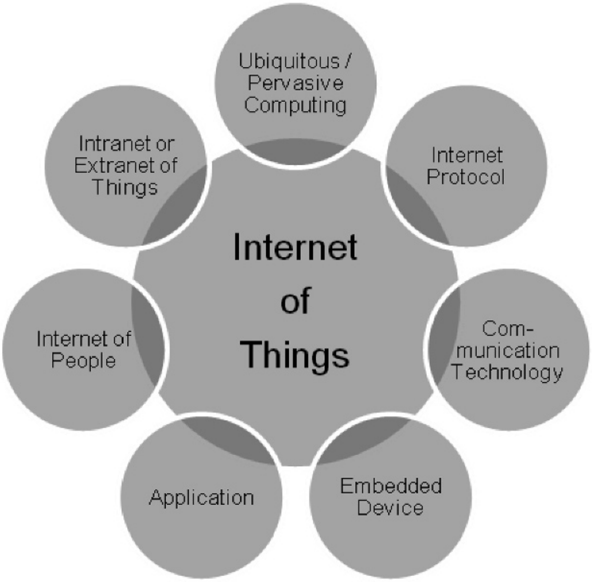

Fig. 1.2 Overlaps of the Internet of Things with Other Fields of Research

The second problem in the CERP-IoT definition is the missing Web 2.0 integration. One could argue that the Web 2.0 is exemplified only by certain types of applications in the Internet of People, which again is not equal to the Internet of Things. However, the Web 2.0 has changed usage of the WWW by providing more intuitive interfaces for user interaction, social networking and publication of user-generated content, without requiring fundamental changes to the design and existing standards of the internet. The primary advantage of Web 2.0 technology has been the use of intuitive interfaces to enable web contributions by end-users irrespective of their technical expertise. The interaction between things and people will be one core issue in the future Web of Things. End-user product ratings and usage instructions provide a valuable set of information on things. Unfortunately today this information is very much scattered across the WWW and there is no direct link to a product identifier.

Thirdly, the reason for success is missing in the above CERP-IoT definition. Maybe a definition on the Internet of Things does not require a benefit statement – the Internet of Things itself surely does, if it is ever to become a reality. Initially, most applications of Auto-ID technologies were internal or closed-loop applications rather than applications across company boundaries. The main reason is the missing benefit for the individual participants. While benefits can be easily calculated across supply chains or product life cycles, input data to cost-benefitanalysis is most often based on "educated guessing" (Gille and Strüker 2008, Laubacher et al. 2006) rather than on hard facts.

Another approach towards a definition of the Internet of Things can be derived from logistics where it is common to ask for the *right product* in the *right quantity* at the *right time* at the *right place* in the *right condition* and at the *right price*. In this analogy the *right product* relates to accurate and appropriate information about a uniquely identifiable physical object as well as its form, fit and function. This includes the usage of Auto-ID and appropriate sensor information or any other kind of linked information to the object that can be accessed through the Internet of Things. The *right quantity* can be achieved through high granularity of information combined with filtering and intelligent processing. The *right time* does not necessarily mean anytime, but more precisely 'when needed'. It may be sufficient to receive information about an object only once a day or only in the case of a status change. Consequently, right-time does not equal real-time, a term that is mentioned quite often in relation to the Internet of Things.

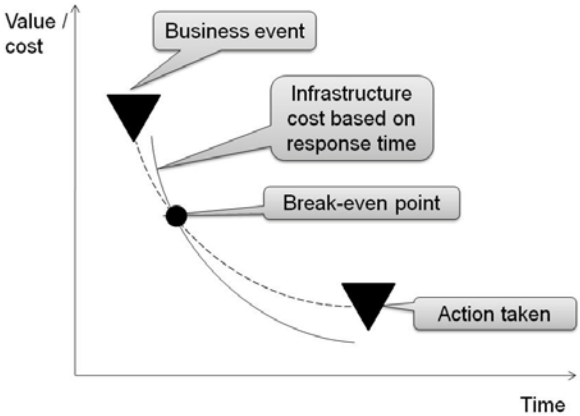

Fig. 1.3 Infrastructure cost vs. response time (based on Hackathorn 2004)

In general, real-time access to data is desirable to reduce the latency between a business event and a corresponding action; the ability to achieve such a reduction is also referred to as agility. Unfortunately, real-time capability is linked to high infrastructure cost (Figure 1.3).

Similarly, the information availability at *right place* does not imply any place - but rather, where the information is needed or consumed (which may not necessarily be the same place as where it is generated). If information is not generated and consumed in the same place and if either of these places have unreliable or intermittent network connectivity, then effective data synchronisation protocols and caching techniques may be necessary to ensure availability of information at the right place. Again, the cost of any place availability has to be seen in relation to its profit potential. But as mobile devices are more and more ubiquitous, there will evidently be an opportunity to access information in the Internet of Things at any place at a reasonable price. The *right information* condition is met if it can be utilised with a minimum effort. This includes human readable information for human interaction as well as semantically and syntactically enriched machine-readable information, which may in turn require transformation of low-level raw data (possibly from multiple sources) into meaningful information and may even require some pattern recognition and further analysis to identify correlations and trends in the generated data. The *right price* is not automatically the lowest price, but instead it is a price between the costs for information provisioning and the achievable market price. Information provisioning costs include labour costs as well as infrastructure costs.

A minimalist approach towards a definition may include nothing more than *things*, the *Internet* and *a connection in between*. *Things* are any identifiable physical object independent of the technology that is used for identification or providing status information of the objects and its surroundings. *Internet* in this case refers to everything that goes beyond an extranet, thus requiring access to information for more than a small group of people or businesses. A closed loop application consequently has to be regarded as an *Extranet of Things*. The *Internet* acts as a storage and communication infrastructure that holds a virtual representation of *things* linking relevant information with the object.

Combining the different approaches we can conclude that *the future Internet of Things links uniquely identifiable things to their virtual representations in the Internet containing or linking to additional information on their identity, status, location or any other business, social or privately relevant information at a financial or non-financial pay-off that exceeds the efforts of information provisioning and offers information access to non-predefined participants. The provided accurate and appropriate information may be accessed in the right quantity and condition, at the right time and place at the right price. The Internet of Things is not synonymous with ubiquitous / pervasive computing, the Internet Protocol (IP), communication technology, embedded devices, its applications, the Internet of People or the Intranet / Extranet of Things, yet it combines aspects and technologies of all of these approaches.*

1.3 A European Perspective on Funded Projects, Technologies and State of the Art in Relation to the Internet of Things

Several projects related to the Internet of Things have been carried out and have contributed to the current state of the art. Especially in Europe, numerous projects have been funded to research certain aspects of the Internet of Things.

EPoSS[1] brings together European private and public stakeholders to create an enduring basis for structuring initiatives, for co-ordinating and bundling efforts and for establishing sustainable structures of a European Research Area on Smart Systems Integration. EPoSS has published the 'Internet of Things in 2020' (EPoSS 2008) report, which elaborates on what the Internet of Things might become in future. In particular, governance, standardisation and interoperability are named as absolute necessities on the path towards the vision of things that are able to communicate with each other. Furthermore, the report states that the real advantages of the Internet of Things have to be shown convincingly, addressing and considering all citizens' concerns when developing innovative solutions and proposals. The objective of the *BRIDGE*[2] project was to research, develop and implement tools to enable the deployment of Radio Frequency Identification (RFID) and EPCglobal Network applications. Based on an initial vision by the *Auto-ID Center*, the architecture of the *EPCglobal Network* (2007) has developed to become an architecture of industry-driven open standards based on unique item identification via the Electronic Product Code (EPC) encoded on data carriers, such as RFID. It defines standards for capturing, filtering, storing and querying EPC data and includes layered standards spanning the whole architecture range from RFID tag memory layout and air interfaces to look-up services that return pointers to data repositories given a particular identifier. The BRIDGE project was dedicated to the development of easy-to-use technological solutions for the European business community including small and medium sized enterprises (SME), ensuring a basis for collaborative EPCglobal systems for efficient, effective and secure supply chains. The technical work in BRIDGE made significant progress on some required services for the Internet of Things, such as discovery services. The ITEA 2[3] funded *Do-it-Yourself Smart Experiences* project (*DiYSE*)[4] has just recently started and aims to enable ordinary people to easily create, setup and control applications in their smart living environments as well as in the public Internet of Things space, allowing them to leverage aware services and smart objects for obtaining highly personalised, social, interactive, seamless experiences at home and in the city. DiYSE is not looking at business-to-business communication. A single architecture that addresses both business and public

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[1] www.smart-systems-integration.org

[2] www.bridge-project.eu

[3] www.itea2.org

[4] www.dyse.org

applications based on a standardised infrastructure would be beneficial to bridge the gap.

In 2010, further projects funded by the EU such as *Internet of Things – Architecture* (IoT-A)[5], *Enabling the business-based Internet of Things and Services* (ebbits)[6], *The Network is the Business* (NISB)[7], *Software Platform for Integration of Engineering and Things* (SPRINT), *Experiential Living Labs for the Internet Of Things* (ELLIOT), *Networked Enterprise transFormation and resource management in Future internet enabled Innovation CloudS* (NEFFICS), *Internet of Things Initative* (IOT-i)[8], and *Internet of Things at Work* (IoT@work) have started their work and will contribute to the ongoing research concerning the Internet of Things in Europe.

There are several projects and standardisation initiatives on sensor networks, which may eventually converge with the Internet of Things. The core objective of the *COBIS*[9] project was to provide the technical foundation for embedded and wireless sensor network technology in industrial environments. *SENSEI*[10] creates an open, business-driven architecture that fundamentally addresses the scalability problems for a large number of globally distributed wireless sensors and actuator devices. It provides network and information management services to enable reliable and accurate contextual information retrieval and interaction with the physical environment. Likewise, other smaller research projects exist, such as *GSN* (Aberer et al. 2006), *SARIF* (Shim et al. 2007), and *MoCoSo* (Sánchez López et al. 2009), that combine concepts of object identification, sensor data and the Internet. Sensor networks can be integrated in the Internet of Things for example. by integration with the EPCglobal Architecture Framework. Although the EPCglobal Network does not yet provide adequate support for the inclusion of sensor values in the streams of data, the Action Groups inside the GS1/EPCglobal community are actively researching issues such as 'Active Tagging' and 'Sensor and Battery Assisted Passive Tags'. The EPC Sensor Network (Sung et al. 2007) is an effort of the Auto-ID Lab Korea to incorporate Wireless Sensor Networks (WSN) and sensor data into the EPCglobal Network architecture and standards. The Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) initiatives are establishing the interfaces and protocols that will enable a 'Sensor Web' through which applications and services will be able to access sensors of all types over the Web. The OGC SWE defines standards for modelling, encoding, transporting, querying and discovering sensor data (Botts et al. 2006). Valuable lessons can be learned from this work and from other standardisation initiatives (e.g., IEEE 1451, ISO/ICE 24753) for incorporation of sensor support into the

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[5] www.iot-a.eu

[6] www.ebbits-project.eu

[7] www.nisb-project.eu

[8] www.iot-i.eu

[9] www.cobis-online.de

[10] www.sensei-project.eu

Internet of Things architecture. A public deliverable from the BRIDGE project provides a detailed survey of standards relevant for integration of sensor information (BRIDGE 2009). While most of the sensor network standardisation activities are still in an early stage, there are already established industry standards promoted through the OPC Foundation[11] and the Association for Standardisation of Automation and Measuring Systems[12] with a focus on industry automation. It should be possible to achieve synergies between these different approaches in an open Internet of Things architecture.

While identification, sensing and actuator integration are core functionalities in an Internet of Things, there are further requirements such as scalability and robustness that need to be addressed. Again, there are numerous existing research activities to build on. Clustering of resources seems to be one valid approach to address this issue. Much work on clustering has been done for MANETs (Mobile Ad-hoc Networks) with little regard to strongly constrained devices, such as those most common in the Internet of Things (e.g., wireless sensor networks). Even so, specialised protocols exist for certain desirable features , for example *energy-efficiency:* EECS (Ye et al. 2005), EDAC (Wang et al. 2004) and HEED (Younis and Fahmy 2004), *mobility:* DMAC (Basagni 1999), *heterogeneity*: GESC (Dimokas et al. 2007), but there is no unified work. Additionally, research on autonomous concepts will influence the further development of the Internet of Things.

Technical projects are supplemented by research and coordination activities on standards and privacy. The *GRIFS*[13] project, seeks to identify all relevant standards for the operating characteristics of physical things (readers, tags, and sensors), infrastructure standards for defining the communications, addressing and structures, and data exchange standards. *CASAGRAS2*[14] looks at global standards, regulatory and other issues concerning RFID and its role in the Internet of Things. *PRIME* [15] focussed on privacy and identity management for private consumers but this proposal did not consider how to empower users e.g. to make informed and balanced choices in their purchasing decisions, supported by the Internet of Things. The *European Research Cluster on the Internet of Things* (IERC[16] finally aims to achieve a consensus on how to realise the vision of the Internet of Things in Europe.

[11] www.opcfoundation.org

[12] www.asam.net

[13] www.grifs-project.eu

[14] www.iot-casagras.org

[15] www.prime-project.eu

[16] www.internet-of-things-research.eu

1.4 Opportunities and Motivation

Even though there are numerous projects and developments concerning certain aspects of the Internet of Things, an open and accessible infrastructure for a wider adoption of the Internet of Things is missing. A more generic approach towards a future development schedule is needed. While technologies are important building blocks, they are not enough to embrace the large research spectrum that needs to be addressed. The following five subject guidelines may be used to trigger successful and sustainable contributions to the Internet of Things.

1. *Envision* – A vision of the Internet of Things needs to provide holistic scenarios focusing on private, social and business benefits. Experimentally-driven, participative research approaches will be needed to allow involvement of different stakeholders for identification of requirements, usability testing, evaluation and active participation. Mechanisms are needed for empowering citizens to fully participate and innovate in the Internet of Things, in order to provide a new multi-directional communication infrastructure for researchers, industries and citizens. This user-centric concept maybe referred to as the 'Web of Things' as it provides intuitive graphical user interfaces that include functionalities familiar to Web 2.0 applications.

2. *Extend* – To leverage state-of-the-art developments and accepted technologies, existing architectures, such as the EPCglobal Network, should be utilised and extended by adding new functionalities to support diverse means of identification (RFID, barcode, 2D-code), sensors, actuators, intelligent devices and other information sources (e.g. user-generated content, commercial databases) within an open framework. The value of product-related data needs to be increased through semantic enrichment. Extending existing approaches will allow utilisation of prior efforts and investments and allow a phased approach towards the Internet of Things. Disruptive new approaches should be avoided unless they provide substantial new benefits or build on existing work. It should be noted that this approach does not exclude integration of other heterogeneous technologies, but it promotes the usage of a single core architecture.
3. *Enable* – It is crucial to solve today's adoption challenges. There is still a lot of research needed on technical challenges that too often are considered to be solved (especially by researchers and practitioners lacking the technical knowledge). Privacy, security and confidentiality are key factors to provide a trustworthy Internet of Things. New mechanisms for sharing costs and benefits to enable the creation of opportunities for new market entrants are needed.

4. *Excite* – New stakeholders need to be excited to contribute to the future Internet of Things. Ease of participation, collaboration and generation of benefits are major requirements to excite new entrants to the Internet of Things. Open frameworks and end-user programming environments may empower citizens to create cost-free as well as billable micro services, such as a product guides and reviews.
5. *Evaluate* – New approaches need to be discussed with a large variety of stakeholders and verified in industry pilots and user-centric environments. A good example for the future Internet of Things is the informed and ethical consumer who requires product-related data (e.g., country of origin, ingredients, dynamic best-before date, carbon-footprint) and who is willing to add information to the Internet of Things. Other popular examples include public user-centric scenarios that build on the concept of Smart Cities and Smart Homes. Furthermore, we need to evaluate the Internet of Things in a philosophical context as things will become social actors in a networked environment.

1.5 Outlook to Future Developments

Based on the development schedule described above, we see a list of key requirements that need to be considered in the Internet of Things:

1. *Meet key societal needs for the Internet of Things including open governance, security, privacy and trustworthiness.* The Internet of Things should not be owned by single interest groups, as it should be an open global infrastructure as the Internet and WWW are today. One of the key issues in Europe and Asia in the past years has been the predominance of VeriSign, an American company operating the Object Name Service (ONS) under contract for the EPCglobal Network (Clendenin 2006, Heise online 2008). Federated structures are needed to provide a power balance. Security, privacy and trustworthiness need to be considered, but are in most aspects not specific to the Internet of Things. The same technologies that have been successfully used in the Internet can be utilised in the Internet of Things as well, although there are some specific challenges due to characteristics of the Internet of Things application scenarios, which often include mobile or portable objects that change custody or ownership during their lifetimes. However, there is a difference in the Auto-ID, sensor and actuator part, where different attacks on the network are possible. Nevertheless, it has to be remembered that the highest achievable security level is not always required. There are for example different levels of security required for passports or logistic applications.

2. *Bridge the gap between B2B, business-to-consumer (B2C) and machine-to-machine (M2M) requirements through a generic and open Internet of Things infrastructure.* While there has been a clear focus on B2B requirements in the last years, B2C and M2M will gain importance in the future Internet of Things. While in B2C ease of use as well as human readable data are important, in M2M communications, the data should be machine-readable structured and semantically well-defined.
3. *Design an open, scalable, flexible and sustainable infrastructure for the Internet of Things.* The Internet of Things has to be open by definition. Open standards are required to use and extend its functionality. It will be a huge network, considering that every object has its virtual representation. Therefore, scalability is required. The Internet of Things will need to be flexible enough to adapt to changing requirements and technological developments. Its development can be accelerated through the availability of open source software, such as Fosstrak[17] to allow anyone to implement and test new functionalities. Another opportunity to experiment and test new functionalities are living lab initiatives, where service providers and users participate in a collaborative environment. Finally, it needs a sustainable infrastructure to provide a basis for the necessary investments.
4. *Develop migration paths for disruptive technological developments to the Internet of Things.* Rather than requiring disruptive new and parallel approaches, there have to be means of integrating new developments into the fundamental infrastructure, otherwise there can be no guarantee of sustainability or enduring value. Examples include autonomous objects that do not essentially require a networked infrastructure. Nevertheless, providing a migration path for autonomous control in the Internet of Things would broaden its usage and provide a solid networked infrastructure for autonomous objects (Uckelmann et al. 2010).
5. *Excite and enable businesses and people to contribute to the Internet of Things.* If stakeholders cannot benefit from the Internet of Things, they will not participate. In contrast, any user benefiting from the Internet of Things will attract and excite more participants. Research on how to benefit from the Internet of Things is needed. Business needs to see a clear business case. End-users need to find a personal benefit. Funded research, such as that described in section 1.3, can trigger new ideas and stakeholders, but in a longer view benefits have to be generated from within the network and not through external funds.
6. *Enable businesses across different industries to develop high added value products and services.* New business models (both industry-specific and cross-sector) are required based on retrieving and contributing information to/from the Internet of Things. Researchers can help to identify new

[17] www.fosstrak.org

potentials but business entrepreneurs are needed to actually raise the potential of the Internet of Things.

7. *Encourage new market entrants, such as third party service and information providers, to enter the Internet of Things.* Information in the Internet of Things can be accumulated, processed and sold independently of owning the physical product. Service providers should be encouraged for example to provide access to multiple sources of information about things and adding technical billing capabilities for information access.
8. *Provide an open solution for sharing costs, benefits and revenue generation in the Internet of Things.* Information should be freely tradable, irrespective of the physical product. Today, wider usage of the Internet of Things is most often hindered by missing concepts on human, organisational and technical shortcomings to share cost and benefits, or even generate revenue from the Internet of Things.
9. *Public initiatives to support the usage of the Internet of Things for social relevant topics.* Legislation has always been a push mechanism for adoption of new technologies. While it is obvious that the Internet of Things can be used to provide society with relevant data, some legislative requirements on topics such as carbon footprint, green logistics, and animal welfare would help to show the utility of the Internet of Things for society.
10. *Enable people to seamlessly identify things to access as well as contribute related information.* How many people carry an Auto-ID reader all day to identify objects and access corresponding information? Mobile phones today already include a camera that can scan barcodes and 2D matrix symbologies. Near Field Communication (NFC) is expected to be the next logical step for user interaction with the Internet of Things. However, it is questionable how many mobile phone owners will use these technologies. Besides mobile phones, there may be cheap dedicated devices. Nabaztag[18] provides a set including reader, tags and internet-based applications for about 40 Euro. Mobile barcode scanners and RFID readers that can be attached to a key chain and that are as easy to operate as a USB-stick are yet another opportunity to enable mass participation in the Internet of Things.

These ten key requirements are not intended to provide a complete set of requirements. They are meant to focus on certain aspects of the Internet of Things to start a rethinking process for future developments.

[18] www.nabaztag.com

1.6 A Possible Architecture for the Future Internet of Things

While it is quite obvious that there are and will be numerous approaches towards the Internet of Things, thus leading to a creative variety of applications in the Internet of Things, we favour an architectural approach that is based on extensions to a successful standardised open architecture – the EPCglobal Network. The EPCglobal Network is widely accepted and has gained the biggest support from IT companies that have adopted the standardised interfaces into their own applications. Numerous products have been developed and certified (EPCglobal 2010). Therefore, the EPCglobal Network provides a solid foundation, despite the fact that it is still under development.

However, the Internet of Things requires a more holistic architecture as described before. This can build on the same design principles as the EPCglobal Architecture Framework (EPCglobal 2007). These include layering of standards, separation of data models and interfaces, provision of extension mechanisms, specification of data models and interfaces, initially in a neutral abstract manner (e.g., using UML), then with provision of specific transport bindings (e.g., web services) and schema bindings (e.g., XML).

A future Internet of Things has to integrate stakeholders who will be affected by the Internet of Things, such as citizens, small and medium enterprises, governmental institutions and policy makers, to meet and match key societal and economic needs. Applications that recognise and improve the fundamental qualities of life for users, businesses, society and the environment are needed.

The foundation will need to provide open architectures, protocols and technologies for new classes of smart Internet-/Web-based public and business applications. Social platforms to share experience and personalised insights will be integrated with business-centric applications. Discovery and retrieval of useful and relevant information beyond personal expectations will be achieved though engineering for serendipity. Users shall be empowered to access more information about things (e.g., Where has an item been produced? – Who owned it previously? - What was it used for?) instantly at their fingertips, subject to compliance with privacy regulations. Mash-ups and end-user programming will enable people to contribute to the Internet of Things with data, presentation and functionality. Things-generated 'physical world' content from Auto-ID, sensors, actuators or meshed networks shall be aggregated and combined with information and events from 'virtual worlds', such as business databases and social platforms, and processed based on new business intelligence concepts. Results will be displayed in a user-centred design, including intuitive interfaces and Web 2.0 functionalities. Direct action on the physical world will be supported through Internet of Things machine-interfaces and introduction of agile strategies. Buying decisions will be supported through the access to relevant information as needed. Agile strategies in this context refer to real-time management and execution capability under consideration of conflicting optimisation values (e.g., shipment size). Information sharing will be rewarded through incentives, including transparent, open billing interfaces between numerous stakeholders, thus transforming the Internet of Things from a cost-focused infrastructure to a benefit-focused infrastructure to accelerate business innovation. Distributed data ownership across the object life cycle will be addressed by integrated billing. Information will be as easily tradable as products and services. The gap between distributed intelligence concepts (e.g., autonomous logistics) and the Internet of Things will be overcome through integration of open interfaces, protocols and lookup services as well as information services on mobile devices, acting as a mediator among decentralised information systems. Openness, scalability and security will be addressed as an integral part of the core architecture. Openness includes social (e.g., governance, privacy), organisational (e.g., industries) and technical (e.g., infrastructures, identifiers) dimensions. The integration and interoperability with mainstream business software platforms will be enhanced and its functionality will be extended through real-time analytics and business intelligence.

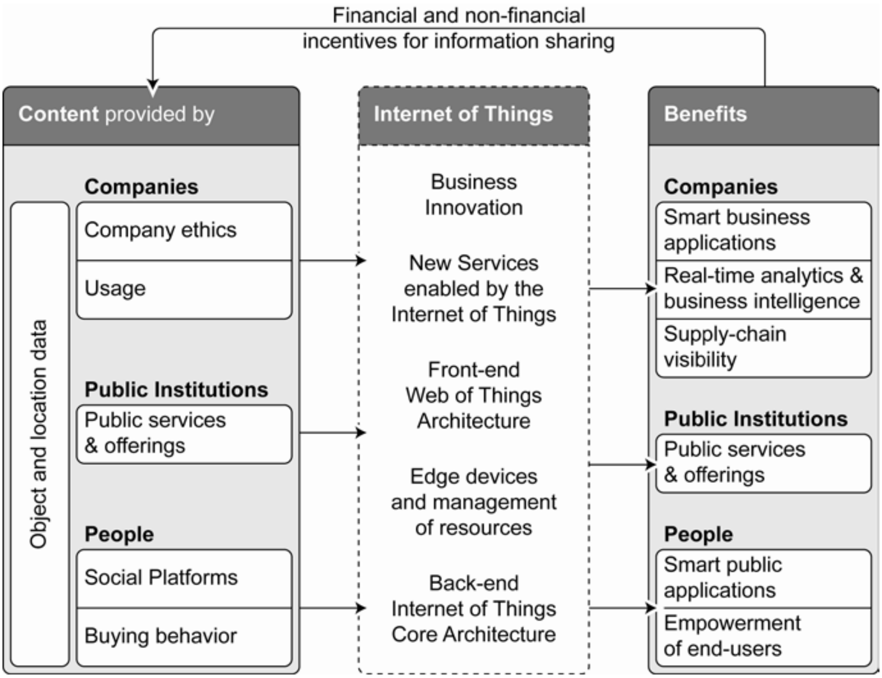

Fig. 1.4 A Holistic Internet of Things Scenario Including Companies, Public Institutions and People

Figure 1.4 shows one possible scenario that includes content providers (producers) and content users (consumers) that utilise the Internet of Things and share benefits. Company data includes for example product and usage data as well as company ethics that may influence buying behaviour. Public institutions as well as people will be able to contribute content. New services and business innovation will be enabled by an enhanced Internet of Things infrastructure including edge devices and back-end services as well as front-end user-interfaces. Companies, public institutions and people will be able to access data for their own benefits and financial as well as non-financial benefit compensation will further add to a fast adoption process of the Internet of Things.

Key goals for a future Internet of Things architecture to achieve are:

- An open, scalable, flexible and secure infrastructure for the Internet of Things and People
- A user-centric, customisable 'Web of Things' including interaction possibilities for the benefit of society
- New dynamic business concepts for the Internet of Things including flexible billing and incentive capabilities to promote information sharing

The EPCglobal Network architecture is currently only one aspect of the broader Internet of Things. However, if openness, scalability and security can be assured, the EPCglobal Network could be the most promising and comprehensive architecture in the Internet of Things. The availability of free, open standards and free open source implementations for the EPCglobal Network architecture may play a significant enabling role in its development, alongside complementary technologies and standards, such as Open Geospatial Consortium (OGC) Sensor Web Enablement. Other extensions, such as support for multiple identifier schemes, federated discovery services, actuator integration and software agents for decentralised data processing and decision rendering, could further extend the functionality of the EPCglobal Network.

The vision of the future Internet of Things includes extended Internet of Things Information Services based on the EPC Information Services. The extensions are necessary to provide a broader support for other identifiers than the EPC, additional static and dynamic data, actuator support, software agent integration, integration of non-IP devices and offline-capabilities. In detail, the vision includes the following components:

- *Extended static data support* – The EPCglobal Network today is based on the EPC. The EPC is not a single identifier scheme but a framework supporting multiple identifier schemes including GS1 identifiers such as Serialised Global Trade Identification Number (SGTIN), Serial Shipping Container Code (SSCC), and Global Returnable Asset Identifier (GRAI). This framework is not limited to GS1 identifiers; EPC formats are also defined for unique identifier constructs specified by the US Department of Defense. In principle, other approaches such as the Uniform Resource Names (URNs) could be used to support identifiers based on ISO 15962 and even identifiers based on Uniform Resource Locators (URLs) could be included, since they are a subset of Uniform Resource Identifiers (URIs). There is a need to support all things that carry a unique ID, because changing an established identifier scheme in an industry can cost millions of Euro and should be compared to the efforts involved for changing databases in the last millennium to make them year 2000 compliant. There have been and continue to be approaches to transform existing established identification schemes into a format that is compatible with the EPCglobal Network, as well as EPCglobal standards such as Tag Data Standard (TDS) and Tag Data Translation (TDT) that enable two-way translation between an EPC representation and an existing legacy representation. Additional structured data in barcodes (e.g., for best-before-date) may need to be supported to fully integrate existing optical identification techniques and to exploit the user memory capabilities of RFID tags, as well as facilitating stock rotation, product recalls, etc. An open, universal identifier translation framework would enable all things that carry a unique ID to be part of the Internet of Things. However, until everything carries a unique ID, the Internet of Things may also need to support objects identified by a classID (productID) and attributes.

- *Integration of dynamic data* – In order to bring the real and the virtual world closer together there is a need to sense environmental conditions as well as the status of devices. A standardized sensor interface to the Internet of Things would help to minimise costs and foster implementation. Sensors are key components of the next generation of internet services because they empower bottom-up interaction with things by enabling the gathering of information about their state or condition within the real world. The state of the things can be used to feed services at the infrastructure layer, transforming everyday things into true enablers of the Internet of Things.
- *Support for non-IP devices* – Non-IP devices offer only limited capability. They can be integrated in the Internet of Things through gateways that take care of the computational overhead required to share physical devices over the Internet, while also providing advanced functionality that are not available on the devices themselves.
- *Integration of an actuator interface* – Actuator integration into the Internet of Things will allow standardised communication with machines executing decisions either rendered by humans or software-agents on their behalf. Actuators complement bidirectional interaction processes by providing the means for services and users to influence the state of things. The combination of sensors and actuators and their integration in the core Internet of Things infrastructure is an indispensable feature and needs to be considered at all layers of the architecture.
- *Optional integration of software agents* – The complexity of global supply networks will require more decentralised and automated decision making. Software-agents have been researched broadly but have not yet gained considerable acceptance in industries. The reason for this may be the lack of standardisation. A standardised interface in the Internet of Things would help to boost the usage of software agents. Smart objects in the Internet of Things need to execute intelligent algorithms to be able to discard irrelevant data, interact with other things in an efficient way, raise warnings about their state or the

state of their environment, and take informed decisions and actions on behalf of human end-users to eliminate or assist control / management activities by humans. Additionally, software agents may help to increase scalability and robustness in the Internet of Things (Uckelmann et al. 2010). In a holistic scenario we imagine things to host a certain infrastructure subset of the Internet of Things. These things may not always be connected to the Internet. Therefore, we envision a certain degree of smart characteristics and autonomy.

- *Extended, federated discovery services* – The EPCglobal Network today does not yet provide ratified standards for federated discovery services, although a technical standard for discovery services is currently under development. At the time of writing, the only lookup service currently provided by EPCglobal is the ONS, which only holds class-level records pointing to authoritative information. This is currently operated under contract by VeriSign Corp. under the onsepc.com domain. The existing ONS implementation is distributed across multiple servers globally. Nevertheless, there are political concerns that the ONS is defined under the .com Top-Level-Domain, which is under the authority of the US Department of Commerce and that the ONS service is operated only by one American company. This has led to political discussions on governance in the Internet of Things, resulting in national focused approaches in China and Europe (Muguet 2009). Federated discovery services are needed to enable open governance, scalability and choice of lookup service in the Internet of Things.
- *Data-synchronisation for offline support* – The EPCglobal Network requires online connection to access data related to the identified product. In certain cases online-connectivity cannot be assured. Data-synchronisation is needed to support mobile scenarios and decentralised decision making.
- *Interface to federated billing services* – In order to enable competition between billing service providers, a standardised interface to these services is needed. This billing interface will enable balancing of costs and benefits as well as new business models and revenue generation opportunities for business and citizens based on micro-trading of information in the Internet of Things.

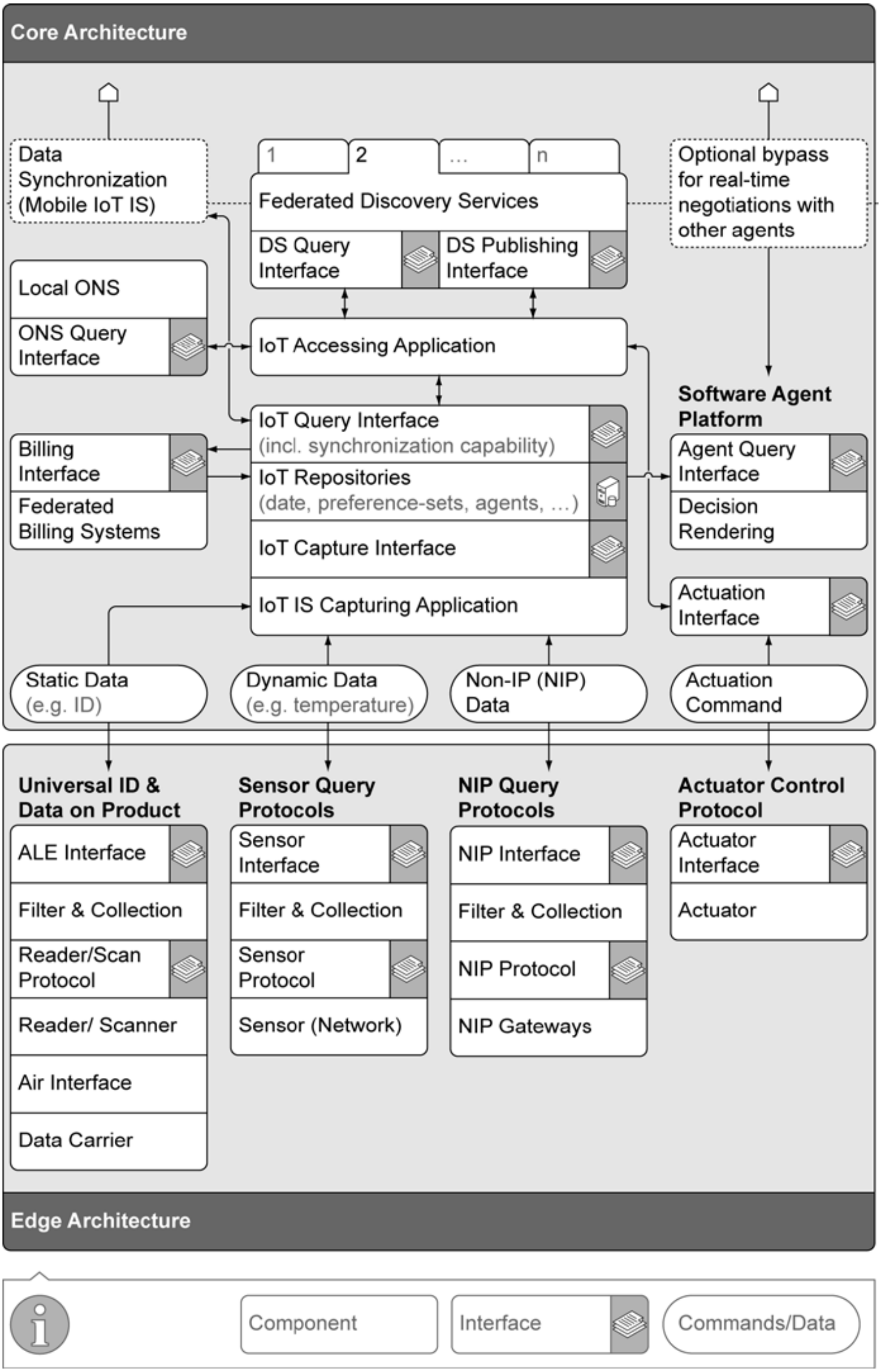

Fig. 1.5 An Extended EPCglobal Architecture Towards a Future Internet of Things

In Figure 1.5 the integration of sensors, actuators and software agents connected to the Internet of Things Information Service (IoT IS) is shown. Parts of this infrastructure may be mobile and disconnected, thus requiring means for synchronisation of data and logic.

Accessibility of information will be enabled through federated discovery services, which will support open governance and choice of lookup service in the Internet of Things. In the Internet of Things, human beings, software systems and smart things will have a strong need for technologies supporting them in the search and discovery of the many distributed resources available, including information repositories, sensors, actuators, etc. These search and discovery services will rely upon mechanisms for universal authentication and access control, at the desired level of granularity, through which resource owners can precisely control the criteria that determine whether their resources may be discovered by others.

1.7 Conclusion and Outlook

Future developments in the Internet of Things will optimise the information flow in industrial and social scenarios and revolutionise business and private communication. Like other milestones in technology, the Internet of Things enables us to measure what could not be measured before. For companies this means additional information for high resolution management of industry and business processes. For citizens the possible implications are manifold, ranging from consumer empowerment to rethinking society.

Different infrastructures and networks will compete and interact in the future Internet of Things. Therefore, the proposed architecture in this chapter is just one possible solution, but it is based on existing developments such as the EPCglobal Network that has already achieved a high level of popularity in business environments.

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