Key Problems and Instantiations of the Internet of Things (IoT)

Dennis Matthias Dominik Picker-Huchzermeyer
Helsinki University of Technology
dominik.pickerh@gmail.com

Abstract

Many concepts, studies, working prototypes and ideas propose to connect simple objects of our daily life to a global network, or rather to let them build dynamic ad-hoc networks, so that they can collaborate, react on changes in their environment and act autonomously with a certain degree of intelligence. Many publications deal with business concepts and opportunities of the Internet of Things (IoT) and draft creative images of the potential future.
However, the concept of the Internet of Things does not only provide opportunities for numerous industries and domains but also contains many different challenges. Several complex and scalable technologies are needed for a successful implementation of the IoT and therefore development and research have to improve dramatically to fulfill these needs.
This paper describes the main opportunities of the IoT on the one hand, and the main challenges for a successful implementation on the other hand. Furthermore it presents affected domains and industries and a concept for an intelligent home as a novel instantiation.

KEYWORDS: Internet of Things (IoT), RFID, Sensor networks, Intelligent Home

1 Introduction

The beginning of present-day internet was the development of the so-called "Arpanet", which had the purpose to connect several american universities to establish a platform for communication and knowledge sharing[1]. In the subsequent decades the number of combined nodes exploded and the rapidly evolving network spread across the whole globe. Nowadays the world wide web influences many areas of our daily life by, for example, automating tasks, providing information or offering communication tools. However, even after many years of development the hardware, which exchanges data via the internet, basically limits oneself to computers of different types and scales. The process flow is mainly controlled by programmed data triggers or manual interventions of human beings using standardized input devices.
Contrary to this current state, the Internet of Things enables the objects in our environment to be active participants, i.e. they share information with other members of the network or with any other stakeholder and they are capable of recognizing events and changes in their surroundings and of reacting autonomously in an appropriate way[23]. Yet these active things are not simply involving electronic equipment but even trivial objects, like for instance food, furniture or books.
This vision of a world containing a huge number of intelligent and reactive things of course involves numerous business opportunities for new industries, which will be eager of maximizing the profit by adding more devices and services to the IoT. Especially the domain of computer-aided manufacturing and logistics presents first approaches of tagging things with semantics and information for several years now and is suggestive of the potential of the IoT concept[14].

The concept of the Internet of Things has been founded in 1999 by the Auto-ID Labs[4] at the Massachusetts Institute of Technology[24]. The general idea behind this abstract term is to connect any object of our daily life with the internet. Therefore every single thing in our environment becomes addressable and consequently furthermore controllable. Automatic machine-to-machine communication and the creation of ad-hoc networks are key concepts for facilitating collaboration among objects and intelligent decision making depending on the current state of surroundings. However, the end points of a communication session in the IoT are not forced to be certain devices or machines, but the connections are highly dynamic and change constantly.

To facilitate the presented kinds of intelligent behavior of the interconnected things, they are tagged with information about themselves or semantic data about their behavior, which thereby enables them to react on all sorts of physical facets of their environment[2].
These possibilities of course lead to many benefits for the end user and numerous publications deal with these issues from the consumer's point of view (see Section 2.2). But on the other hand the application of the Internet of Things is not limited to qualitative improvements of the user experience, but moreover contains a great optimization potential for the business processes and services[6].

This paper presents the key technologies, which are needed for a successful implementation, and the challenges for their particular improvement. Furthermore the following sections illustrate different examples for possible applications of the Internet of Things in several domains and the associated opportunities for the business world on the one hand and the end user on the other hand.
The document has the following structure: Chapter two presents the opportunities of the IoT concept from different point of views. The proximate third section deals with technical challenges as well as other critical circumstances that might prohibit or delay the development of the Internet

of Things, like for example privacy and legal issues. The fourth section presents various exemplary application scenarios whereupon the fifth chapter describes a basic concept for an intelligent home as an example of a novel instantiation. Finally the paper ends with a short conclusion of the topic in section six.

2 Opportunity

The Internet of Things and its application provides the opportunity to establish and market entirely new services and products. Companies which already successfully operate in one or multiple existing industries as well as new startups could participate in forming this new market by inventing, implementing and distributing new goods which provide significant value for the end-user. The following two subsections present the opportunities of the Internet of Things from the business perspective as well as from the end-user perspective.

2.1 Business opportunity

The key business opportunities derive from the most important features of the particular devices of the IoT[23]:

- localization and positioning (indoors and outdoors)
- recognizing changes in the environment by using sensors, machine vision or biometrics and reacting to them
- storing contextual data
- collaboration with other entities

Localizing participants of the network is for example very useful for the optimization of stocks through intelligent shelves and automated monitoring and management[23]. An example of the benefit of the responsiveness to environmental changes is the efficient usage of energy and other resources by monitoring the particular need[11] and storing contextual data on the things or devices for instance leads to an optimization of the manufacturing process by storing product information and by automatically routing the individual goods through the production process[9]. Moreover, the collaboration of different entities in the network is for example important for the implementation of Body Area Networks (BAN), as they have been proposed in [13].
Further examples of business opportunities of the IoT concept are presented in section 4.1 and **??**, which focus on current and future applications, and in section 5, which describes the concept of an intelligent home as a novel instantiation of this concept.
In general, the Internet of Things affects many different industries, like for example automotive, telecommunications, healthcare, manufacturing and logistics or transportation, to mention just a few of potential application domains[23]. However, the effect on a single industry cannot be examined individually but rather this concept has the potential to establish changes in many parts of the daily life, driven by the entirety of involved companies. Furthermore the IoT as central change affects not just certain industries, but also the complete society and environment at the same time[8]. This aspect has also been identified by the International Telecommunication Union in their executive summary: "However, for these ground-breaking innovations to grow from idea to specific product or application for the mass market, a difficult process of commercialization is required, involving a wide array of players including standard development organizations, national research centres, service providers, network operators, and lead users"[8].

2.2 End-user opportunity

The previous section presented business opportunities of the IoT concept, but these benefits of course just make sense and could be realized if the offered services and products provide benefit and value for the end-user. Consequently the end user must have opportunities as well, which are presented in this subsection. Similar to the changes in the business world, the application of the Internet of Things does not only affect certain parts of our daily lives, but even our practices and habits as a whole. The available literature proposes uncountable ideas of services or products, affecting private individual lives, complete families and whole society[23].
The first major benefit for the end user is the facilitation of interaction between things and a human being resulting of new types of devices offering gesture recognition and similar intuitive ways of manipulating the systems and their environment[14]. Mobile devices, like for example smartphones, which nowadays get more and more important and which provide a growing set of features, will probably be the main device to control every interactive thing of our environment. They will make use of contextual information that are offered by the environment and that are recognized by networking devices[22].
Furthermore the Internet of Things might have a major impact on our way of collaboration and of acting in social networks by providing a semi-automation of social activities by adding semantic information and letting devices communicate with each other. In this context, Vazquez et al. use the term of "social devices", which are "able to spontaneously discover, exchange and share context information with other fellow semantic devices as well as augment this context information via reasoning in order to better understand the situation and perform the appropriate reactive response"[10]. The consequence of this is: All connected things in our environment become the new interfaces for social networks and other collaboration tools.
Another interesting opportunity of the IoT concept is the improvement of quality of life in developing countries by e.g. monitoring water quality to guarantee that it is not polluted, monitoring and improving the reliability and distribution of drugs or the intelligent detection of mines[8]. However, there are not just direct opportunities for the end-users, but also indirect ones resulting from opportunities for environmental protection, for example by establishing intelligent networks monitoring the environment and alerting possible disasters, prevent the loss of resources by automatic fault detections for instance in long pipelines and by assisting the consumer in all kind of resource usage[8].

3 Challenges

The previous section presented several opportunities of the concept of the Internet of Things, but of course there are also different kinds of challenges. These challenges have several reasons: At first a successful implementation of the IoT makes use of many different technologies which currently are at the beginning of development[23]. Furthermore the conceived number of network participants is very high, which creates the need of scalable solutions. The global scope and the heterogeneity of the participating devices result in the necessity for standardizations and of course also legal, privacy, social and psychological issues are important concerns that have to be taken into account[8]. The following subsections present selected challenges in more detail.

3.1 Network technology

This subsection describes the challenges regarding the network technology and presents at first the general challenges, then describes selected challenges of the RFID technology and finally focuses on sensor networks.

3.1.1 General challenges

The main goal of the Internet of Things is to connect the entities in our environment in a network, or rather a network of small and dynamic networks. However, these things are absolutely heterogenous and might belong to different application domains and provide different functionality, but nevertheless must be able to share the same communication protocols and schemas. This of course is not a trivial task and therefore describes a major challenge to the network technology[23]. Another challenge results from the dynamics of the networks: Things and devices should build local ad-hoc networks, which in turn might as well be connected to bigger networks. Consequently the objects need unique identifiers to be addressable unambiguously and the network has to know and manage these IDs. Furthermore an entity might not just have one identifier, but perhaps several ones, and it is possible that they are changing continuously. The network technology must be able to deal with these issues, which is also a major challenge[23].
In comparison to established network solutions, like for instance the internet, the traffic in the Internet of Things will be much higher and consequently the network engineers must develop new high-performance methods to deal with this requirement. A similar problem is the challenge of data distribution, synchronization and caching in the network. The underlying technology must guarantee that the relevant data is available in any device at any time. In addition to this, the network must respect the data ownership and must therefore control the availability of the data depending on the context and the rules of the source entity. None of these issues has been present in this dimension in any technical problem before and consequently the network technology has to deal with a completely new set of challenges[23].
The protocol of the network for the Internet of Things can possibly also be the Internet Protocol (IP), which has proven its functionality and scalability for the Internet, Gershenfeld et al. discuss this possibility with more detail in [7].

3.1.2 Radio Frequency Identification (RFID)

RFID has the clear advantage that its development is quite far and that manufacturing processes and supply chains already use it widely. This technique allows object identification and localization without the need of direct sight as well as storing information[6]. Passive tags even do not need a power source because they are powered by the reading device. This independence makes them a light-weight component and allows the item-level tagging of consumer products[12].
However, the large-scale application of RFID in the Internet of Things depends on 4 different aspects[12]:

- Price of tags and reading devices
- Size, to even fit on small items and products
- Performance, e.g. read ranges and robustness against environmental influences
- Storage capacities

The development of this technology is ongoing and manufacturing and retail applications already use billions of tags[12], but the development of RFID is still not far enough concerning the four presented aspects to be applicable for the IoT during the next years[17].
In addition to the challenges of the RFID tags and the other necessary devices, Sheng et al. mention three additional challenges regarding the processing of data stored in RFID tags:[21]

- Data cleansing: recognizing and removing redundant or erroneous data resulting from duplicate readings or "ghost reads"
- Data compression: the huge amount of data (e.g. seven terabytes per day for Walmart [21]) leads to high storage costs and performance decreases
- Data transformation: to reveal the implicit meaning and connect it to other data or items

The mentioned authors provide a detailed comparison of possible solutions for logistics and retailing, namely barcodes, RFID and sensor networks. Decker et al. provide detailed mathematical models covering several different parameters to analyze the costs of the potential solutions[6].
The future development and studies of the different alternatives will show which development meets the requirements of IoT on the one hand and at the same time is efficient enough to be used in enterprises on the other hand.

3.1.3 Sensor networks

Sensor networks consist of autonomous sensors, which monitor their environment and react on changes. By building a dynamic network, they can collaborate and share their data. In contrast to RFID tags, sensors are able to process data in complex computations and therefore are active parts of information systems[6].
Similar to the challenges of RFID tags the price is also a major challenge for sensors and their networks but, however, the necessary software leads to more important problems. Aberer et al. mention two key challenges in their study:[2]

- "minimizing the development and deployment efforts which are key cost factor in large-scale systems"[2]
- "data-oriented integration of very large numbers of data sources" [2], the authors even demand "Zero-Programming-Deployment"

As it has already been identified as a general challenge of the network technology, the heterogeneity of the sensors, which provide different functionality and which should be able to communicate in the same network, and maybe build ad-hoc networks in specific situations, is a major challenge for the sensor networks as well. This is the reason why Aberer et al. formulate the need for an abstraction layer and introduce the concept of a "virtual sensor" and an appropriate middleware architecture[2].
Sensor networks are not necessarily a contrary alternative to RFID technology, but both approaches could work together in coexistence. In this scenario RFID tags are passive data containers and the sensors are the active reading devices and processors, which are responsible for global data distribution[9].

3.2 Software application

The challenges of the network technology of course include challenges regarding the embedded software, but even more complex problems exist concerning the software needed for other functional parts of the Internet of Things. This section deals with these particular problems.
The first software challenge is the creation of an appropriate development environment offering specific tools which fit to the characteristics of the IoT. The software developers must be able to produce services which are be used by the middleware[23]. Furthermore the ID management, which has already been mentioned as a challenge of network technology, of course also is a software problem. Another important challenge is the result of one of the main functionalities of the software, which runs on the heterogeneous things: The software must be able to perform different types of discovery: It must discover and recognize the devices and things in its environment, their role and functionality, semantics, how the entities could interact and collaborate and how to invoke and use the provided services and functionalities of other objects. All these processes depend on contextual information and depend on machine-understandable semantics. All together this is a problem of immense complexity and demands superior designs and architectures.
The network participants should be able to decide on their own how to react on specific events and how to collaborate efficiently to reach a specific goal. This creates the need for complex problem-solving and intelligent automatic inference algorithms. A general formulation of the software challenge is the problem to build a huge, coherent system of numerous, heterogeneous modules which are developed by many different enterprises in the world, with a high number of different actors which participate dynamically in the network[23]. According to this view, Rellermeyer et al. see the software problem as another instantiation of the problem to build modular software and they therefore propose an exemplary study for building a scalable solution in Java by using the OSGi model and connecting this to results of other programming languages[16].

3.3 Other challenges

Beside technical challenges there are several other challenges resulting from the numerous impacts the IoT might have on the society and the daily life of each individual. At first, the spread and standardization of needed infrastructure, like for instance frequency bands and availability of broadband networks, are of course very important for a successful and global implementation of the IoT. The International Telecommunication Union presents the penetration and costs of broadband internet in different countries and shows that there is a lot work to do until a global Internet of Things becomes realistic[8]. Besides basic cable networks of course the spread of the mobile market is also an important parameter, the executive summary of the ITU also presents penetrations and costs for this segment with similar implications[8].
A psychological challenge is to convince the end users of the opportunities of the IoT. This can be a serious problem due to skepticism regarding privacy, data ownership and security and because the people suspect tracking of their movement, shopping and other sensitive data[8]. Protest movements against attempts to introduce item-level tagging by Gillette and Benetton show this skepticism impressively[12]. Especially when user data is handled in process chains, e.g. on RFID tags, data protection and privacy concerns have to be taken into account from user-perspective but as well from enterprise perspective. For example the RFID tags in the manufacturing process could contain detailed information about the whole process, which usually should not be shared in the entire supply chain. Again, data ownership and the requirement to decide which data is provided by which device in which situation appear to be major challenges for the IoT concept. Concerning the legal issues, Schmid provides a summary, comparison and categorization of different RFID legislations[19].
A main challenge for the whole conceptualization and design process of the Internet of Things is the multidisciplinarity. Different stakeholders with completely different backgrounds, like for instance engineers, software developers and lawyers, are involved into the development process and consequently the success of the entire approach might depend on the ability to join al different attitudes, concerns and requirements[15]. Finally, enterprises could just make profit by offering IoT products if the user acceptance is available. Complex studies and marketing campaigns are necessary to make different user groups feel comfortable with the new concepts, as shown in an exemplary study by Rothensee, who examined the acceptance of an intelligent fridge system and describes the sensitivity and diversity of the reactions[18].

4 Application

This section presents examples for the application of the IoT concept for different domains and industries. The first subsection focuses on solutions which are already available or for which stable prototypes have already been introduced.

The second subsection describes the domains which are affected by the IoT and presents selected examples of services and products which have been mentioned in several publications.

4.1 Scenario Examples

Although the Internet of Things is still far away from being reality and many of the key technologies are still in an early development or conceptualization phase there are some promising products, or prototypes of these products, available. The first interesting concept is the idea of an intelligent refrigerator. This device is able to recognize the items it contains by reading the information stored on RFID tags on the individual food itself. Therefore it can search the internet for important facts like for instance testimonials of other customers, nutrition facts or information about the manufacturing process. Furthermore the refrigerator is able to manage the expiry dates of the food and might therefore alert the user if a certain product is about to expire. The machine could also be fully adjusted to the eating and drinking habits of the user to guarantee a basic supply of the desired food by automatically ordering the products which are consumed regularly. Different sources on the internet explain this concept and basic approaches[1] and [5] transfer the idea of monitoring perishable goods in whole supply chains.
The second example of developments is an intelligent system to monitor the transportation of sensitive goods. IBM in cooperation with the danish transportation company "Container Centralen" developed[2] a transportation system whose complete process chain is assembled with appropriate sensors, which are able to detect the condition of the transported goods. The result of the continuous measurement is the adjustment of certain environmental parameters, like for instance the temperature, or alerting responsible persons. An additional benefit of this system is the transparency of the transportation status of each handled good, which is another result of the continuous sensor activity.
The third and last example is the british startup Pachube[3], which provides realtime access to sensor data around the world. The user can register a certain device which is connected to the internet or is able to send SMS and can henceforth monitor the sensor measures on a geographic map. Pachube has consequently built a prototype of a sensor network which allows the realtime sharing of sensor data from different locations, although this data currently is not brought in relationship or combined with machine-understandable semantics in any way.

The following list describes just an extract of possible application domains in more detail[23]:

1. **Automotive**: The impact of the Internet of Things on the automotive industry can be examined from different perspectives. The time between ordering and actually getting the car could be decreased dramatically by using intelligent manufacturing methods in the complete supply chain. Cars are more customizable and the production process is able to adjust to the particular customer needs. Driving the car is much more convenient because intelligent traffic systems are able to use the data, which is collected by the cars on the road, to find an optimal route for each driver. Functional sensors make it easy to recognize any technical problem and facilitate the problem-solving process for the mechanics, or the reparation process could even be fully automized. Automatic accident reporting and localization of alerting cars can make driving much more secure. Consequently the IoT concept leads to benefits in costs, time or effort for the user, the manufacturer, the repairing industry and the emergency infrastructure.

2. **Healthcare**: The benefits of the Internet of Things for the healthcare industry result on different levels. Regarding the distribution of drugs an automatic identification of both the patient and his illnesses as well as of the drugs and their outcome, ingredients and side effects makes it possible to automatically determine the best medication for a customer on the one hand, and to prevent drug abuse and the disappearance of dangerous substances on the other hand. Specific identification devices would furthermore be helpful for doctors who have to make ad-hoc diagnosis' or who need to know specific details about the medication or sanitary history of the particular patient. Intelligent devices forming a Body Area Network (BAN) [13] continuously measure the important body functions and are able to automatically report the results to emergency institutions in case of dangerous abnormalities. Adamer et al. furthermore examined the benefit of a wearable assistant which provides important facts about a patient or his therapy during ward rounds in hospitals[3].

3. **People and goods transportation**: The transportation of either persons or goods can be strongly facilitated by the concept of the IoT. The public transportation industry benefits from automatic fare collecting systems and an increase of security by automatically scanning the luggage and bags of the passengers for weapons or other similar items. The logistic industry is able to build much more efficient process chains and the circumstances could dynamically be adjusted to the type and condition of the transported good, as it has already been discussed in section 4.1.

4. **Shopping**: Adding specific product information and semantics to the items of a shop facilitates and expedites the decision making for the customer. Persons who are interested in certain goods are able to query relevant information about specific products, their attributes or about the whole product range of the shop by for instance reading the data which is stored on RFID chips with their cell phone. This enhances the shopping experience for the customer on the one hand and leads to decreased costs for the shop by automating the guidance for the customer on the other hand. Schmitz et al. propose an interactive shopping assistant for wines

[1] for example `http://www.crookedbrains.net/2007/04/worlds-very-first-intelligent.html` offers a basic description and a video demonstrating a prototype

[2] Information can be found under `http://www.readwriteweb.com/archives/top_5_web_trends_of_2009_internet_of_things.php`

[3] `http://www.pachube.com/`

based on RFID and acceleration sensor technology as an extensive example for this application domain[20].

Besides these examples there are of course many more domains and industries which could benefit from an application of the IoT concept. [23] and [14] describe a more complete list including aerospace, telecommunications, oil and gas, safety and security, environment monitoring, retail and logistic, smart buildings and many more. Some of them have already been mentioned in the previous sections or are topic of the next chapter. The Internet of Things offers great opportunities for potential applications and even more might be discovered during the development of more concrete concepts and technologies.

5 Novel Instantiation: Intelligent Home

The domain of intelligent buildings and ways to improve the quality of living by facilitating or automizing common tasks has been the focus of many studies and research work[23]. This section presents a basic approach for an application of the Internet of Things concept to individual living spaces with the goal to create an intelligent home.
The functionality of the intelligent home is in our opinion dividable in specific, distinct categories, which are described in this subsection:

1. **Use of Resources**: Conceptualizing an intelligent home does not just mean thinking about convenient and helpful functionality, but also take the informational needs of the persons into account. The use of resources like electricity, water or gas are getting more important as a result of increasing prices and an increasing awareness of the importance of protecting the environment. Therefore the intelligent home collects data about the consumed resources via several sensors which collaborate to transform the individual results into a meaningful statistic. The user consequently always has the possibility to analyze his resource consumption. Furthermore the consuming devices and also the sensors are able to identify situations in which resources are wasted and make propositions for the user how to avoid these situations.

2. **Security**: Safety and security are important issues for an intelligent home. The building should contain several sensors to monitor the building itself and the close environment to detect potential attacks or dangers. Video cameras, microphones, and smoke and movement sensors are allocated in the whole building and the according estate to guarantee a complete coverage. The different sensors are sharing their measures to combine them to a coherent picture of the current situation, which could for example enable the sensors to recognize the movement patterns of detected persons to make an implication about their target destination. All sensors must be accessible at any time for the house owner to monitor the situation at home from any location. The sensors can automatically detect dangerous situations and react in an appropriate way. If for example the house owner has just left the building and forgot to close a window the system alerts him to come back and fix this issue. In a more dangerous case, like for instance a fire, the sensor network automatically calls the emergency, transmits a detailed report about the situation and tries to inform all persons in the building.
The entrance to the building is secured by biometric detection sensors and all external interfaces which give access to the system are secured by appropriate passwords and encrypted communication channels.
Furthermore the whole system continuously communicates with public services to get information about important incidents, like for example a storm moving in direction of the building, an earthquake warning or just usual weather data to assist the home owner in choosing appropriate clothes.

3. **Living**: One of the main purposes of the intelligent home is to improve the comfort of living. This is accomplished via several functions. The most important aspect for facilitating the usage of the intelligent home is to offer one uniform device, which is used to configure, monitor and customize the whole system. The interface must be convenient and uniform to be usable by any kind of person and could for example be integrated in a smartphone or something similar.
The system enables the home owner to configure different themes which influence the settings of the building, like for example the temperature, brightness of the lights, volume of TV or audio systems and maybe even the alignment of different pieces of furniture. The system is furthermore able to identify the person entering a room and load its preferred theme depending on circumstances like for instance daytime or mood. Any kind of media is stored in a central place of the building and is consequently distributable to any location. Media collections can be shared with other intelligent homes if this is confirmed by both parties and an audio or video conference is also possible in any room of the building.

Of course it is possible to imagine many more features and functionalities which would enhance the system, but the described set provides a solid, basic set of facilitation and is furthermore even realistic with current technologies.

6 Conclusion

The Internet of Things promises many benefits for different domains and industries. The businesses, end users and even the whole society are affected by the potential changes resulting of applications of this concept and a successful implementation of a network of intelligent, interactive and autonomous things would probably change the daily life of each individual.
However, this paper also presented several challenges and problems which have to be solved before a working Internet of Things is realistic. Many of the key technologies must strongly increase regarding different aspects to be applicable and scalable in a network of the expected size and kind of the

IoT. Besides thinking about the technical problems and possible solutions we should not forget that a major change of the persons' lives cannot be established from one day to another but needs careful and long-term effort to make the people comfortable with new services and their role in the complete system. Each development must be examined regarding the value and the user benefit and if it matches the need of the society. The realization of the Internet of Things is an interdisciplinary and collaborative process, which will just be successful if all important concerns are taken into account. The executive summary of the International Telecommunication Union expresses this key aspect in one, very meaningful sentence: "Unless there are concerted efforts involving all government, civil society and private sector players to protect these values, the development of the Internet of Things will be hampered if not prevented"[8].

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