Bachelor Thesis

Internet of Things

-Foodstuff Traceability and Transportation with Consideration of Logistic Processes in Cold Chain Management-

submitted by

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Erklärung

Ich versichere, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

	Ja	Nein
Mit der Einstellung dieser Arbeit in die Bibliothek bin ich einverstanden.	☒	☐

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Abstrakt

Diese Bachelorarbeit liefert einen umfassenden Überblick über das Thema Internet of Things (IoT). Mit der Hilfe eines ersten Literaturüberblicks sind wichtige Charakteristiken, Architekturen und Eigenschaften aufgezeigt wurden. Das Hauptziel der vorliegenden Bachelorarbeit ist es zu bestimmen, ob durch den Einsatz von IoT im Transport von Lebensmitteln unter Berücksichtigung der Einhaltung der Kühlkette Vorteile für Unternehmen gewonnen werden können, um Lebensmittelverschwendung zu reduzieren. Hierfür ist ein zweiter Literaturüberblick mit Lebensmitteltransportsystemen ohne den Einsatz, sowie mit dem Einsatz von IoT durchgeführt worden. Auf Grundlage des Literaturüberblicks, soll es am Ende möglich sein, ein „ideales" System für den Lebensmitteltransport in Kühltransportern unter Berücksichtigung der jeweiligen Technologien zu bestimmen. Die Ergebnisse von verschiedenen Autoren haben gezeigt, dass oft signifikante Verbesserungen in der Überwachung, dem Transport allgemein, oder der Verfolgbarkeit von Lebensmitteln erreicht werden können und letztlich auch die Lebensmittelverschwendung reduziert werden kann. Dennoch können auch Vorteile durch den Einsatz von neuen Technologien gewonnen werden, die nicht auf IoT basieren oder darauf zurückgreifen.

Somit ist die Haupterkenntnis dieser Bachelorarbeit, dass ein theoretisches „ideales" Transportsystem eine sinnvolle Kombination aus Technologien mit und ohne IoT beinhaltet. Dieses System beinhaltet den Einsatz eines Drahtlosen-Sensor-Netzwerk für die Echtzeitüberwachung der Lebensmittel, sowie eine Alarmfunktion, wenn die Temperatur einen Höchstwert überschreitet. Eine Echtzeitüberwachung mit GPS, welche mit einem Überwachungszentrum für die Vermeidung von Staus verbunden ist, smarter und energieeffizienter Verpackung und schließlich der Einsatz der neuen „supercooling"-Technologie machen das System deutlich effizienter bezüglich der Reduzierung von Lebensmittelverschwendung.

Dies zeigt, dass Unternehmen bei der Auswahl eines möglichst effizienten und gewinnbringenden Transportsystems für Lebensmittel mit Kühltransport nicht nur auf den Einsatz von IoT setzen müssen. Auf dieser Grundlage ist es empfehlenswert, die bisherigen verwendeten Systeme und Technologien mit IoT zu kombinieren, um ein möglichst hohes Maß an Lebensmittelverschwendung zu vermeiden.

Keywords: Internet of Things, Lebensmittel, Kühlkette, Lebensmitteltransportsystem

Abstract

This bachelor thesis delivers a comprehensive overview of the topic Internet of Things (IoT). With the help of a first literature review, important characteristics, architectures, and properties have been identified. The main aim of this bachelor thesis is to determine whether the use of IoT in the transport of food, considering the compliance with the cold chain, can provide advantages for companies to reduce food waste. For this purpose, a second literature review has been carried out with food transport systems without the use, as well as with the use of IoT. Based on the literature review, it is possible at the end to determine a theoretical 'ideal' system for food transport in refrigerated trucks. The respective used technologies are also mentioned. The findings of several authors have shown that often significant improvements can be achieved in surveillance, transport in general, or traceability of food, and ultimately food waste can be reduced. However, benefits can also be gained using new non-IoT-based technologies.

Thus, the main knowledge of this bachelor thesis is that a theoretical 'ideal' transport system contains a sensible combination of technologies with and without IoT. This system includes the use of a Wireless Sensor Network (WSN) for real-time food monitoring, as well as an alarm function when the temperature exceeds a maximum. Real-time monitoring with GPS coupled with a monitoring center to prevent traffic jams is another task. Smart and energy-efficient packaging, and finally the use of the new supercooling-technology, make the system significantly more efficient in reducing food waste.

These highlights, that when choosing a transport system, which is as efficient and profitable as possible for food with refrigerated transport, companies need not just rely on the use of IoT. On this basis, it is advisable to combine the systems and technologies used so far with IoT in order to avoid as much food waste as possible.

Keywords: Internet of Things, Foodstuff, Cold Chain, Food Transportation System

Preface and Acknowledgment

Writing a bachelor thesis is a lengthy and very exhausting process, which I only overcome, because of the lovely help of my family. Without help from my mother and my brother who always encouraged and motivated me, I would not have stood this time. Writing the work was not easy for me, my supervisor often had suggestions for improvement. But in the end, this work has been carefully built and I am very happy and proud of the result of my work.

So, I am extremely happy for my family, thank you very much! Special thank goes to my mother who supported me as well financial as psychically during the whole higher education and especially while the writing process of this bachelor thesis. She always had an often ear for all my problems and difficulties and helped me whenever she could. Special thanks also to my brother, who whenever I needed a distraction from writing he was the best I could ever imagine. The constant encouragements of him and the generally very lovely manner have always motivated me to continue writing. If I did not know any further, he was by my side and helped me with new ideas.

Thanks, are also due to Maria and Marc, who proof-read my thesis and gave me good tips for continuing my work. I would also like to thank Jun.-Prof. Dr. Schaarschmidt. He as my supervisor makes it possible to write this bachelor thesis and during the writing process, he gave me helpful suggestions for improvement, which always brought me to think in a new way about my work. His friendly, uncomplicated and open manner was very facilitating for me.

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1 Introduction

“In most countries, around 30% of food products are said to be wasted throughout the supply chain” (Akkerman, Farahani, & Grunow, 2010, p. 12). This means, that millions of people must hunger due to the large waste of food, which can be avoided. To tackle this problem, this bachelor thesis combines the food transportation process in the cold chain with the Internet of Things (IoT). The term Internet of Things was first mentioned by Kevin Ashton in the year 1999 and refers to a global network with billions of interconnected smart objects, which communicate with each other and exchange data (Aazam, Khan, Alsaffar, & Huh, 2014; Lee & Lee, 2015; Noura, Atiquzzaman, & Gaedke, 2019). The amazing growth of the IoT technology and its increasing meaning for the world makes it very important to handle the topic in this bachelor thesis.

This work presents the results from two comprehensive literature reviews. The first one, for a detailed overview of the IoT topic and the second review for the foodstuff topic, to find advantages using IoT. Furthermore, the results of the second literature review include a detailed comparison of food transportation systems with and without IoT. During the literature reviews, I often recognized many Journal Articles which only handle one specific aspect of IoT like focusing only on the history, technical aspects of one application area. Or current literature only presents a system for supporting the transportation procedure of food in the cold chain. So, either one work delivers in-depth insights to the technology IoT or to one concrete system. However, very few works, which provide a comprehensive overview of the IoT technology, present a special topic too. During the two literature reviews with a detailed comparison and evaluation, I did not find such a combination in other papers. This thesis combines these two approaches and eliminates the respective weaknesses: A detailed overview of the IoT technology with its basic principles, main characteristics, and technologies is provided. Moreover, history and some application areas are provided. The thesis also covers one specific topic, namely the consideration of food waste during food transportation with cold chain management in refrigerated trucks, in order to detect advantages and benefits using IoT. Relate to the work with his aims I can make a strong focus on the topic IoT.

The present work is structured as follows: After the rest of the Introduction in chapter one, chapter two forms the theoretical background for understanding the following chapters. Subsequently, the methodological approaches of this bachelor thesis are provided in chapter three. The next chapter delivers an in-depth consideration of the IoT topic with characteristics, technologies, and architectures. Chapter five presents different application areas where IoT can improve systems or processes for more practical insights. Afterward, the special topic of foodstuff transportation with a detailed overview of various systems is handled in chapter 6. The discussion and conclusion are provided in chapter seven and finally, this bachelor thesis concludes with the used references.

1.1 Research Issue

Regarding the global annual food waste, approximately one-third of all produced foodstuff between the field and plate get missed. The cause is often incorrect drying storage as well as transportation faults (Akkerman, Farahani, & Grunow, 2010; Bundesministerium für Ernährung und Landwirtschaft, 2018). This very high percentage of wasted food is catastrophically for millions of people, which could be partially avoided using IoT in an efficient way. Therefore, the thesis presents two literature reviews. The first one for getting a detailed overview of the IoT technology and the second one for an in-depth comparison between transportation system with and without using IoT. Whether in Energy, Telecommunications, Intelligent Buildings, Healthcare, Retail, Safety, Insurance or in Recycling, many application areas exist where the Internet of Things (IoT) can take place (Patel & Patel, 2016; Sundmaeker & Saint-exupéry, 2010). In general, transported goods can be food, pharmaceuticals, flowers or chemicals. This work focusses on the application area food transportation for logistics companies regarding foodstuff waste. Especially logistic processes with foodstuff have the immense financial potential for logistic companies, but temperature-sensitive products are perishable. Comprehensive cold chain management is necessary for preventing bacterial, microbial or fungal contaminations (Luo et al., 2016). The storage of food in warehouses and transportation into refrigerated trucks without IoT is often not able to guarantee security from infections or proper storage, because of lack of temperature standards or out-of-date technologies.

1.2 Scope and Concepts

This bachelor thesis focused on two main concepts: The first one is the providing of a detailed overview of the Internet of Things, which is handled in chapters four and five. The second concept is an introduction into the foodstuff topic with a detailed comparison between foodstuff traceability and transportation system, regarding the cold chain management with their logistic processes. But before the two concepts could be developed, chapter two is necessary for getting a first impression of what IoT includes and how it is being affected the people's daily lives. Therefore, chapter two briefly provides the relevance of IoT for other researchers and delivers a historical overview with its development from a relatively small technology to its eminent size today. Afterward, chapter three presents the methodological approaches to this thesis. The reasons for describing the approaches in an own chapter are the following: Firstly, chapter two handles with the general content of IoT which is not a result of the method chosen. Moreover, the procedure and content of the method section are too much which would otherwise exceed the scope of an introduction. Therefore, chapter two delivers important facts to get background-knowledge of the IoT topic, while chapter four continues with in-depth knowledge and results gained from the methodological approaches in chapter three.

The first main concept of this work provides an in-detail overview of the relatively new technology IoT. Therefore, a comprehensive literature review, which provides basic information for IoT with different objects of investigation, is provided. The presented results from the literature review are established on 57 papers, which were searched, compared and analyzed from different databases and mainly include journals. With the help of this literature review, a common understanding of the topic IoT with its different definitions, key characteristics, important elements, etc. is provided. So, the scope of the first part of the bachelor thesis is to guide the audience through the different aspects and properties of the topic IoT. By and by the audience can follow the results of the thesis by learning the important concepts, different characteristics, and elements from various researches. Moreover, significant technologies, which mainly influence the IoT, and diverse architectures are provided. Therefore, the single subsections of this thesis are established on each other in sequential order. After the presentation of the most important principles, the work briefly introduces different application areas, where the usage of IoT can improve various facets: Intelligent Buildings to create a Smart Home should provide, with the help of IoT devices and sensors, more comfort for people by doing daily and returning tasks automatically. In contrast, the usage of IoT in Healthcare takes care of early symptom and disease detection and will improve the living conditions of humans by creating for example smart hospitals or smart senior-citizens home. While the use of IoT in Retail and the Supply Chain Management both improve the economic situation for companies, the integration of Blockchain with IoT deals with generating more trust by dispense with a third centralized company.

The second main concept of the bachelor thesis is a combination of a comprehensive literature review and a detailed comparison of foodstuff transportation systems in Cold Chain Management with and without the use of IoT. With the help of the review, advantages and improvements using IoT in the logistics are identified. This is possible by comparing three different systems without the usage of IoT and four systems using IoT for their logistic. So, the second concept of the bachelor thesis is the presentation of foodstuff traceability and transportation systems once with IoT and once without IoT in order to provide a comparison. The scope of the second part of the thesis is not to guide the audience through different aspects and properties, but the part should provide both similarities and differences by comparing the two approaches.

The results of the comparison will show more advantages and improvements using IoT than the non-use of it. With the help of IoT, food waste could be significantly reduced by supporting the transportation and storage process, which will result in the generally improved food supply of people. At the end of this bachelor thesis, the author presents the meaning of a theoretical 'ideal' system for reducing as much food waste as possible. A detailed description of the literature review procedure and the comparison are described in chapter 3, where the two conducted methods are presented. Overall, more than 70 papers from different sources like Journal Articles, books, and conference proceedings were analyzed for both parts of the thesis. More than 25 sources from web pages and newspaper articles for numbers and facts were combined with the scientific sources. Altogether, 100 sources for this Bachelor Thesis were analyzed. The next subsection lists the main aims of this work in detail.

1.3 Aims of this Work in Detail

Overall, the following main aims are answered with this bachelor thesis:

1. The first aim is the presentation of a detailed overview of the whole IoT technology with its characteristics, main elements, and used architectures. Moreover, some application areas, where IoT can improve processes and help people, is provided.
2. The second aim concentrates on the comparison of food transportation systems, to identify advantages using new technologies in the cold chain management and using IoT for the logistic processes.
3. With the help of the identified advantages, what could be a theoretical 'ideal' system, offering its properties for the transportation of foodstuff in the cold chain? Does this system only consist of using IoT or a combination of traditional new technologies and IoT?

These three aims are the most important ones which are answered during the bachelor thesis, nevertheless, each chapter adds his respective contribution by providing specific content.

2 The context for the Internet of Things Topic

In the following, the audience should gain a feeling about why the topic of this bachelor thesis is important, given the different subtopics it includes. This chapter delivers basic subsections which are important for the Internet of Things (IoT) topic. Furthermore, this chapter serves as an understanding of this work, which is necessary for the later developed methods and results. The context chapter is not a result of the later-described method section, but it rather serves as basic of understanding the following chapters.

The main contributions of this chapter are presented as follows: Firstly, an overview of the relevance of the IoT topic, by presenting affections to people's daily lives. By introducing the significance of the Internet for daily life, IoT technology should bring some benefits and comforts for people. The distinction between the classification of IoT as evolution and revolution of the Internet, identified by different authors, are provided. As well as a brief view on the market share with its financial importance and the Gartner Hype, to underline the current and future importance of the IoT topic. This is provided in the first subsection. The second subsection, to support the context, is the historical evolution of IoT, to understand the development from the very beginning, in the year 1999, until today with short regard to its possible future development. Eventually, the subdivision of the IoT history in three different generations concludes the second subsection. Figure 1 illustrates the scope of this chapter with the different objects of investigation relevance for daily life and historical evolution.

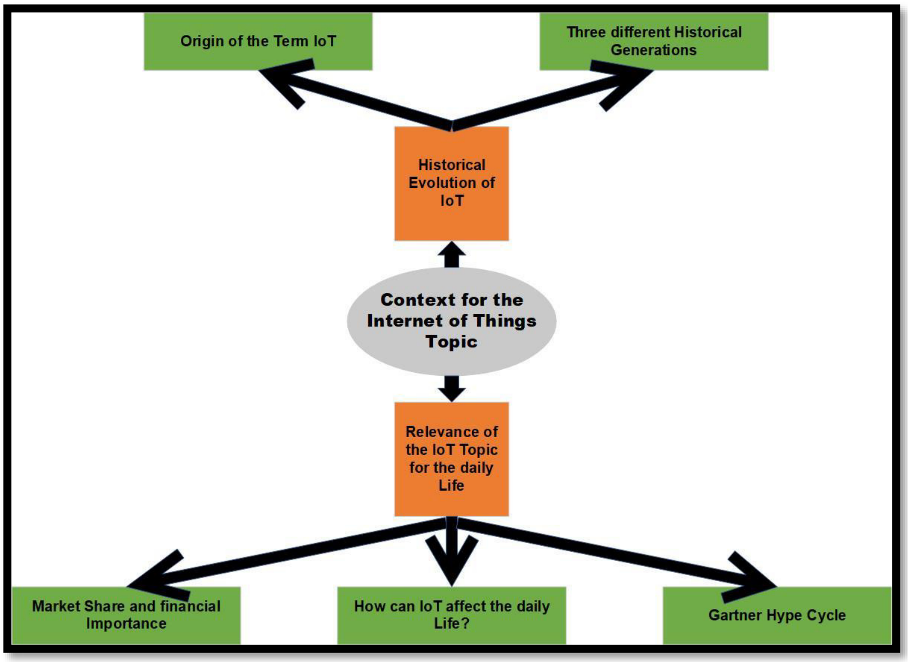

Figure 1 Scope of the chapter: Context for the Internet of Things Topic (Source: Own presentation)

2.1 Relevance of IoT for the daily Life

This subsection delivers a detailed overview of the relevance of the Internet of Things. As well as the significance of our daily life with their changes that can result in using IoT as its possible future development is provided. Moreover, the actual and future financial market share are briefly summarized, to gain an understanding of economic importance. Moreover, the IoT technology is placed by US market researcher Gartner on its Hype Cycle to emphasize the relevance of IoT for today and the next 10 years. With the help of this subsection, the audience will gain a first impression of the relevance of IoT and its importance for the global economic market.

How can IoT affect daily Life?

Nowadays, the internet with all its applications and services is necessary for billions of people. They use the internet not only for entertainment but also for their daily tasks and work. Many people are not able to fulfill their work without using the internet, so it has become a basic need (Burhan, Rehman, Khan, & Kim, 2018). In the year 2018, about 3.9 billion people used the internet, which was 51 percent of the world's population. This means that more than half of the people are using the internet either for their special needs or their work. Moreover, the communication and synchronization via the internet are quite easy (Statista, 2019a). Because of the numerous benefits that the internet offers, Internet of Things (IoT), as an emerging technology, becomes a more and more essential part in the human's lives. This increasing relevance is reflected in the daily growing number of IoT devices. The major aim of these devices is to provide comfort, as well as perform tasks in a working environment. The work often contains necessary tasks, which are important for humans, but also very time-consuming. With the help of IoT, these tasks could be automated and, at the same time, controlled, to provide time-savings for people, so that they can concentrate on their really important tasks (Burhan, Rehman, Khan, & Kim, 2018). The devices should learn the user's preferences to support him at the right time with the right level according to his needs (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014).

Some researchers classify IoT as the next evolution or further development of the Internet which fit the people's needs in a better way and can perform more things than the conventional internet. For example, the ongoing trend to ubiquitous computing, where every object is going to be connected to the internet, is seen as an enabler for IoT, which will be more pervasive (Aazam, Khan, Alsaffar, & Huh, 2014; Yassein, Al zoubi, Mardini, & Shatnawi, 2017; Sehrawat & Gill, 2018). The aim of the pervasive context of IoT does not mean that computers or devices will take over humans' tasks in total. The programming and construction process should still be done by people. The aim is rather that the IoT sensors and actuators become invisible for the people while communicating and exchanging data with each other to support people's duties and life. Because, people only have limited time and accuracy, automatically gather data and send them to the internet is an important advantage through the use of IoT (Bhabad & Sudhir, 2015). This aim is familiar with the ubiquitous computing context, but one important characteristic which classifies one network to IoT is the exchange of data outside the network with other people to create knowledge and wisdom. Ubiquitous computing, on the other side, has the need to go beyond local networks and may not even be networked (Sprenger, F., & Engemann, C., 2015). Furthermore, some authors classify the IoT technology only as a trend arguing the things-concept is not new. Only the interconnection of the sensors, actuators with the devices for the people and regard of interoperability between the standards should be a new concept (Lokshina, Durkin, & Lanting, 2017).

Other researchers compare IoT to a revolution that has the power to fundamentally change people's daily lives with the help of progressing computing and communication mechanisms (Madakam, Ramaswamy, & Tripathi, 2015; Rose, Eldridge, & Chapin, 2015; Williams, Hardy, & Nitschke, 2019). This revolution will be a silent one, which bit by bit will become part of our daily life. Not only in the user's households, but also for the industry with new business models, products and services in different domains IoT can enable immense advantages. One possible business model could be the 'pay for what you use approach' which means, that users pay only for the service and time that they really use. These improvements are not limited to special countries, as well nationally as globally the use of IoT can enable them (Asplund & Nadjm-Tehrani, 2016; Williams, Hardy, & Nitschke, 2019).

Market Share and financial Importance

For the financial importance and market share of IoT, many different analysts, organizations, and researchers show tendencies of its development. A selection of them is provided in this paragraph. Some analysts like Gartner calculate, that the growth of IoT devices and things has rapidly increased during the years. The total number of connected things worldwide in the year 2017 was 8.4 billion which is a growth of 31 percent in comparison with the year 2016. Moreover, Gartner foresees, that the number of connected things in the year 2020 will reach 20.4 billion, which would be growth times 30 compared to 2009 (Gartner, 2017). Table 1 provides an overview of the development of the thing which is being installed from 2016 to 2020.

Table 1 Number of connected things from the year 2016 to 2020 (Source: Own presentation based on Gartner, 2017)

Year / Category	2016	2017	2018	2020
Consumer	3,963	2,544	7,036	12,863
Business: Cross-Industry	1,102	1,501	2,132	4,381
Business: Vertical-Specific	1,316	1,635	2,027	3,171
Grand Total	6.381	8,380	11,196	20,415

On the other hand, the global leader in IT and networking Cisco foresees, that in the year 2020 about 50 billion devices are connected to IoT with a potential market of $14 trillion (Kramp, van Kranenburg, & Lange, 2013). And in the year 2022, Cisco predicts that the number of sensors which work together and exchange data in the IoT network will reach about 45 trillion. The global leader also forecasts other interesting future scenarios: In the year 2021, the annual global IP traffic will reach 3.3 Zettabytes and Smartphones will be responsible for about 33 percent of the total IP traffic. General traffic form wireless and mobile devices in the year 2021 will be about 63 percent (Afshar, 2017).

Another organization, like the international management consultation Boston Consulting Group (BCG), predicts that Business-to-Business expenditures will reach 267 Billion USD in 2020 with half of the total expenditures for industrial application areas like smart logistics, smart transportation or smart manufacturing, which all refer to the smart factory approach (Columbus, 2017). By considering RnR Market Research, it assumes that the combined market of IoT and Machine-to-Machine communication reach $498.92 billion in 2019 and $1423.09 billion in 2020. This means, that IoT and Machine-to-Machine market will increase to over 285 percent in only one year (Khodadadi & Dastjerdi, 2015). By considering the year 2025, McKinsey Global Institute forecasts that the total annual economic impact produced by the IoT industry will reach between $2.7 trillion to $6.2 trillion (Al-Fuqaha, 2015; Hoffman & Novak, 2018; Williams, Hardy, & Nitschke, 2019).

Thus, many researchers and organizations, which make forecasts for the IoT market and its sensors exist. One last interesting examination from the NIC forecasts, that in the year 2025 nearly everything like food packages, paper documents, house equipment’s, etc. will contain one internet node like an RFID tag. The importance of IoT is omnipresent and will increase to a powerful global technology in only a few years (Zhu, Leung, Shu, & Ngai, 2015).

Gartner Hype Cycle

Every year, the US market researcher Gartner investigates emerging technologies and assigns them to his Hype Cycle. Five different phases, which reflect the technology's actual potential are available: First, each technology is an innovation. In the second phase, it reaches the peak of exaggerated expectations and then goes through a period of disillusionment. The technology can only reach in phase four its productive and value-adding potential. In the Emerging Technologies Hype Cycle 2018, various IoT technologies are available. Figure 2 provides an overview of the Hype Cycle in the year 2018. For examples, IoT Platforms, which are very important to offer access to the IoT network, compression, availability, etc. is on the peak of inflated expectation. However, only in 5 to 10 years, Gartner foresees that this technology displays its full potential due to the skills shortage. Another technology on the Gartner Hype Cycle is the Connected Home. This technology is on the threshold from the peak of inflated expectation to the trough of disillusionment. As IoT Platforms, it will reach its productive phase in only 5 to 10 years (Panetta, 2018). So, it is important, that the whole IoT technology reach the fourth phase reaching its full potential (Sprenger & Engemann, 2015).

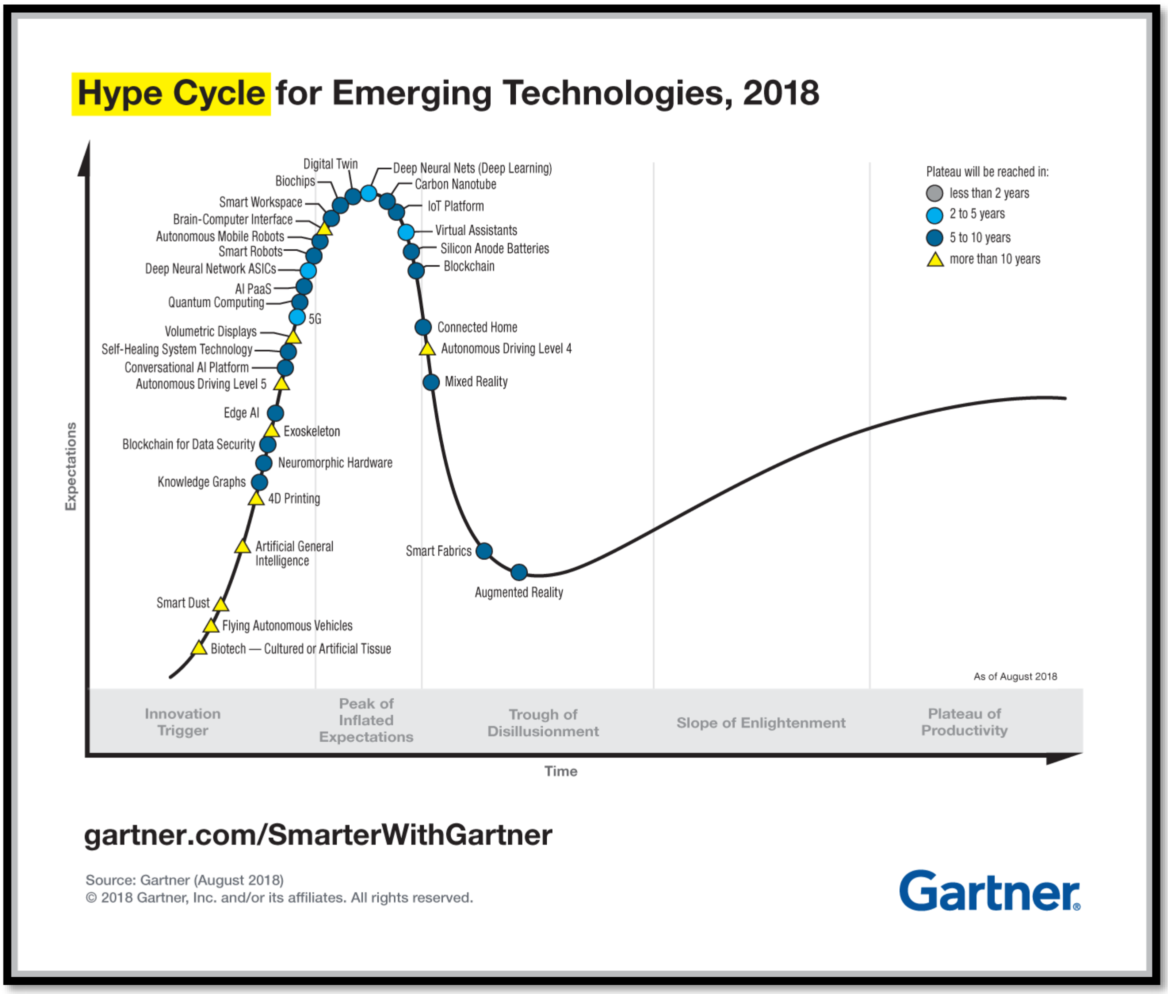

Figure 2 Future Evolution of IoT applications (Source: Panetta, 2018)

2.2 Historical Evolution of IoT

This subsection provides the historical evolution of IoT. As well as the origin of the term Internet of Things and the three main generations are discussed, which should support a better understanding of how IoT has developed from a relatively small technology to the eminent important one it is today. Regarding the origin of the term IoT, different persons, which influence the term like Kevin Ashton, or the International Telecommunication Union exist. The distinction into the different generations supports the development from technology in only a few areas of applications to its enormous size spectrum which it offers today. The historical evolution of IoT is another important building block for the overall understanding of the methodological approach, which is presented in chapter three.

Origin of the Term IoT

The term 'Internet of Things' was firstly coined by the founders of the MIT Auto-ID Center and in particular by the British RFID specialist and executive director Kevin Ashton in 1999 during a presentation for the company (Procter & Gamble Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010; Borgia, 2014; Perera, Zaslavsky, Christen, & Georgakopoulos, 2014; Sprenger & Engemann, 2015). According to Ashton "The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so" (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010, p. 11). Kevin Ashton compared IoT to an interconnected world, where physical things attached with ubiquitous sensors communicate with each other. Providing and gathering information from the environment to improve humans comfort and their daily life is one major aim. According to Ashton, a shift from information that is processed by a computer to computer sensing will occur.

After that presentation from Kevin Ashton, the MIT Auto-ID center officially presented the IoT vision in the year 2001 (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010; Perera, Zaslavsky, Christen, & Georgakopoulos, 2014). Before the year 2005, when the International Telecommunication Union (ITU) officially published their first report regarding IoT, nearly no interest in researchers or industries in the topic of IoT had existed. But after this report, the different stakeholder began with their IoT projects and research in not only RFID but also other addressable technologies to use IoT took place. Another important historical fact was the invention of the IPv6 protocol in the year 2011, which should build the base for trillions of objects, which must be addressable in the context of IoT (Borgia, 2014; Dvali & Belonin, 2014). The development of the things and machines over the centuries is also an important aspect: The machines of the nineteenth century were only able to perform tasks, that where learned beforehand, while the machines of the twentieth century also learned to think. Nowadays, machines and things are learning to perceive, which means that they can sense and respond to humans and to other machines. This evolution marks the increasing importance and research needs which amongst other things build the base for IoT (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010).

Three different Historical Generations

It has been many years since the development of IoT until it became what it is today. The idea of IoT has evolved over the years. In general, three different generations are identified by researchers, each of them played an important role in the whole IoT technology and contributed to the current state of the technology. Several transformations are being influenced by the IoT and change it. The author first names and describes the three-generations and delivers a brief overview of the main technologies.

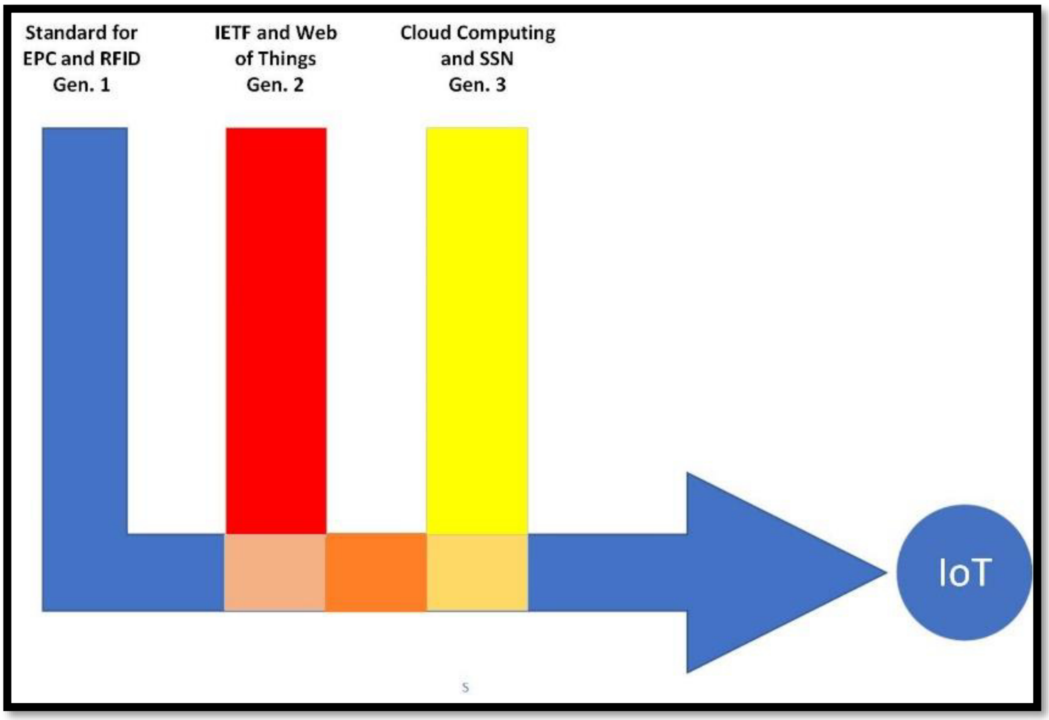

Figure 3 Historical evolution of IoT (Source: Own presentation based on Atzori, Iera & Morabito, 2017, p. 5)

The first generation was mainly influenced by the development of an industry-driven global standard for Electronic Product Codes (EPC) and RFID tags. These two technologies offered a world-wide scale of IoT and the aim was to replace classical Barcodes to achieve identification with unique identifiers. These unique identifiers should support cost-effectiveness and an identification method for every physical object. Not only RFID and EPC were important technologies, but also Wireless Sensor Networks (WSN) and Supervisory Control and Data Acquisition (SCADA) for remote sensing technologies are designed. One important researcher network for the first generation of IoT is the EPCglobal Network, which nowadays is necessary for trading partners to exchange product data, identify objects by linking information and access the EPC code (ITWissen, 2013; Atzori, Iera, & Morabito, 2017).

In the second generation, the interest around RFID tags and EPC solutions lost in importance. The focus was on providing the capability for simple objects or things so that they can be directly connected to the internet. One important organization was the Working Groups of the Internet Engineering Task Force (IETF), which developed a solution for connecting the IoT with the IP protocol by adopting the basic functionalities for Personal Area Networks. Another new part was that IoT took place in web applications, like the web browser, to enter the so-called Web of Things era. The integration of wireless sensor nodes required HTTP-based services and IoT devices built one essential resource of the World Wide Web. Important technologies for the second generation were the wireless connection of things and Low power Wireless Personal Area Networks (6LoWPAN), which is a more energy and resources efficient alternative of IPv6 for constrained devices (Atzori, Iera, & Morabito, 2017).

The last generation of IoT depended on several other technologies. The first is cloud computing with its different internet services, Platform as a Service (PaaS), Software as a Service (SaaS), Networks as a Service (NaaS) and Infrastructure as a Service (IaaS). Another parallel upcoming technology was the social networks of things and finally the general transformations of the internet. These three main influence factors characterize the Future Internet. Cloud Computing is necessary for handling a huge amount of data, which are produced by billions or trillions of IoT sensors and actuators. It can also handle heterogeneous devices by creating a common IoT application environment. The possible integration of Cloud Computing and IoT is named as Cloud of Things. For more information about Cloud of Things see subsection 4.4. Social networking concepts are already upcoming, which also influences IoT. To allow objects to have and establish social relationships for creating their own social network. One of the most important efforts for the third generation is the creation of the Semantic Sensor Network Ontology (SSN) for describing sensor and actuator properties with their observations and involved procedures (Atzori, Iera, & Morabito, 2017; Open Geospatial Consortium (OGC), 2017).

3 Methodological Approaches

The general process of the bachelor thesis in detail was the following: First, the author took the decision about which topic the bachelor thesis should have. Referring to the subsection Research Issue in Chapter 1, the author was conscious of the amazing field of Internet of Things. So, he decided to read basic literature to get an overview of the main properties, considerations, and principles of IoT. After the first reading, the author decided, that the topic Transportation in combination with the cold chain management fit his interest. Furthermore, the author considered it to be meaningful to connect the transportation in cold chain management with foodstuff, in order to avoid food waste. So, the objective and scope of this bachelor thesis were set. In order to achieve this goal, a comprehensive overview of the IoT technology must be given advance, so that the reader also receives a detailed overview of IoT. As mentioned in subsection 1.1, this thesis will achieve two main aims.

The first one is the detection of an added value and finding concrete benefits for logistics companies and their transportation of food with the help of cold chain management. Therefore, a detailed comparison of the transportation system, using IoT and using it not is necessary. For realizing these two aims, the bachelor thesis consists of two methodological approaches. The first one is a comprehensive literature review for chapters four and five. A second literature review was also conducted in chapter six, which will be briefly described below and at the beginning of chapter six in more detail. The review was conducted in combination with a detailed comparison of literature and is therefore not the same procedure as in chapter four and five. In consequence, this chapter only handles the methodological approach for chapter four and five. A literature review should provide an overview of relevant literature in an effective way of advancing knowledge. It is an established research genre with the purpose to synthesize and interpret the main literature in a specific domain to visualize new ways of thinking (Webster & Watson, 2011; Schryen et al., 2017). The process of the literature review for the two chapters in detail was the following:

- Initially, the author decided to use mainly relevant Journal Articles published in scientific databases like *Elsevier* from ScienceDirect, *informs* from PubsOnLine and scientific search engines like *ResearchGate* and *Google Scholar* from scholarly papers. Nevertheless, books and conference proceedings were also analyzed for the thesis. Overall, more than 55 articles, mainly Journal Articles were analyzed for the first comprehensive literature review. In addition, approximately 12 sources from web pages and newspaper articles for numbers and facts were combined with the scientific sources.
- In the next step, the author searched in the beginning for general key terms like *Internet of Things, historical evolution of Internet of Things, key technologies of IoT, challenges regarding IoT, the architecture of IoT, etc*. This first searching process for literature was essential to become familiar with the important and fundamental contents. He categorized the sources in different classes like *definitions, history, external technologies, basic literature, more specific literature, application areas,* etc. The thought behind that is, that sources with familiar content could be analyzed together to find similarities and combine the ideas of the different authors in a structured way.
- After 45 sources, the author had enough content analyzed to start with writing the first literature review for chapters four and five. But during the writing process, the author encountered some gaps in content which he applied by a continuing more detailed literature search. By doing so the author used more specific key terms, like *layer "architecture" of IoT, IoT and "smart home", Retail with "IoT", Integration of Blockchain and "IoT", Internet of Things in "medical" technology, "Internet of Things" for the supply chain management,* etc. These more specific key terms helped

to close theoretical gaps in knowledge, which were identified during the writing process. As mentioned above, during the first literature review web pages and newspaper were added for more actual numbers and facts.

- With the help of the literature review, laymen can understand the eminence of the topic IoT and have all insights which are necessary to follow the methods and information of chapter six. For chapter six, a new comprehensive literature review, with a combination of a detailed comparison was conducted, to find benefits and improvements using IoT for logistics companies, with their food transportation. For the second literature review, more than 15 sources were analyzed. 75% of the sources without the usage of IoT and 25% of the papers with the use of IoT in cold chain management were found. With the help of the review, advantages and improvements using IoT are identified which are described at the end of chapter six. As mentioned above, a more detailed description of the used methods in chapter six will be done at the beginning of chapter six.

To give more insights about the origin of the sources, Table 2 lists the number of reviewed papers regarding their geographical area or source of publication. Moreover, the papers are categorized in time intervals starting from the year 2010 and ending 2019. A similar table can be seen in chapter six. Most of the reviewed papers discussed the Internet of Things from a general perspective, some of them were focused on special topics. Table 2 presents, that about 49% of the papers (reviewed in this work) were published during 2016 and 2018, so most of the paper is very actual. 30% were published during 2013 and 2015, 18% between 2010 and 2012 and only 3% in 2019. Unfortunately, no paper specifically focusing on Africa was identified.

Table 2 Number of reviewed papers from 2010 to 2019 (Source: Own Presentation)

Year / Geographical area	2010-2012	2013-2015	2016-2018	2019	Grand Total
Europe	5	6	14	0	25
America	4	5	4	2	15
Asia	1	4	10	0	15
Australia and New Zealand	0	2	0	0	2
Grand Total	10	17	28	2	57
Share of total number	18%	30%	49%	3%	100%

As a result, both literature reviews and the detailed comparison serve for deep insights into the IoT topic, with specialization in transport with the cold chain management. These deep insights are written down in chapter seven, where the conclusion summarizes the results. Moreover, the identification of research gaps, with future research needs, are presented in chapter seven. With the help of the chosen methods, the scientific community gets a detailed overview of the IoT technology in chapters four and five and can follow the procedure and findings in chapter six.

4 Key Properties for the Internet of Things

With the help of this chapter, the audience should get a detailed overview of the Internet of Things to better comprehend the functionality and importance of the technology. All properties presented are based on the results analyzed in the literature review. As mentioned in chapter three, with the help of more than 55 different Journals, similarities were analyzed. Moreover, all key properties depend on the frequency identified in all read sources. The main contributions of this chapter are presented as follows: Firstly, I present different definitions with variable main emphasis from authors, researches and professors. With the help of the presented definitions, I was able to do my own definition at the end of subsection 4.1. Subsequently, the key properties knowledge of IoT are presented with its characteristics, important elements and technologies in the subsections 4.2 until 4.4. The last subsection handles with different layer architectures for IoT. The choice for one of the provided architectures depends on the desired aim and use of IoT. Figure 4 illustrates the scope of this chapter with the different objects of investigation.

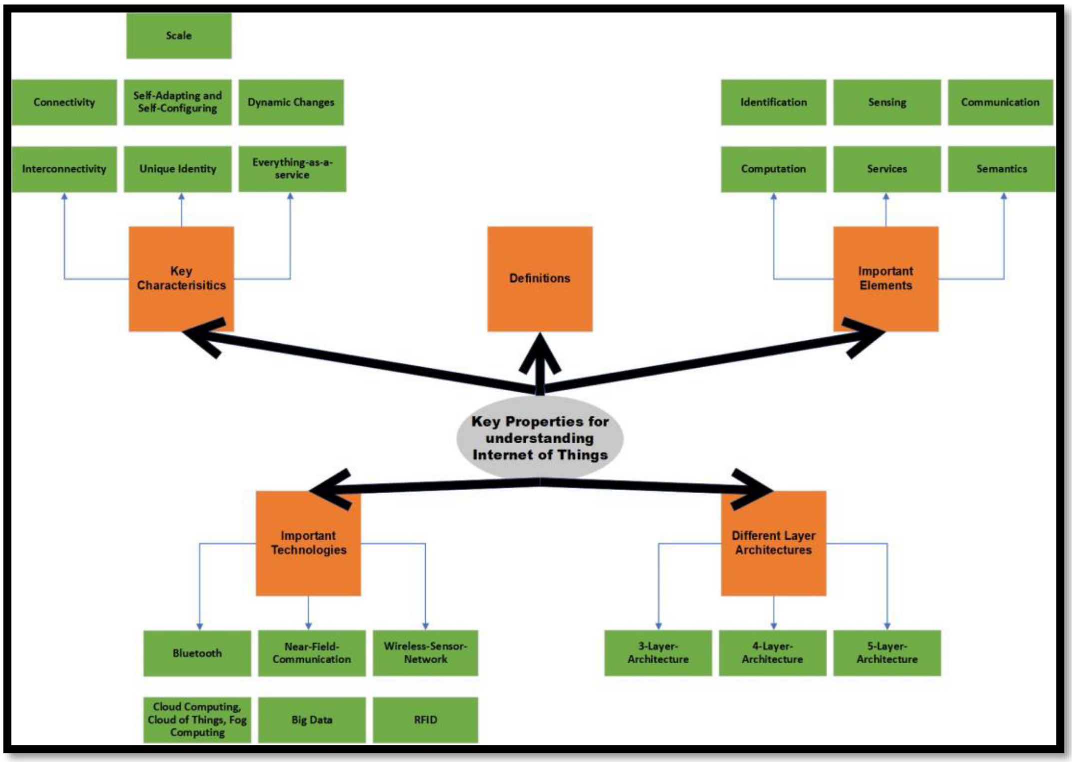

Figure 4 Scope of the chapter: Key Properties for understanding Internet of Things (Source: Own presentation)

4.1 Definitions

During the literature review, I did not find one single common definition of the term Internet of Things (IoT). But by a detailed comparison of them, similarities and recurring specialist terms could be identified. To build an own definition of IoT, first, several definitions from different sources are analyzed to find these similarities. For this subsection, all definitions related to IoT or its functionality were considered. These different definitions were classified into categories like business or technical aspects. They are presented in ascending order, which means that each paragraph extends the knowledge of the previous one to get a comprehensive understanding of the whole technology. With the help of this detailed comparison of different definitions of IoT, the author builds his own definition, which will cover the most important aspects of IoT.

The first definition of the Internet of things refers to connected objects via a network with the help of Radio-Frequency Identification (RFID) technology which has the potential to transform the world in a way like the Internet did (Ashton, 2009). A more far-reaching definition defines IoT as a fast-growing technology which includes opportunities for business and risks, which must be considered. Important is the connection of physical objects, like chairs, tables, factories, etc. with the digital world by using smart sensors, mobile devices and actuators (Sri, Prasad, & Vijayalakshmi, 2016; Ray, 2018).

Many other sources characterize IoT as a network or infrastructure, which can connect billions or trillions of things at any time, anyplace with anyone by using evolving intelligent services and interoperable information (Srivastava, 2006; Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010; ITU, 2015; Patel & Patel, 2016). In this network, humans are not in the focus contrasting to other networks. Nevertheless, they still play an important part. Here, things and systems get actors and become active participants which should assist people to make their daily life easier in business, social processes and many other fields (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010; Keller Marco, Pütz Stefan, 2012; Suduc, 2018).

An important requirement for the connection of devices and their communication among each other is an IoT platform, which offers solutions for companies to make use of their IoT devices for knowledge and to earn money (Mineraud, Mazhelis, Su, & Tarkoma, 2016). Even today, the real meaning of IoT is still unclear, some people reduce IoT on RFID, others imagine IoT as a large network consisting of many sensors, placed in the environment, which relate to each other and communicate with the help of machine-to-machine communication to form global connectivity. Many types of researchers think about a conceptual framework with hundreds and thousands of interconnected heterogeneous devices, which work together, by sending and receiving data to offer different applications like smart cities, smart home, digital health, smart grid, automated environment pollution control, smart factory and many more (Atzori, Iera, & Morabito, 2010; Chen, 2012; Mineraud, Mazhelis, Su, & Tarkoma, 2016; Patel & Patel, 2016; Benkhelifa, Welsh, & Hamouda, 2018; Suduc, 2018). The fact that IoT is not only affecting a few areas in the people's lives but also nearly all areas, places and situations make it difficult to summarize IoT in one single definition. The way how people work and how they can stay healthy and many other things are changing significantly (Yeo, Chian, Ng, Wee, & Tuan, 2014).

By considering technical aspects, IoT includes everyday objects which are readable, locatable, addressable and recognizable via the internet. These objects are not only limited to electronic objects like vehicles, smartphones, tablets, home appliances, industry apparatus, etc. but also non-electronic objects like plants, walls, animals, and peoples are also included (Madakam, Ramaswamy, & Tripathi, 2015; Patel & Patel, 2016). Important other technical elements are protocols and standards, which are indispensable for identities, attributes, and personalities for the things (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010). One major challenge of the network consisting of interactive physical objects is Big Data. These interconnected objects generate a huge amount of data by their sensing, acting, communication and processing abilities. Therefore, scalable computer systems with significantly higher performance processing than in the normal Internet are required (Perez, Memeti, & Pllana, 2016). Sometimes, researchers split IoT into three categories, which are the following. The first category people to people (P2P), which means direct communication between humans with the help of smart devices. The second category is a communication channel, People to machine (P2M), where humans communicate with a computer. IoT also supports the new communication from machine to machine or things to things (M2M), where machines are interacting through the internet to communicate with each other and to exchange data (Patel & Patel, 2016).

With the help of all these definitions, it is possible to identify the key components of IoT. These are Services, (Big) Data, networks, and sensors. To simplify the complexity of IoT in a single formula, the following could be used: "Services + Data + Networks + Sensors = Internet of Things" (Atzori, Iera, & Morabito, 2017, p. 18). In general, the Internet of Things contains two essential words. The first one is the word 'Internet' which refers to the network where trillions of different objects connect and exchange information with each other. The second word 'Things' applies to the first word because in the network the different things interact with the others. In combination, these two words provide the meaning of "a world-wide network of interconnected objects, uniquely addressable, based on standard communication protocols" (Bhabad & Sudhir, 2015, p. 2)

For the following work, the author defines IoT as the following:

> Internet of Things (IoT) refers to a global network, including trillions of interconnected devices and smart objects, which share information and communicate with each other. This network enables things, supported by their sensors and actuators to provide information at any time, from anywhere, for anyone and anything. IoT is a revolution of the internet and it is already radically transforming our lives.

My definition is not all-encompassing, but it combines a lot of important properties of the presented definitions.

4.2 Key Characteristics

In this subsection, key properties to understanding the characteristic features of IoT are presented. First of all, the name of the respective characteristic is presented. Subsequently, a detailed description follows. The choice of characteristics is completely arbitrary and does not follow a special pattern. IoT enables a lot of possibilities and improvements for people. All characteristics which I present are the result of the first comprehensive literature review with 57 Journals. So, all provided characteristics were mentioned in the work from at least two previous authors, researchers, and professors and are not a favorite selection from my side. The reason for the use of characteristics from at least two authors is that when several researchers came to the same results, they are important enough for this work and not only one single appearance in the literature. Thus, with the help of the first comprehensive literature review, it is ensured, that no important characteristic was forgotten and at the same time only important results influence this work.

Interconnectivity, Interoperability, and Heterogeneity

The first characteristic of IoT is interconnectivity. Regarding my definition, anything, as well as electricity objects like smartphones, tablets, sensors as physical objects like chairs and tables, can be connected to form a network to get as much information as possible. But it is also very important that different things can communicate with the help of protocols. These protocols must have the property to be interoperable with the other ones to communicate and exchange data (Interoperability). In this context, another important characteristic considers the difference of things. Heterogeneity refers to a huge number of different devices and sensors that are integrated into the IoT infrastructure with many different properties, like bandwidth, the scale of community, standards, and protocols. Different offering services and disparate geographical locations increase the risk of lack of interoperability, especially when sensors, actuators, and devices are from different vendors (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014; Patel & Patel, 2016; Saarikko, Westergren, & Blomquist, 2017; Ray, 2018).

Intelligence for making Decisions

Intelligence is strongly connected to the ability to generate knowledge. The process of generating knowledge starts with the collection of data and putting them into different clusters and different categories. By combining the data with the respective context, the knowledge is generated. Normally, IoT does multi-hop which means that many different sensors can interact among themselves, to find matches and make decisions. With multi-hop, it is possible to increase energy efficiency and lengthen the networks lifetime (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014; Ray, 2018).

Dynamic Changes and Self-Configuring

Another characteristic is the ability to make dynamic changes in different cases. State of the devices can dynamically change either the device inactive or in sleeping mode to save energy. When the devices must send or communicate with other ones, they must be connected, but when no need for sending or receiving data exist, they are disconnected. Especially, when devices are placed at vehicles or any other moving objects the location changes dynamical as well as the speed of their moving. The devices can also be separately discovered in the network and can communicate their state to as well as other devices as the user. IoT solutions are furthermore self-configuring. The devices with the system should be able to interact dynamically regarding changing conditions and should fit the user's needs. A home alert system, for example, must be able to change monitoring audit either in darkness or brightness. Moreover, changing the home alert systems camera resolution must change from normal to high-resolution when detecting a moving object (Patel & Patel, 2016; Ray, 2018).

Scale and Complexity

One key characteristic concerns the scale of connected devices which is very huge. In 2016, the number of connected devices was approximately 6 billion, which is expected to reach over 20 billion in 2020 (Statista, 2019). So, the number of connected devices increases year after year, this increases the demands on the management of these devices as well. The generated data, which is being created by the IoT sensors and devices is more critical because, for Big Data, special software and tools are required. This enormous scale results also in a complex system, because of the large number of objects which are connected to the network (Complexity). The complexity results in the autonomously interacting things which can communicate, exchange data and make decisions on their own. Moreover, it is realistic, that in one IoT network several billion messages, tasks, etc. must be handled simultaneously which increases the complexity too (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014; Patel & Patel, 2016).

4.3 Elements for IoT

In the last subsection, the author provides key characteristic properties of IoT for understanding the features. This subsection deals with elements which underline the functionality, activity, and task of IoT. With the help of the first literature review, exactly six elements were identified in three different sources. In all of them, the name was the same and the meaning was similar. Therefore, all presented elements are not a favorite selection from my side. Since the same elements were mentioned in all different sources, I assume that they are uniformly recognized in the literature, thus the only relevant ones for this work. The procedure of this subsection is the same as in subsection 4.2: At first, the name of the respective element is provided and afterward the detailed description of it. The choice of elements is completely arbitrary and does not follow a special pattern.

Identification

The first mentioned element is identification. Identification plays a very important role in IoT to address single objects (Zhu, Leung, Shu, & Ngai, 2015). The identification process includes two phases: naming and addressing. Naming means the name of the smart object or device like T-2345 while addressing refers to the unique address of the object like a unique number. It is important to understand, that addressing is only one-time used while different objects can have the same name. Many naming methods like electronic product codes (EPC), ubiquitous codes (uCode) and IPv4 or IPv6 for addressing the objects are available. Nowadays, often IPv6 is used, because of its huger address space. So, identification is important to provide an unequivocal identity for each object which sends and communicate within the IoT network with other objects (Al-Fuqaha, 2015; Burhan, Rehman, Khan, & Kim, 2018).

Sensing

The second element for the IoT functionality is sensing, which is also divided into two processes. IoT sensing is the process of gathering data from the actuators, smart sensors, RFID tags, wearable devices which are spread in the network and the environment. Sending data means the transportation of the data back to storage media, like warehouses, data centers, the cloud or databases. In these storage media, the data is analyzed to gain information of them and to perform specific actions depending on the required services (Al-Fuqaha, 2015; Zhu, Leung, Shu, & Ngai, 2015; Burhan, Rehman, Khan, & Kim, 2018). A wide variety of IoT sensors exist like temperature sensors, wearable sensing devices, humidity sensors, air pollution sensors, mobile phones and other smart devices (Al-Fuqaha, 2015; Zhu, Leung, Shu, & Ngai, 2015).

Communication

Another important functionality, which each device or sensor must enable, is communication, which is nearly related to the functionality of sensing. Communication is necessary to exchange information between interconnected heterogeneous devices to offer services. It includes the whole process of sending and receiving files, messages, commands, etc. (Al-Fuqaha, 2015; Zhu, Leung, Shu, & Ngai, 2015; Burhan, Rehman, Khan, & Kim, 2018; Conti, Dehghantanha, Franke, & Watson, 2018). Very often the need for IoT sensors is to operate while using low power energy consumption, because of small batteries or low-performance processors (Al-Fuqaha, 2015). Popular examples of communication protocols used for the IoT are Bluetooth, Wi-Fi, Near Field Communication (NFC), RFID and Long Term Evolution (LTE) (Zhu, Leung, Shu, & Ngai, 2015; Burhan, Rehman, Khan, & Kim, 2018).

Computation

The fourth element, which was detected in the literature is computation, which is often referred to the one main abilities of IoT (Al-Fuqaha, 2015). Computation is performed by processing units like microcontroller and microprocessors, which represents the hardware as well as software applications to execute the required task. The processing units and software applications can perform their task with the help of computation. In the computation context, often so-called IoT platforms[1] are mentioned which have the function to provide access to the gathered data, remove unnecessary information, big data processing in real-time and to benefit from the information by building knowledge (Al-Fuqaha, 2015; Zhu, Leung, Shu, & Ngai, 2015; Lucero, 2016; Burhan, Rehman, Khan, & Kim, 2018). Moreover, cloud computing with their cloud platforms is another strong tool to provide fast computational power in real-time, by extracting all kinds of information which could be valuable from the data (Zhu, Leung, Shu, & Ngai, 2015).

Services

The fifth IoT element, services, are generally categorized into four classes: Identity-related Services, Information Aggregation Services, Collaborative-Aware Services, and Ubiquitous Services. Identity-related services are only used to get the identity of the objects that are sent which is especially important by mapping real-world objects into the virtual world. Moreover, the identity-related services build the foundation for the other services. The next service, information aggregation, gather and summarize the measured data from the sensors and actuators which must also be processed to the IoT application to gain knowledge of the data. The third class is named either collaborative-aware services or just collaborative services, which analyze the received data from the sensors to make responding decisions to the devices. The last class includes the ubiquitous services which have the task to provide the collaborative-aware services to anyone, at any time and anywhere without considerations about time and place (Al-Fuqaha, 2015; Zhu, Leung, Shu, & Ngai, 2015; Burhan, Rehman, Khan, & Kim, 2018). The main aim of every service is to come into the ubiquitous service, where they become invisible for the people who use them. With the help of services, IoT can offer special application areas like smart home, smart grid. Some application areas will be discussed in Chapter 5 (Al-Fuqaha, 2015).

Semantics

The last of the six IoT elements are semantics which has the task to extract knowledge from different machines, smart things, etc. in an intelligently way. With the knowledge, IoT can provide the required tasks and services from the user which is one of the most important tasks. Semantics includes several processes like discovering and using resources in an energy-efficient way. The recognition and analysis of the data are further tasks. Semantics are often referred to as the brain of the IoT, because of the right response and resource making decisions from the IoT network by analyzing the data which are important for the service element and to fulfill the people's requirements. Popular technologies on the level of the semantics are, for example, the resource description framework (RDF), web ontology language (OWL) and efficient XML interchange (EXI) (Al-Fuqaha, 2015; Zhu, Leung, Shu, & Ngai, 2015; Burhan, Rehman, Khan, & Kim, 2018).

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[1] Lucero, S. (2016). IoT platforms : enabling the Internet of Things. *Ihs*, (IHS Technology). Retrieved from https://cdn.ihs.com/www/pdf/enabling-IOT.pdf

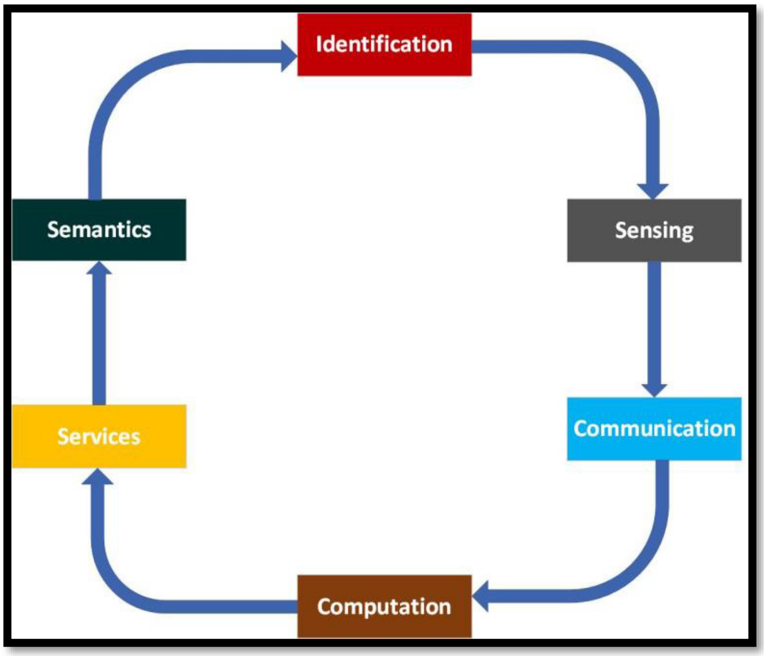

Figure 5 Six Elements for understanding the functionality of the Internet of Things (Source: Own presentation based on Burhan, Rehman, Khan & Kim, 2018)

4.4 Several Technologies for IoT

Another important component for IoT are technologies, which support the use of it and can fulfill the user's requirements in a comfortable way. Therefore, this subsection presents some technologies, which are often mentioned in the literature for IoT. More specifically, only for this subsection, 17 papers were analyzed during the first literature review. All these papers dealt with different technologies, but six of them were mentioned in the majority by all of them. These are the following ones: The first technology is Radio Frequency Identification (RFID), which was mentioned in 88% of all papers. Subsequently the main theme of Cloud Computing with 76%. Afterward, the technology Bluetooth with 59% appearance and Wireless-Sensor-Networks (WSN) with 53% occurrence. The last two technologies are Near-Field-Communication (NFC) and Big Data, which were both referenced in 47% of the papers. The first four technologies are presented in this subsection because more than 50% of all papers used this term and explained it, so they are important for IoT.

The usage of two other technologies, Long Term Evolution Advanced (LTE) and Machine-to-Machine communication (M2M), instead of NFC and Big Data, was possible. But for the scope of this thesis, eight technologies would be too many. LTE and M2M have not been used as often as the other two technologies. Furthermore, the transportation of physical objects into the virtual world to form a global network and the connection between these devices require energy. But often, the physical property of the sensors, actuators, and devices does not offer the high capability for strong energy use. Therefore, energy-efficient technologies must be used (Benkhelifa, Welsh, & Hamouda, 2018). LTE is often unsuitable for IoT, because of its high energy consumption. M2M is also not presented in this detailed overview because IoT works on it. So, M2M is the base for IoT, but not a technology which should be described here (Aazam, Khan, Alsaffar, & Huh, 2014).

RFID

The first technology, which was mentioned in nearby all papers from the authors, is Radio Frequency Identification (RFID) and therefore it is indispensable to present. RFID is still the driving force for IoT, that had the goal to replace bar codes from the 1970s. Barcodes have two essential drawbacks: Firstly, they can store only a small amount of data and secondly, the scanning process is relatively complex for humans. So, RFID uses low-power wireless frequency waves, powered by the electromagnetic field of the reader. This enables communication between two devices and in contrary to cloud computing, RFID is a low-cost technology and hence ideally for using IoT (Sprenger, F., & Engemann, C., 2015; Ray, 2018).

RFID has three parts: Passive, active or semi-passive/active tags, a reader and a database. While active tags use batteries for power, passive tags need energy from the reader to transmit the data. Semi-passive/active tags use board power when needed. All tag types are attached to objects and store the information with the help of the reader, it can read the information of the object trough of them. With a reader, the stored information is transmitted and subsequently store into a database signal (Zhu, Leung, Shu, & Ngai, 2015). Caused by the fact that passive tags have no constant source of energy, the lifetime is very high, up to several decades. Therefore, passive tags are very cheap and popular for many different applications. Because they have no own power source, they absorb some of the signal's energy, which is enough to send a small amount of data. The range differs from 15 meters to 25 meters with either 124-135 kHz or 860-960 MHz (Panko & Panko, 2014: Palano et al., 2015; Zhu, Leung, Shu, & Ngai, 2015).

RFID tags are very small microchips with unique identifiers, which is enormously important for clear recognition. Depending on the tag, encryption while sending the information is provided or not. Passive tags cannot do encryption, because irrelevant information is sent, which need no protection. Semi-passive/active tags support the data encryption standard (DES), which is a symmetric-key method with a 56-bit key. This means that the same key is used for encryption and decryption. Active tags can use advanced encryption standard (AES) which are more secure than semi-passive/active tags. The possibility to choose a 128-bit, 192-bit or 256-bit key depends on the security needs. Nevertheless, all tags do not verify the reader, that means they present the information the reader without authentication (Burhan, Rehman, Khan, & Kim, 2018).

RFID is very powerful in the automatic identification of anything in a very short time and therefore often used in logistic, retail and supply chain management (Gubbi, Buyya, Marusic, & Palaniswami, 2013). Fast recognition is possible with the Electronic Product Code (EPC), which is a unique number that is stored in an RFID tag. The EPC architecture is open, scalable, interoperable and reliable. Since 2006 the new EPC tags (Gen 2 tags) are used with better services than the passive RFID (Ning & Wang, 2011; Gubbi, Buyya, Marusic, & Palaniswami, 2013). As mentioned above, RFID is still the driving force for IoT, and the technology is ideal for many application areas regarding IoT.

Cloud Computing, Cloud of Things, Fog Computing

Cloud Computing with Cloud of Things and Fog Computing can play an important role for IoT and was therefore described in more than 76% of all papers. Cloud Computing is defined by the US National Institute of Standards and Technology and his infrastructure which is available since 2006, provide the functionality to aggregate and evaluate large amounts of data while the user must not be worried about maintenance and managing of the resources (Al-Fuqaha, 2015; Sprenger, F., & Engemann, C., 2015). The users must only pay for their ordered service (pay-as-you-use), while the smartphone can become a mobile data center to see the data and services everywhere. Commonly, four services are provided by Cloud Computing: Platform as a Service (PaaS) is the provision of resources for the development of applications and services, Software as a Service (SaaS) the provision of an application that is hosted by a provider and accessed by the customer via the Internet, Networks as a Service (NaaS) providing Network services virtually over the Internet and Infrastructure as a Service (IaaS) refers to the provision of hardware for a customer (Aazam, Khan, Alsaffar, & Huh, 2014; Schubert & Winkelmann, 2015; Zhu, Leung, Shu, & Ngai, 2015). Another important characteristic, which was found in the literature is the everything-as-a-service approach. This approach means to provide 'everything' as a service, which is not already provided by the four other forms SaaS, NaaS, IaaS, PaaS. By regarding cloud computing with its business model similar trends can be identified in IoT. The everything-as-a-service model is scalable and easy to use and by considering IoTs enormous potential in any area, sharing and communicating everything and any place seems to be very realistic (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014).

In general, cloud computing is a relatively new computing paradigm, which can offer access to a shared amount resources, in order to determine the state of the device and to view its behavior (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014; Want, Schilit, & Jenson, 2015). Cloud Computing often makes sense in the context of IoT, because hundreds of thousands of sensors are placed in the environment and send together a noticeable amount of data. When the IoT network is owned by governments or business organization, as well as the sharing process inside the organization is very easy. Moreover, it is possible to store huge amounts of data (Big Data) with high processing power in an efficient way (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014). Cloud Computing can realize the vision of IoT by integration with sensors that generate data, tools like Cloud Computing which analyze the data and the whole process disappears into the background, invisible for the user (Gubbi, Buyya, Marusic, & Palaniswami, 2013).

This integration of Cloud Computing and IoT is called Cloud of Things (CoT) in literature. This new paradigm includes the concepts of IoT with sensors which produce a huge amount of data and the Cloud Computing capabilities which can store, analyze and make proper use of the data (Aazam, Khan, Alsaffar, & Huh, 2014). Also, the paradigm of Fog Computing (edge computing) exists, which is optimal for hiding the complexity of the network structure of IoT and Cloud Computing. While cloud computing serves for offering services like software-as-a-service, fog computing is a model in which data, processing, and applications are concentrated in devices at the network edge and not entirely in the cloud (Al-Fuqaha, 2015). Thus, the usage of cloud computing and its integration with the Internet of Things (Cloud of Things) can bring valuable improvements.

Bluetooth

The next important technology for IoT, which was mentioned in more than 59% of all papers, is Bluetooth, which is based on the IEEE 802.15.1 standard. Two main forms of Bluetooth are mentioned in the literature: The classic Bluetooth from the Bluetooth Special Interest Group and Bluetooth low energy. Bluetooth classic is a short-range radio technology in 2.4 GHz band with low power energy consumption and designed for low-cost wireless communication in personal area networks. Bluetooth was one of the first replacement technologies for cable. The range of Bluetooth is limited by a short-range of eight to ten meters. Moreover, the speed rate is at most 3 Mbps fast, but this is enough for the most constrained devices and sensors. In contrast to Wi-Fi with high power, Bluetooth classic has low power consumption, which results in a long battery life-time. This property makes Bluetooth ideally for IoT because many of the smart sensors have only a very constrained capacity and need technologies with low-power. The protocol of Bluetooth is very easy, because of the absence of many-to-many networking, like Wi-Fi and Ethernet but this circumstance simplifies Bluetooth as makes it attractive for low power energy devices. Nevertheless, Bluetooth classic supports the so-called master-slave control. One device, for example, a mobile phone, can have up to seven slaves and can send controls and tasks to them (Panko & Panko, 2014; Burhan, Rehman, Khan, & Kim, 2018; Ray, 2018).

The new and more energy-efficient variant of Bluetooth is Bluetooth Low-Energy (BLE), which was merged in the year 2010 and uses short-range radio with ultra-low power energy consumption (Ray, 2018). Also, BLE was adopted by the Bluetooth Special Interest Group and uses the Bluetooth v4.0 standard. In contrary to classic Bluetooth, BLE uses only a minimal amount of power and the batteries have a lifetime of several years with a range of approximately 100 meters. Because of this, BLE has excellent conditions for IoT: The transmission power lies between 0.01 milliwatt to 10 milliwatts with great possibilities for integration with a product which is nearly invisible and has enormous energy-saving properties that fit several sensor and devices requirements (Want, Schilit, & Jenson, 2015). Like classic Bluetooth, BLE supports the master-slave control in a star topology. Compared with ZigBee, BLE is much more energy-efficient and has a higher speed rate (Al-Fuqaha, 2015; Burhan, Rehman, Khan, & Kim, 2018). Thus, Bluetooth classic, but especially his more energy-efficient alternative Bluetooth low-energy is adequate for the IoT needs and therefore a useful technology.

Wireless Sensor Network

Sensor Networks and especially Wireless Sensor Networks (WSN) are the fourth important technology for IoT. First, I provide a brief overview of a general sensor network. Sensor networks are considered as one of the most important technology for IoT, because sensors networks can exist without IoT, but not vice versa. A sensor network provides a lot of kinds of hardware by providing access to actuators and sensor. It consists of one or more sensor nodes, which can be homogeneous or heterogeneous for communication. By connecting several sensor networks together, it is possible to create an overall network like the Internet (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014). A WSN consists of sensor nodes, a base station, batteries, microcontrollers and memories and is normally a self-organized ad-hoc network (Palano et al., 2015; Burhan, Rehman, Khan, & Kim, 2018). The sensor nodes have the task to work cooperatively together to monitor physical or environmental conditions like sound, temperature, vibration, pressure and to collect data and store them in the memory or send data to a centralized system. While each sensor node has only low processing, limited power, and storage capacity, the base station is much more powerful (Zhu, Leung, Shu, & Ngai, 2015). Even nowadays, WSN is powered by batteries which are efficient, low cost and have a low power consumption. The radio signals are based on IEEE 802.15.4 and have an outdoor range of approximately 100 meters which covers the physical and medium access control for low-power communication (Palano et al., 2015).

In the following, a brief description of the components which are important for a complete monitoring Wireless-Sensor-Network is provided. The first component, as mentioned above, is the WSN hardware with sensor interfaces, processing units, transceiver, etc. to provide communication. The second component is the WSN communication stack, which acts as a gateway and should be able to interact with the internet. The next important component for a WSN monitoring network is the Middleware, often a platform to provide access to different sensor resources. The last component is the secure data aggregation to ensure reliability, security and correct data from the sensor nodes (Gubbi, Buyya, Marusic, & Palaniswami, 2013). Although the energy consumption of the WSN is relatively low, the power consumption is higher than other technologies (Palano et al., 2015). Nevertheless, WSNs can bring valuable benefits for IoT applications and as mentioned above, sensor networks are indispensable for IoT.

Near-Field-Communication

The next technology which can bring benefits for IoT applications and use cases is Near-Field-Communication (NFC), which is headed by the NFC Forum. This technology uses a high-frequency band at 13.56 MHz and supports data rate up to 424 kbps. The idea for this technology is the positive effect by reducing the distance between devices to reduce the transmission power as well. Typical areas of applications are electronic payments but in the special context of IoT the communication between an active reader and a passive tag or between two active readers (Al-Fuqaha, 2015). The possibility that smartphones can read passive NFC tags, which can store a Uniform Resource Identifier (URI) to identify a resource is also available (Want, Schilit, & Jenson, 2015). Although, the communication radius amounted up to 10 cm is the limitation of 424 kbps, this technology offers an enormous safety against eavesdropping, read and catch messages from outside.

NFC is based on the RFID protocols and uses, therefore, a similar method. But one decisive difference between NFC and RFID is that NFC cannot only read tags but also write information. Moreover, as mentioned above the communication between devices is possible in both directions. So, this technology has a great amount for the IoT, because of its low transmission power and the high energy efficiency of NFC devices. Moreover, NFC devices often use inexpensive batteries, which can have a lifetime of months or years, due to energy efficiency (Panko & Panko, 2014). NFC must not be equated with RFID, because it is a special sub-category from RFID which can perform data exchange between two devices.

Big Data

The last important technology, which was mentioned in the literature with almost 50 % for IoT is not really a technology, but rather a negative side effect from the IoT sensors, Big Data. The term Big Data, in general, refers to information, which cannot be analyzed or process with conventual tools. In the literature, the so-called five V which are the properties of Big Data exists: Volume, Variety, Velocity, Veracity, and Value. Volume means the amount of data, while Variety classifies three main types of data: Structured, semi-structured and unstructured data. Velocity means the speed of produced data, Veracity the faultlessness, trustworthiness and availability of the data. The last property is the financial value for the company (Zikopoulos, Eaton, DeRoos, Deutsch, & Laplis, 2012). In the context of IoT, billions or trillions of connected devices, sensors, and actuators which exchange data in the network must be considered. Together, this amount of data is so huge, that it can be classified to Big Data (Burhan, Rehman, Khan, & Kim, 2018). Moreover, some further problems with Big Data like the heterogeneity, scale, complexity and privacy problems exist (Lokshina, Durkin, & Lanting, 2017). Therefore, efficient and secure Big Data analytics is necessary to ensure reliable data processing and is identified in the literature to be a requirement for IoT. Data management, that can handle the huge amount of data and efficient computational technologies for the analysis is important. Big Data analytics is sometimes viewed by researchers as a key initiative of IoT. Some researchers even go as far as to argue that Big Data analytics is driving a "next wave of IoT innovation" (Williams, Hardy, & Nitschke, 2019, p. 2). In conclusion, Big Data seems to be one indispensable technology, or more precisely phenomenon that should be tackled in the context of IoT. Its benefits for IoT can be manifold: On the one hand, Big Data can offer more effective ways of managing and analyzing the enormous scale of data. On the other side, with the help of the managing and analyzing methods it can bring order into the IoT system (Williams, Hardy, & Nitschke, 2019).

4.5 Different Layer Architectures

One of the most important aspects when considering IoT is its layer architecture, which builds the base for all application areas, services, and infrastructures. IoT architecture, in this context, is 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” (Ray, 2018, p. 3). This definition indirectly contains some important components, which are as well indispensable for IoT as important for this subsection: Sensors, Actuators, Devices, and Applications. A sensor is a hardware component which acts as the eyes and ears of a device. It has the task to measure different parameters in a physical environment and detect changes. A sensor is also identified as the input to a system. An actuator, on the other hand, provides a mechanical response according to input provided by sensors. It can translate electric signals into physical action and is also identified as the output from a system. The device is connected to the sensors and actuators which uses software to process the data from the sensors. Devices are also classified as things that can be connected to the digital world. An application uses the data from devices with their sensors and from actuators to fulfill users demand like measuring and controlling of temperature (Guth, Breitenbücher, Falkenthal, Leymann, & Reinfurt, 2016).

During the literature review, I did not find a single and common agreement about IoT architecture. Several researchers, scientists, and professors of universities have been proposed many different versions of possible IoT architectures. During the first literature review, the three-, four-, five- and six-layer architectures were identified and all of them are presented in this subsection. The most common one is the three-layer architecture which very often builds the base for use cases and other models. During the review, I also found examples for a four-layer and five-layer architecture. Especially the five-layer architecture is often recommended by researchers because the three-layers cannot ideally fit the requirements of applications (Burhan, Rehman, Khan, & Kim, 2018). In some cases, the six-layer architecture is proposed as an enhancement to fit these requirements in a better way. Important to understand is, that regardless of which architecture is chosen, dependencies exist between each layer. No layer stands alone, but all are interwoven with each other. In the following paragraphs, I provide the identified layer architectures to give a comprehensive overview. Moreover, typical attacks that affect the respective layer are briefly mentioned.

3-Layer-Architecture

The base layer architecture contains the 3-layer: Sensor/perception/device Layer, Network/transport/transmission Layer and Application Layer (Khan, Khan, Zaheer, & Khan, 2012; Bhabad & Sudhir, 2015; Madakam, Ramaswamy, & Tripathi, 2015; Guth, Breitenbücher, Falkenthal, Leymann, & Reinfurt, 2016; Burhan, Rehman, Khan, & Kim, 2018). It was the first base architecture to fulfill the basic requirements and needs from the users to IoT. The sensor layer builds the bottom of the architecture has the task to identify things or objects, collect and process data from them, which are spread in the environment (Aazam, Khan, Alsaffar, & Huh, 2014; Al-Fuqaha, 2015). A wide variety of different sensors exist, which can measure for example humidity, temperature, pressure, vibration, air pollution, noise, etc. Of course, the sensors are chosen according to the users or the company's requirements. Relevant attacks on the sensor layer are for example eavesdropping, where an attacker tries to intercept and manipulate transmitted data through phone calls, text messages or IP-telephoning. To add so-called fake nodes with input fake data in order to destroy the existing network (Khan, Khan, Zaheer, & Khan, 2012; Madakam, Ramaswamy, & Tripathi, 2015; Burhan, Rehman, Khan, & Kim, 2018).

The network layer carries the data, that are gathered and produced from the sensors and transmit them to the application layer. For the transmission, as well as wired transmission like Fiberoptic, Powerline and Digital Subscriber Lines (DSL) as wireless transmission technologies like ZigBee, Cognitive Radio, Cellular Network, Wireless Mesh, Bluetooth, WIFI, etc. are possible (Madakam, Ramaswamy, & Tripathi, 2015). The network layer is often compared as a bridge between the sensor and application layer that connects smart things, devices and whole network with each other for data exchange and manages them (Khan, Khan, Zaheer, & Khan, 2012; Aazam, Khan, Alsaffar, & Huh, 2014; Al-Fuqaha, 2015; Burhan, Rehman, Khan, & Kim, 2018). Because of its importance, the layer is attractive for attackers for example by manipulating the integrity. Possible attacks are Denial of Service (DOS) attacks where the attacker tries to make a computer or a network unavailable to its users. Another possible attack is the Man-in-the-Middle attack whose goal is to manipulate or intercept communication between sender and receiver. Also, the direct attack on the storage from devices or the cloud is possible to change the gathered information or make them unavailable (Burhan, Rehman, Khan, & Kim, 2018).

The last layer on top of the 3-layer-architecture is the application layer, which includes applications that use IoT technology and provide it for global management (Khan, Khan, Zaheer, & Khan, 2012; Aazam, Khan, Alsaffar, & Huh, 2014). A huge variety of application areas can be found in the literature, which ranges from smart home over the smart city, smart health, smart agriculture, smart logistics to smart buildings (Madakam, Ramaswamy, & Tripathi, 2015). Moreover, the application layer provides the services from the different applications, that depend on the gathered data from the sensor layer which are transferred with the help of the network layer and which must fit the user's demands (Al-Fuqaha, 2015). The application layer is the closest to the end-user and must protect and ensure security. One possible attack it the so-called Cross-Site Scripting, which the goal to inject a trusted site with harmful code like JavaScript to alter the content or change the original information is an illegal way. Malware attacks are another form, where harmful code tries to infiltrate poorly protected devices to cause damage. Another possible attack is more a challenge for the applications, that they are able to handle with Mass Data (Big Data) in order to not negatively influence the data transmission between users (Burhan, Rehman, Khan, & Kim, 2018).

4-Layer-Architecture

The four-layer architecture is a development of the three-layer architecture. Although the approach is not common in literature, it is briefly introduced here. The three-layer sensor, network, and application are the same as in the three-layer architecture, but a new layer called support or interface layer is added (Khodadadi & Dastjerdi, 2015; Burhan, Rehman, Khan, & Kim, 2018). The main reason to add this fourth layer is to improve the security of the whole architecture. Because in the three-layer approach, data is sent directly from the sensor to the network layer, without any protection or authentication methods which could cause security threats or data misuse. Therefore, the support layer proof the user's identities to guarantee authenticity with the help of pre-shared secrets like passwords and protect the architecture from general threats. The layer also transfers the data wired or wireless from the sensor layer to the network layer. As for the network layer, one danger is a DOS attack for the support layer, where large amounts of data should make a computer or a network unavailable to its users. By using a security mechanism like passwords the danger of malicious attacks where an attacker tries to get the user's credentials exists (Burhan, Rehman, Khan, & Kim, 2018).

5-Layer-Architecture

During the literature search and the following literature review, the 5-layer architecture was often suggested by many authors for IoT, because it could best implement the requirements of IoT and fit the security needs better than the four-layer architecture. This architecture includes the three-layer sensor, network, and application layer from the three-layer architecture. Between the network and application layer, a newly middleware/processing layer is placed and on top is the business layer. As mentioned, this architecture should be able to fulfill the IoT requirements in the best way (Burhan, Rehman, Khan, & Kim, 2018). Because the sensor, network, and application layer are the same as in the three-layer approach, only the middleware and the business layer is provided.

The middleware layer is placed between the network and application layer and has the tasks to manage the incoming data from the network layer. Managing in this context includes temporary storage of data, eliminate unnecessary extra information that has no meaning, extract only the useful information which can avoid Big Data, link to the database and store data of the company into the database (Khan, Khan, Zaheer, & Khan, 2012; Aazam, Khan, Alsaffar, & Huh, 2014; Perera, Zaslavsky, Christen, & Georgakopoulos, 2014; Vashi, Ram, Modi, Verma, & Prakash, 2017; Burhan, Rehman, Khan, & Kim, 2018). Moreover, the middleware layer performs information processing and takes decisions automatically based on results and transfer the relevant data to the application layer (Khan, Khan, Zaheer, & Khan, 2012; Aazam, Khan, Alsaffar, & Huh, 2014; Al-Fuqaha, 2015). A lot of attacks which can disturb or completely stop the performance of IoT. One attack refers to exhaustion, which is an after-effect of attacks like DOS attacks or those, which try to exhaust battery and memory resources. Another common attack on middleware solutions is malware in from of executables codes or scripts which is included in viruses, worms, trojans horses, etc. The aim is to steal confidential information (Burhan, Rehman, Khan, & Kim, 2018).

On the top of the five-layer architecture, over the application is the business layer. The business layer is responsible for making money with the other four layers by providing a business concept for the company and it handles the user's privacy. This business concept includes business models, flowcharts, graphs, innovative proposals which base on the application layer and its data from the other layer. He acts like a manager that manages the different applications, layers, and services. Moreover, the layer processes information to create knowledge and for the company wisdom to finally earn money (Khan, Khan, Zaheer, & Khan, 2012; Aazam, Khan, Alsaffar, & Huh, 2014). Additionally, the layer has the task to analyze, evaluate and develop new IoT system elements, which are very important regarding the success of the IoT technology and for determining future business strategies (Khan, Khan, Zaheer, & Khan, 2012; Al-Fuqaha, 2015). With the help of the middleware and application layer, the company is able to make decisions which bases on Big Data processing to understand the customer needs in a better way and to generate new wisdom through the connection of the data (Al-Fuqaha, 2015). A possible attack on this layer is the so-called business logic attacks, which depend on a flaw in a program of the application layer which the administrator or user of the application has not solved with a Patch. The attacker tries to control the information exchange between the users and the database. Another familiar attack, the Zero-Day Attack takes advantage of a vulnerability for which no patch or other workaround has been released. These attacks are very dangerous because no way how the user can prevent it is available (Burhan, Rehman, Khan, & Kim, 2018).

In the literature, few researchers introduce a six-layer architecture, as a development of the five-layer architecture for a better fit of the IoT requirements provided. This approach bases on the five-layer approach with their layer, only one new layer is introduced. This architecture is not common in literature, different layer solutions and added values through the new layer can be found. Some researches introduce a coding layer for assigning a unique ID for each object in the IoT network (Mehta, Sahni, & Khanna, 2018). Other researchers developed a security layer which should enhance the overall security of the IoT network (Burhan, Rehman, Khan, & Kim, 2018). But both solutions are already partially handled with the five-layer architecture, why these 2 improvement approaches are not further discussed here.

5 Different Application Areas

The whole field of IoT includes more than 100 different application areas. Figure 6 delivers a ranking of Top IoT Segments in the year 2018 form IoT analytics. The first column shows the top ten IoT Segments. The next column visualizes the global market share of IoT project in percent and the last column lists the three biggest economic areas Americas, Europe and APAC (Asia Pacific). Measured by the market share, top ten application areas are presented which had in the year 2018 the biggest proportion: On the top was in the year 2018 the Smart City concept with 23% market share, followed by the Connected Industry (17%) and Connected Buildings (12%). Eighth is Smart Supply Chain (5%), followed by Smart Agriculture (4%) and 10th Smart Retail (4%). In nine out of ten IoT application areas, the Americas economic area has the largest share of projects, only in the Smart City area is Europe the leader and in nine out of ten IoT application areas, the APAC Economic area has the smallest share of projects, only in the Smart Agriculture area is Europe the taillight (Scully, 2018).

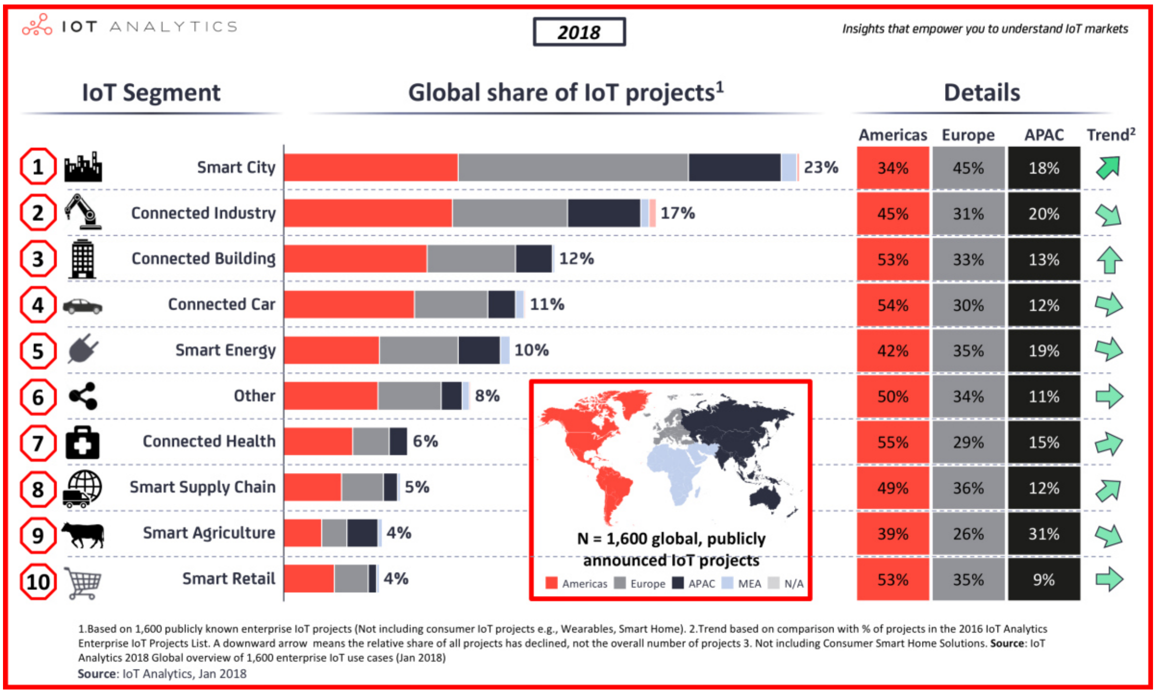

Figure 6 Application Areas market share in 2018 (Source: Scully, 2018)

Commonly, the goal of all application areas is to reach a level where ubiquitous services are omnipresent. All things could be recognized, monitored and controlled easily with a minimum of human intervention (Al-Fuqaha, 2015). In the literature, some researches categorize the IoT application broadly into consumer and enterprise, while others use the classifications industry, environment, and society. For the first possibility, Home Automation, Smart Meters, Smart Healthcare, etc. refer to the consumer while Fleet Tracking, Smart Warehouse, Smart Supply Chain, etc. refer to enterprise (Yeo, Chian, Ng, Wee, & Tuan, 2014). The second classification with industry, environment, and society classifies Supply Chain Management, Smart Automotive, Logistics, etc. to industry. Society related areas are for example Smart Healthcare, Smart Building, and Smart Home while Smart Agriculture, Smart Recycling and Environmental Monitoring refer to environment application areas (Perera, Zaslavsky, Christen, & Georgakopoulos, 2014).

In the following subsections, different application areas are presented to get a more practical overview of how IoT can influence them and can bring benefits. All the provided application areas are a result of the first comprehensive literature review. But the choice of the respective areas was my decision. My aspiration was to present very popular areas like Intelligent Buildings, Supply Chain Management, and Medical Technology. But also, less known concepts like the combination of Blockchain with IoT and the Retail sector are provided. So, the choice of the application areas was my own, but the results and findings based on the literature review.

The main contributions of this chapter are presented as follows: Firstly, an overview of the Intelligent Buildings concept is provided. Subsequently, Retail in traditional shops with the help of IoT, and afterward the Blockchain technology with IoT is presented. After Blockchain, Medical technology is briefly described and eventually the Supply Chain Management. Figure 7 illustrates the scope of this chapter with the different application areas.

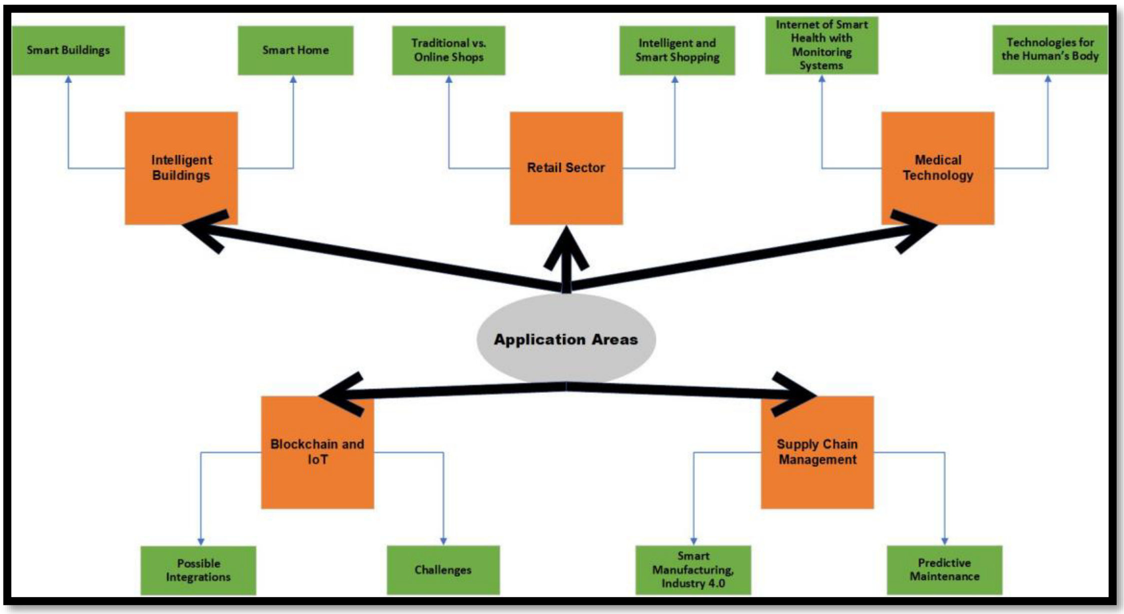

Figure 7 Scope of the chapter: Different Application Areas (Source: Own presentation)

5.1 Intelligent Buildings

The first application area is Intelligent Buildings with its two concepts Smart Buildings and Smart Home, which could be connected to form an encompassing comfort for humans. Especially in the Smart Home context, a wide variety of appliances is available.

Smart Home

A first popular appliance in the Smart Home context is the general connection of household appliances: Refrigerators with a screen to tell us what is inside, which products will soon expire. Intelligent washing machines decide efficiently the time of washing in relation to the current electricity price. Kitchen stoves can be monitored remotely, to check the food which is inside (Keller Marco, Pütz Stefan, 2012; Patel & Patel, 2016; Burhan, Rehman, Khan, & Kim, 2018). To increase the comfort for the inhabitants, Amazon Echo or Google Nest are famous examples for playing music, providing weather reports, remember tasks or do calls (Lokshina, Durkin, & Lanting, 2017). Another appliance is safety monitoring with intrusion detection systems which include the home alarm system, cameras, window detection and door opening which are connected to the Smart Home system for extra safety (Patel & Patel, 2016; Mehta, Sahni, & Khanna, 2018). A general, but the important appliance is the overall improvement of inhabitant's quality by doing daily and unimportant things through IoT use. A lot of possibilities, like automatically open the garage when inhabitants reach their home are possible. The complete wake-up process could be automated, starting by automatically raising the shutters when the alarm rings, prepare the favorite temperature, coffee-making or playing the desired music. The aim of doing the daily tasks automated is that the people can concentrate of the important things and safe as good energy as time (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010; Chen, 2012; Kramp, van Kranenburg, & Lange, 2013; Al-Fuqaha, 2015). A further very important appliance is the use of energy and water. For the gardens, sensors which measure humidity, temperature light and other factors could be used for an optimized irrigation of plants. With the monitoring and needs-based energy consumption control it is possible to manage lights, heating system or water supply to save costs and energy (Keller Marco, Pütz Stefan, 2012; Khan, Khan, Zaheer, & Khan, 2012; Gubbi, Buyya, Marusic, & Palaniswami, 2013; Kramp, van Kranenburg, & Lange, 2013; Zhu, Leung, Shu, & Ngai, 2015; Patel & Patel, 2016; Mehta, Sahni, & Khanna, 2018).

Smart Building

Energy monitoring is one main aspect of a Smart Building, which often uses a Smart Grid. The overall aim of a Smart Grid is to reduce with the help of IoT the energy consumption of houses and buildings. In this context, smart meters are important, which measure the consumption of energy and water. With the connection of millions of smart meters to form a national network, the energy providers can use the provided data to analyze the consumer needs and fit to them in a more efficient way (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010; Al-Fuqaha, 2015; Zhu, Leung, Shu, & Ngai, 2015). Smart Buildings often have building automation systems, which are connected to IoT. The buildings automation systems offer possibilities to control and manage lighting. Improving the security with intrusion detection, the complete Heating, Ventilation, and Air Conditioning (HVAC) system is another advantage. Furthermore, entertainment like music, television or telecommunication can be enhanced. Like a Smart Home, a building automation system can reduce energy consumption and increase the maintenance of buildings (Al-Fuqaha, 2015). But Smart Buildings have more configuration possibilities like the processing of information, self-configuration, and self-maintenance techniques. To emphasize the enormous energy consumption in buildings, about 61% of energy is consumed by electricity, 11% by refrigerating and cooking and 21% by the HVAC system. So, providing Smart Buildings with intelligent energy management information systems can result in saving energy and money (EOT LAB, 2016). Thus, automation and energy consumption are not only possible for companies and public buildings, but also for the home to build an environment where things communicate with each other to automate processes and fulfill specific needs of the customers.

5.2 Retail in traditional Shops

This subsection deals with the application area Retail and its changes through IoT in traditional shops, which can bring immense opportunities and revenues for the retail sector (Kramp, van Kranenburg, & Lange, 2013; Lokshina, Durkin, & Lanting, 2017). In general, the Retail sector in traditional shops like supermarkets can be divided into the shops with shelves management and logistic processes for the management and the customer side with the shopping experience.

It is expected, that using IoT cost reductions are possible of 30%. The overall efficiency could be enhanced by 32% and revenues by 31% (EOT LAB, 2016).

Traditional vs. Online Shops

Regarding the growing competition from online retailers, traditional shops have to increase the overall shopping experience for their customers. Many customers would like to have this better experience by scanning barcodes with their smartphone or use the smartphone for payment. The traditional shops should use the possibilities with IoT to improve the overall market, coordination, and communication with the customer that they come back into the shops. Many more possibilities, which can improve the customer shopping experience and the binding to the market like the combination of the offline experience, comparisons between similar products, the physical feeling of products with online experience are possible (Kramp, van Kranenburg, & Lange, 2013; Longo, Kovacs, Franke, & Martin, 2013). In this context, beacons and coupons are important to mention. Nowadays, 28% of all purchases are linked to the smartphone with the use of online coupons or special offers. By scanning QR-codes, compare prices of products or search for ingredients, the smartphone becomes more and more important. Therefore, the use of beacons, small hardware transmitter, which uses Bluetooth low energy (BLE), can provide additional shopping experience elements: The first possibility is the providing of business information, such like coupons and individualized offers, also payment with the smartphone is possible with beacons. Another important advantage is the tracking of human behavior for a better understanding of their decisions, better placed and signalized offers. Finally, met the customer requirements in a more efficient and profitable way is the overall aim (Nowodzinski, Katarzyna, & Puto, 2016).

Intelligent and Smart Shopping

When shopping becomes more and more automated with intelligent shopping ventures, a guidance trough the market is possible. When, for example, the customer shares his digital shopping list to the shopping ventures, it can navigate the user to the right shelves and provide more information about the product, like allergies (Kirsch & Fromm, 2017). When each product has an attached RFID tag, cash registers could be replaced by an intelligent gate which scans the entire shopping ventures and the customer only has to pay with a smart pay method like biometrics (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010). But more possibilities for how retail organizations and supermarkets can gain added value through the use of IoT exist. So-called smart shelves are possible, which are equipped with an RFID tag on each product. As soon as a product category is empty the employee gets a message and can order new stuff. Smart shelves have two positive aspects: Firstly, the shelves are always full, so the customer can buy the article. The supermarket does not miss out on earnings, which are very important, because it is estimated, that around 4 percent is lost from supermarkets by empty shelves. Secondly, over-production and underproduction can be avoided, because the employee has an overview of the stock and can order the right number of products in real-time (Nowodzinski, Katarzyna, & Puto, 2016; Mehta, Sahni, & Khanna, 2018). With RFID tags, that are attached to product pallets, it is easily possible to check the receipt of the goods automatically. Another positive effect of a gate which acts as a replacement for the cash registers: Shoplifting becomes considerably more difficult because when each near product has an attached RFID tag, every product is scanned. Also, the problem, that RFID tags are often too expensive exists, when for example the marge of a single yogurt is just one or two cents for the producer (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010). Thus, the combination of the retail sector with IoT can result in many advantages and profits for companies.

5.3 Blockchain and the Internet of Things

The integration of IoT into Blockchain technology is the next presented application area. As mentioned, a central achievement of IoT is the connection of physical objects to form a global network, where smart objects exchange data. In the literature, different approaches to combine IoT with Blockchain Technology (BCT)[2] are available, because central coordination of IoT seems to be impossible. Because of this apparent impossibility, the BCT can perfectly fit this problem while the public Blockchain has a complete decentral property (Schütte, Fridgen, Prinz, Rose, & Urbach, 2017). In the following two paragraphs, I firstly provide a short overview of possible integrations of the BCT with IoT and in the second paragraph challenges that will occur in the IoT context are outlined.

Possible Integrations

The general combination of IoT and BCT with a peer-to-peer (P2P) storage system could be used to ensure privacy, robustness and the absence of a single point of failure, what is mostly an organization, which stores and processes the produced data. Moreover, by using the safety storage system all operations could be registered and authenticated by the Blockchain. A need to trust a centralized company exists not anymore. The data is safely stored, authenticity is guaranteed, and unauthorized access could be avoided (Conoscenti, Vetro, & De Martin, 2017). Especially for companies, a lot of advantages through the BCT-IOT integration like the enmeshment of resources and goods to exchange their conditions for an optimal added value are available. Whether processes in companies like the management of quality, process cost calculation or where-use lists, all important documents, and pieces of evidence can tamper-proof saved or provided. In particular, the providing of transparency and security make the BCT suitable for IoT. A very useful application of BCT to fulfill the company's requirements are Smart Contracts (SA). SA can be used to make contracts with machines. One essential aspect for guaranteeing security about a SA is that if the user does not pay for the service, the machine does not do the service, so a safety relationship is on both sides exists. Of course, it is important that SAs and the whole network is written correctly for providing all desired functions and to avoid any unwanted errors. A possible scenario is the automated settlement of machines with their user services and the storage of the money in a storage system like an electronic wallet, which acts as an account for the company. It does not matter if the machine is connected to the internet during the service because it can synchronize the service later when a connection is restored (Schütte, Fridgen, Prinz, Rose, & Urbach, 2017). Also, firmware updates are no problem, because all machines of the company are connected to the same IoT-BCT network, making updates easily transferred (Christidis & Devetsikiotis, 2016). So, the BCT can bring many advantages and benefits for companies using it in combination with IoT. Regarding companies or organizations, private Blockchains make more sense, than the public, because the public one's transfer company-intern data in a secure way. That means, that only people with access rights can read or write data. The circle of persons with these access rights could be

[2] Zheng, Z., Xie, S., Dai, H., Chen, X., & Wang, H. (2017). An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. In Proceedings - 2017 IEEE 6th International Congress on Big Data, BigData Congress 2017 (pp. 557–564). https://doi.org/10.1109/BigDataCongress.2017.85

Braibanti, T. (1971). A Taxonomy of Blockchain-Based Systems for Architecture Design. Annali Di Radiologia Diagnostica, 43(6), 401–403. https://doi.org/10.1109/ICSA.2017.33

exactly determined and ensures confidentiality. Moreover, public blockchains are much faster than the public ones, because the need in a company to use a consensus algorithm like Proof of Work is often not necessary. Nevertheless, the access rights in a company should be defined in detail to avoid unauthorized access for the employees and for the supplier.

Challenges

But with the integration of IoT and the BCT, many challenges occur, which should be considered. In the following, I present three major challenges: Scalability, storage capacity, and the consensus algorithm. Storage capacity and scalability are still problems because the BCT was often designed for a scenario, where powerful computers solve hard cryptographical puzzles to ensure consistency, security, and immutability. But most of the IoT devices have only a constrained possibility to transfer and gather data because they often must ensure energy efficiency and low consumption. That is one possible border for an integration of the two technologies. Moreover, one single IoT network from a huge company, for example, have to generate and gather gigabytes of data in real-time (Reyna, Martín, Chen, Soler, & Díaz, 2018). Often the BCT can only handle a little data size up to one megabyte. By considering the complete size of the Bitcoin network in the first quarter of 2019 from the popular cryptocurrency Bitcoin, only 210 Gigabytes were produced which is compared to terabytes from an IoT network only a fraction (Ernst, 2019). This challenge must also be addressed by creating a powerful integration of IoT and the BCT. Another challenge refers to the consensus algorithms, which are indispensable for the most popular Blockchain Proof of Work algorithm. Because IoT devices are calculating-constrained, they are not able to take part in the Proof of Work process directly. Also, the mining process is eminently too hard for the devices. But coming up solutions to delegate the calculating tasks either to gateways which undertakes the tasks of computing, or the overall Blockchain complexity is hidden at the application level without a need to compute the tasks for IoT devices (Conoscenti, Vetro, & De Martin, 2017; Reyna, Martín, Chen, Soler, & Díaz, 2018). In the literature some possibilities how the IoT and the BCT components can communicate with each other and where the interactions could take place to exist. The first possibility is the so-called IoT-IoT approach where only a part of the gathered data is stored into the BC and most of the communication and data exchange takes place without using the BCT. The second opportunity the IoT-Blockchain approach handles all interactions with the Blockchain for a complete and safety record which causes high bandwidth and data. The last Hybrid approach is similar to the first one. Here only a pre-determined part take in place in the Blockchain, the rest of communication and data exchange between the IoT devices (Reyna, Martín, Chen, Soler, & Díaz, 2018).

To conclude, the integration of IoT and BCT can cause powerful and useful advantages which ensure confidentiality, integrity, availability, security, and immutability of the data. Often, a private Blockchain is more useful, because of the limited number of participants and the faster speed. Nevertheless, the use of a private Blockchain is not without problems. Therefore, it is important that companies estimate where an integration from IoT and Blockchain makes sense, and where not.

5.4 Medical Technology and Healthcare

The combination of the application area medical technology and IoT can result in several powerful functions like the monitoring, tracking and helping of people for more comfort and to save lives in emergency situations. This application area is not only important, because of its relevance for everybody, but also because of the worldwide market in Healthcare which should reach $136 Billion in the year 2021 with an annual growth rate of 12,5 percent (EOT LAB, 2016). In the following, I present two main topics of Medical Technology: The first one handles the monitoring systems for monitoring, tracking and tracing the patients to provide a better and more individual care. The second paragraph focusses on technologies which are placed either near the body or inside it. The whole topic of Medical Technology and Healthcare has the main aim to improve and save human's lives.

Internet of Smart Health with Monitoring Systems

One possible combination of Medical Technology with IoT can result in the Internet of Smart Health to provide efficient IoT healthcare with intelligent monitoring systems. "The aim of an efficient IoT healthcare system is to provide real-time remote monitoring of patient health condition, to prevent the critical patient conditions and to improve the quality of life through smart IoT surroundings" (Dewangan & Mishra, 2018, p. 2). This definition includes several important characteristics of Smart Health. One characteristic is the monitoring and tracking of people. With the help of embedded sensors like RFID-sensors and the usage of a cell phone, the vital monitoring of people, like checking their body temperature, blood pressure, heartbeat rate, etc. is very easy. But also, for clinical care in hospitals Smart Health can help for monitoring the patient seven days in the week on 24 hours to enable ad hoc diagnosis (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010; Al-Fuqaha, 2015; Patel & Patel, 2016; Zhu, Leung, Shu, & Ngai, 2015; Bhatt & Bhatt, 2017; Burhan, Rehman, Khan, & Kim, 2018).

Another important characteristic of Smart Health is the non-attachment of the patients to a specific place. Especially for an urban situation where the next physician is several miles away, healthcare monitoring systems are valuable. The doctor can easily get to the traced people's health histories and can give an efficient remote treatment (Kramp, van Kranenburg, & Lange, 2013; Dewangan & Mishra, 2018). Regarding the non-attachment to a special place Smart Health can significantly reduce the doctors and nursing stuffs tasks by providing important information automatically. Even today, many procedures like various risk assessments which nursing staff of hospitals must do executed manually. This unnecessary time-lost could be replaced with the help of IoT that doctors can use their time more efficiently. For example, with the help of Ultra-high-frequency RFID (UHF RFID), tracking the patients in hospitals is quite easy (Uken, 2014; Asplund & Nadjm-Tehrani, 2016; Lokshina, Durkin, & Lanting, 2017; Mehta, Sahni, & Khanna, 2018).

Moreover, the reduction of faults is a further advantage of using IoT. When the nursing staff writes the number of drugs manually, the danger of spelling mistakes exists. Typing the exact number of drugs into one monitoring system supported with IoT, the system can warn the nurse when an unusual amount has been entered in, to ensure the right amount of drug administration (Palano et al., 2015; Bhatt & Bhatt, 2017). The combination of IoT and Medical technology can also result in better chances of elderly people for independent living. Sensors and devices can help people with their daily tasks using reminding services. Alarm services, to prevent the elderly from damage is another possibility. A so-called fall detector can detect, and report falls automatically to a hospital. So, IoT can bring valuable benefits for people with more comfort by supporting daily activities (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010; Chen, 2012; Khan, Khan, Zaheer, & Khan, 2012; Perez, Memeti, & Pllana, 2016).

Technologies for the People's Body

The second big area where medical technologies in combination with IoT can bring enormous advantages and benefits for people is the usage of technology for the human's body. In this context, several possibilities could be used as the usage of nanotechnology in the form of on-body or off-body networks or wearable technologies. The first large scope of application is nanotechnology in IoT. Generally, nanotechnology includes all sensors and devices with a range between one to few hundred nanometers which can perform several actions, like monitoring, tracking and tracing inside the body. It is possible, that these sensors inside the body can create complete networks which are able to communicate with outside devices, e.g. to transfer important data. Basically, two types of networks must be distinguished: On-Body Networks and Off-Body Networks. While on-body networks are inside the human's body with monitoring and tracking tasks, off-body networks are in the near of the body. They can be placed in the people's context like in streets, buildings, etc. which often measure the common health or provide other services (Bhatt & Bhatt, 2017).

Two other possible forms to combine medical technology with IoT exist. So-called implantable wireless identifiable devices or chips that can be eaten. The implantable wireless devices can save people's lives in emergency situations with their stored health information. When, for example, a person had a car accident and comes into a hospital, the electronically stored health records with allergies, blood type, diseases like diabetes, coronary heart disease, etc. could easily provide this information in very short-time for the doctors and nurses in a structured way. In this case, the staff can interact very fast and save people's lives instead of checking people's allergies and other intolerance manually. Also, chips that can be eaten by people for checking and acting in favor of their health situation are possible, e.g. for paraplegic persons who need muscular stimuli (Sundmaeker, Guillemin, Friess, & Sylvie Woelfflé, 2010). A very powerful tool, which can exchange data with sensors, networks or the cloud is the Wearable IoT (WIoT). This kind of technology uses computer technologies worn on the body or on the head which are interconnected e.g. with Bluetooth to support activities in the real world by exchanging data. WIoT plays a very important role in personalizing treatment, because every disease has the same pattern of symptoms, but the effects and their strength differ from people to people. Therefore, WIoT can provide useful information about the actual health situation of the patient for better-personalized care (Bhatt & Bhatt, 2017).

5.5 Supply Chain Management

This subsection deals with the topic Supply Chain Management (SCM) which can be divided into Smart Manufacturing with its industrial importance and focus, the concept of Industry 4.0 with its four key components[3] and Predictive Maintenance. The content of this subsection is structured as follows: Firstly, the general concept of Manufacturing is provided, after that, the concept of Industry 4.0 and its development with four key components. Subsequently, a short future view of a Smart Factory is presented. At last, Predictive Maintenance as one of the most valuable concepts for factories with machines is discussed. Although this subsection deals with

[3] Wang, K. (2016). From Idea to Performance Strategies and Innovations to Support "Industry 4 . 0." WIT Transaction on Engineering Sciences, 113. https://doi.org/10.2495/IWAMA150301

several different approaches, they can all be subdivided under the context of Supply Chain Management.

Smart Manufacturing, Industry 4.0 and Smart Factory

The general concept of manufacturing is still one of the most important parts of the economy. By combining this term with IoT, smart manufacturing is possible to connect physical and intellectual infrastructures for a faster and more quality production which fit in a better way the customer needs. The whole process of manufacturing has often changed over the centuries. The changes were partially so serious, that often the term 'revolution' has been used. Before understanding the concept of Industry 4.0, the historical context with three previous industrial revolutions is necessary to provide. The first industrial revolution refers to the change from manual work to machine production with its weaving mills in England and the steam engine by James Watt. This revolution was also the beginning of energy supply with a higher focus on machine work than manual work. The next revolution was characterized by Frederick Winslow Taylor and his rationalization principles of standardization, division of work, standardization and production with more quality standards. The last revolution of the industry was influenced by the begin of automation with the usage of computer and Information and Communication Technology (ICT). Configurable machines and the appearance of industrial robots for a more faster and accurate production was important (Wang, 2016).

Nowadays, the next industrial revolution is present, which will change the industry, Industry 4.0. The overall aim of the Industry 4.0 concept is to provide a more individual and customized production of products at the same cost which builds on the smart manufacturing concept. This revolution is characterized by an integrated global communication network with smart systems and the focus on internet-based solutions for an optimized and more flexible production (Li, Wang, & He, 2016). Commonly four main components to form an Industry 4.0 are necessary: Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data with Data Mining (DM) and Internet of Service (IoS). CPS is for monitoring physical processes, transform the physical world into the virtual world to make decisions, which base on a decentralized concept. It provides new functions, of how humans can interact with these systems. With the help of IoT, the real-time communication and data exchange between hundreds or thousands of sensors, actuators, and devices which generate mass data (Big Data) is possible (Li, Wang, & He, 2016; Wang, 2016). Finally, IoS offers internal as well as cross-organizational services for the participants and users of the company. Not the product is here in the focus, but services for better interaction and communication of the different partners from a company by providing industrial automation (Al-Fuqaha, 2015; Zhu, Leung, Shu, & Ngai, 2015; Li, Wang, & He, 2016; Wang, 2016). So, Industry 4.0 provides connected and together working machines for better products and services. Furthermore, Industry 4.0 enables the idea of a Smart Factory, where CPS work together to form more efficient and faster processes, providing not only the products identity but also their history, properties, etc. to offer nearly perfect IoS (Li, Wang, & He, 2016).

Predictive Maintenance

Due to the fact that the machines and robots are becoming more and more important for the company, maintenance is also becoming a significant task. When a large amount of the company's profits depends on the availability and processing of machines, downtimes can cause big financial damages. The availability and reliability of machines could be significantly improved, by using Predictive Maintenance. In the literature, many researchers believe that classic maintenance with monitoring, repair, and rebuilding activities are not enough for the

Industry 4.0 context. During the literature review, three different forms of maintenance were identified: Corrective Maintenance (CM), Preventive Maintenance (PM), and Predictive Maintenance. CM and PM only focus on the repair of already defect machines or the prevention of it. CM when a failure has already occurred, and PM is carried out in predetermined intervals. To ensure, that failures of machines are detected before they occur predictive maintenance is necessary which uses smart sensors (Li, Wang, & He, 2016). These smart sensors ensure to design upcoming maintenance not only maximally cost, but also power-efficient. Predictive maintenance reduces downtimes of machines and costs of maintenance. It can detect changes in the physical conditions of equipment, so-called signs of failure, to optimize the life of machines and processes. To minimize disruption to regular system operation, a large portion of the predictive inspections can be completed in parallel with the operation of the plant. It guarantees a zero-failure manufacturing rate by telling the user a fault that might occur. This process ensures the future potential of Industry 4.0 because the prevention of faults before they will happen is a very powerful tool for each company. So, a fault has occurred before the machine threatens a loss of performance (Li, Wang, & He, 2016; Wang, 2016).

Thus, in the industrial context, several tools to save the companies productivity exist. The smart manufacturing with the concept of Industry 4.0 increases the factories profitability by making them more productive and efficient. Predictive maintenance offers new possibilities to prevent downtime of machines which help to realize the future idea of a Smart Factory. The improvement in gaining more value for companies and better fit the customer's needs are some approaches.

6 Food Transportation - with or without Internet of Things? -

In this chapter, the author presents a detailed comparison between food transportation systems combined with cold chain management, with the use of IoT and without. The basis for the detailed comparison was a second new comprehensive literature review where only aspects, which are important for this chapter, were analyzed. After the review, a detailed comparison of properties which appeared on both sides, with and without IoT, was possible to identify advantages and benefits for companies. Finally, with the help of the identified advantages, the author can provide his meaning of a theoretical 'ideal' transportation system in chapter seven.

To give more insights about the origin of the sources Table 3 lists the number of reviewed papers regarding their geographical area or source of publication. Moreover, the papers are categorized in time intervals starting from the year 2000 and ending in the year 2019. A similar table can be seen in chapter three. Most of the reviewed papers discussed food transportation and traceability in combination with the company's cold chain management. Table 3 presents, that about 44% of the papers (reviewed in this thesis) were published during 2016 and 2019, 25% for the years 2010 to 2012. 19% were published between 2013 and 2015 and finally only 12% between 2000 and 2009. Most of the published papers were found in Europe. Unfortunately, no paper specifically focusing on Australia and New Zealand and Africa was found.

Table 3 Number of reviewed papers from 2000 to 2019 (Source: Own Presentation)

Year / Geographical area	2000-2009	2010-2012	2013-2015	2016-2019	Grand Total
Europe	1	3	2	3	9
America	0	1	0	3	4
Asia	1	0	1	1	3
Grand Total	2	4	3	7	16
Share of total number	12%	25%	19%	44%	100%

The process of the methodological approaches for this chapter was the following:

- After chapters two, four and five the audience had got deep insights into the IoT technology. This chapter is a specialization of the previous content and builds on the theoretical technology knowledge of IoT. For the second literature review, the author decided to use also relevant Journal Articles published in scientific databases, like *Elsevier* from ScienceDirect, *informs* from PubsOnLine and scientific search engines like *ResearchGate* and *Google Scholar.* Overall, 16 articles, mainly Journal Articles were analyzed for the second comprehensive literature review. In addition, approximately 15 sources from web pages and newspaper articles for numbers and facts were combined with the scientific sources.
- Subsequently, the author searched now only for key terms which fit the special requirements of this chapter. Key terms like *Internet of Things for logistic companies, IoT in the logistic, IoT and food transportation, food traceability, tracing livestock, food recall, food traceability and IoT, food traceability technology and "IoT", perishable Food logistic, perishable food and "IoT"* were considered.

- With the key terms, more than 25 papers were found. Afterward, all papers were scanned and skimmed based on their titles, abstracts, introductions, conclusions and used figures. These two methods were perfect for finding the more relevant papers and the number could be reduced to 16 relevant articles. Approximately 75% of the papers, companies handle the transportation of perishable foodstuff without IoT and 25% use IoT for their business.
- With the help of the second comprehensive literature review, the author was able to make a detailed comparison. This comparison included finding out advantages and benefits using IoT and how companies can earn more profit with IoT. For this purpose, properties were compared that appeared on both sides in order to be able to compare them. These properties are presented in Table 4 for the purpose of finding out the benefits.

6.1 Context of Food Transportation

The whole chapter 6 serves as a comparison between food transportation systems about cold chain management. Both systems with their specific details about how the food is packed and transported and the approximate percentage of food lost in context with and without IoT is presented. This chapter uses the second literature review with more than 15 sources to fulfill the second and third aim of this bachelor thesis. As mentioned above, only perishable food like vegetables, fruits, meat, eggs, poultry, aquatic products, etc. are considered, whereas the view includes the cold chain management and as a mode of transport food trucks with an integrated cooling system to keep the food fresh. I decided to choose the transportation by food trucks, because it has the largest share of total freight transport (Mercier, Villeneuve, Mondor, & Uysal, 2017). With the help of subsection 6.2 which presents transportation systems without IoT and subsection 6.3 with transportation systems that use IoT, subsection 6.4 considers concrete advantages on the base of the previous subsections. But before the two transportation systems are described, I provide the basic context for better understanding the following subsections and to be familiar with the main definitions.

The general importance of this chapter is the following: Most countries of the world waste about 30% of all produced food products throughout the delivery (Bosona & Gebresenbet, 2013; Wei & Lv, 2019). More precisely, regarding the global annual food waste, approximately one-third of all produced foodstuff between the field and plate get missed. The cause is often incorrect drying and storage as transportation faults (Akkerman, Farahani, & Grunow, 2010; Bundesministerium für Ernährung und Landwirtschaft, 2018). This very high percentage of wasted food is catastrophically for millions of people which could be partially avoided using IoT in an efficient way. In the year 2013, the Federal Office of Consumer Protection and Food Safety had controlled 1,450 cooling trucks and in about one-third of the trucks, the temperature in the cooling room was too high. Although nearly all vehicles had thermometer and temperature recorder, about 13 percent of the truck drivers were not aware of the prescribed temperatures they had to comply with. Studies in recent years have shown similarly negative results (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit, 2014). Moreover, food waste is mainly responsible for high carbon emissions and cause ecological damage (Wakeland, Cholette, & Venkat, 2012).

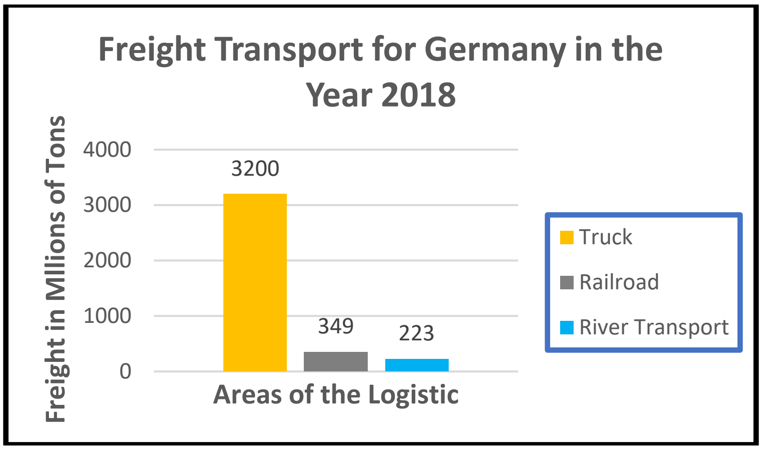

Figure 8 Overview of the freight transport in Germany in the year 2018 (Source: Own presentation)

To tackle the food waste problem, this bachelor thesis gives an overview of food transportation systems with some facts about the usefulness of IoT. Furthermore, the transportation process is one of the most important for the German economy. Around $295 Billion in sales were generated in 2017 across all industries in Germany and the whole market in Europe has an amount of $1.163 Billion (BVL - Bundesvereinigung Logistik e.V. Bremen, 2018). Figure 8 provides an overview of the freight transport market in Germany in the year 2018, to visualize the choice of the truck as a means of transport. The realization of efficient and complete food traceability is very hard, because of its complexity, and is therefore very seldom (Akkerman, Farahani, & Grunow, 2010).

Food, Food Types, and Food Properties

In the following paragraphs, different definitions, approaches and important elements for the food and cold chain context are provided which are partially used in the next subsections. For understanding the whole context of food transportation, firstly an exact definition of food is needed. Food is generally defined by the European Parliament and of the council (2002) as the following:

> '[F]ood' (or 'foodstuff') means any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans. 'Food' includes drink, chewing gum and any substance, including water, intentionally incorporated into the food during its manufacture, preparation or treatment. It includes water after the point of compliance as defined in Article 6 of Directive 98/83/EC and without prejudice to the requirements of Directives 80/778/EEC and 98/83/EC. (p. 7).

After this very detailed description of food, which includes the main food types, it is important to illustrate them in more detail. In principle, six classifications for food types during the supply chain are distinguished: deeply frozen, frozen, chilled, cold, fresh and hot. The deeply frozen food is cooled by temperatures below -30°C while frozen food requires a temperature below -18°C, only special products like ice cream requires an even lower temperature of -25°C. Chilled food has a temperature between -°2C and +2°C while cold food needs a temperature between 0°C to +7°C like vegetables, fish and fruits. Fresh food requires a constant temperature of 18°C and hot food above 60°C to avoid bacteria education (Kuo & Chen, 2010). This bachelor thesis does not focus on the hot or deeply frozen food class, because no need for efficient cold chain management exists or the temperature is too low for classic cooling trucks. Therefore, just frozen, chilled, cold and fresh food is presented. Furthermore, this work is not focused on a specific food like frozen meat or fresh fish but delivers only the presented food types from the literature review.

In the Literature, quantitative approaches for the food distribution which refers to transportation management can be detected. Three different quality criteria are distinguished and each of them focuses on specific characteristics of food. The first one is the consideration of food safety. Food production, processing, packing, storage, transportation, etc. are characteristics which influence food safety (Maksimović, Vujović, & Omanović-Mikličanin, 2015). The main task of food safety is the prevention of illnesses which can result in the eating of contaminated food. During the food transportation procedure, the food often shows continuous quality changes which, in the worst case, can result into contaminated food and finally into food scares when it is consumed (Akkerman, Farahani, & Grunow, 2010; Aung & Chang, 2014; Tian, 2018). Two popular food scares in Germany were, e.g. in the year 2001 when the organization "Stiftung Warentest" found out that packed smoked and wild salmon are spoiled and harmful for health before the expiration date was reached (RP ONLINE, 2017). Or secondly, in the year 2011 around 50 died as a result of the dangerous EHEC-intestinal pathogens from raw tomatoes, cucumbers and lettuce (WELT, 2013). Because of the increasing number of food scares, the quality criteria of food safety must get more and more attention and some legislation has been enforced too. Of course, food safety is also an economical factor regarding competition and in case of food damages, product recalls and food scares can be catastrophically for the company (Kuo & Chen, 2010; Tian, 2018). So, food scares can cause immense damage to their respective companies. According to the WHO, every year around 23 million people suffer from contaminated food and 5000 of them die, because of the consequences in Germany. But the overall situation in the whole world is much more catastrophically: 600 million people worldwide become ill, because of consuming contaminated food and more than 420,000 of them die (SPIEGEL ONLINE, 2015). To avoid food scares and the improve food safety, several different standards and systems were established, like the Hazard Analysis Critical Control Point (HACCP) system, the ISO 22000 standard and the British BRC standards (Akkerman, Farahani, & Grunow, 2010).

The next important criteria for food transportation are food quality. The food quality includes two main principles: The first one is the physical property of the food, while the second principle concentrates more on the way how the product is presented by the final consumer, like texture, flavor, color or maturity level. To guarantee the quality of food products possibilities like certification, quality assurance, and seals of quality like "EU organic" logo, "Bio" seal, "Bioland", "Demeter", "Fairtrade" label or "Rainforest Alliance" are available (VIS Bayern, 2013). The last characteristic of food products considers sustainability. Sustainability has earnt more and more attention in the food industry during the last years. "Sustainability commonly refers to how the needs of the present human generation can be met without compromising the ability of future generations to meet their needs" (Akkerman, Farahani, & Grunow, 2010, p. 9). Sustainability considers two main dimensions, environmental aspects, and social aspects. Possible criteria for sustainability are for example Recycling / Upcycling, energy, and resource efficiency, climate-friendly, reduced pollutant, longevity, regional production, animal welfare, etc. (Greenpicks, 2019). The importance of sustainability is increasing during the last years. In the year 2016, about 48% of people between age 18 to 24 and approximately 61% of people over age 45 in Germany pay attention to sustainability when buying products (Statista, 2016). Another favorite form to visualize sustainability is the concept of labeling. Labels exist for the various aspirations, like “Nature & Respect" and "Label Rouge" for requirements for poultry meat, the label “Für Mehr Tierschutz” for a higher level of animal welfare or the “V” label to ensure that products are vegetarian (Verbraucherzentrale, 2019). The two characteristics of food safety and food quality are similar but do not pursue the same aspirations. Food safety is a simple concept, because only two forms are possible: Either food safety is reached with the help of safety requirements or not. The criteria of food quality are more complex because several properties must be included in the viewpoint. Many dependencies between the achievement of food safety and food quality exist. For example, to ensure the food safety with the help of the ISO 22000 standard the food quality is also increased through the supply chain, because when the food is free from contaminations, the texture, flavor, and color are improved as well (Akkerman, Farahani, & Grunow, 2010).

Food Transportation System and Food Traceability

Another very important component in the context of food transportation is an efficient Food Tracking System (FTS), which has as the main task to support the identification of food products, to enable an improved food safety and quality. Moreover, the identification of incidents with a specific place and time, where the problem has occurred is a task. One important part of each FTS is the traceability of food. In general, according to International Organization, ISO 8402, traceability is “the ability to trace the history, application or location of an entity by means of recorded identifications” (Bosona & Gebresenbet, 2013, p. 3). Moreover, traceability refers to the identification of food products, their routing, the trace of connected data and specific tools to support the tracing. Food traceability builds on the traceability with its planning and controlling parts for the food flow and helps to ensure the quality and safety of the food at any time. Thus, FTS helps with their food traceability property to avoid food crises and to ensure food safety as well as food quality. Although, the consumer is not very interested in the technical process of food traceability, rather in a label, the whole procedure is eminent for every logistic company and for its food products (Bosona & Gebresenbet, 2013).

The whole transportation process for companies is extremely complicated and differs in terms of used technologies, product packing, etc. Also, managerial decisions are important for the procedure, which can be divided into distribution network design, distribution network planning, and transportation planning. All the decisions represent different time horizons. The distribution network design only considers long-term decisions, which highly affect the overall transportation process, e.g. the number of warehouses. The distribution network planning focuses on mid-term decisions, while transportation planning considers the transport to the final customer. On the level of the transportation planning decisions, like the used means of transport (truck, rail, air) or the exact packing are made. This bachelor thesis affects the distribution network design as well as transportation planning. The decision of a company to realize their food transportation with cold chain management with the help of IoT is a long-term decision and the complete infrastructure must be reorganized. And the choice of this work to only consider transportation with trucks affect transportation planning (Akkerman, Farahani, & Grunow, 2010).

Cold Chain Management and its Importance for the Logistic Process

The last important element for this chapter is the Cold Chain[4], which refers to "the transportation of temperature-sensitive products along a supply chain through thermal and refrigerated packaging methods and the logistical planning to protect the integrity of these shipments" (Luo et al., 2016, p. 2). The Cold Chain Management (CCM) regard of the monitoring and control of the temperature for perishable food products to ensure their safety and quality (Kuo & Chen, 2010; Mahajan & Frías, 2011). The whole process of the CCM includes freezing processing, freezing storage, freezing transportation and distribution, freezing sales (Wei & Lv, 2019). To ensure, that food products can comply with the required cool temperature, which is essential for perishable food, some task must be performed. The first one is the right preparation of food, which means that the industrial processing of foodstuff has happened under the statutory quality measures and not already rotten food is processed. The next task is the correct storage of foodstuff, warehouses, and refrigerated warehouses are free from bacteria and the maximum temperature is not exceeded. Transport and monitoring of the food products are the last two important tasks, which interdepend. For correct and safe transportation of the food, comprehensive monitoring to guarantee the food's safety and quality is nice (Mahajan & Frías, 2011; Luo et al., 2016). So, the cold chain is decisive for guaranteeing that perishable food can comply with his safety and quality for the consumer.

6.2 Food Transportation Systems without IoT

In this subsection, three systems from different researchers with a subsequent evaluation of the usefulness of these systems are provided. All presented companies and researchers use a system to track or trace food with the usage of cold chain management for their products. I present the functionality and components of the systems with the technical aspects only in very shorten form. The paper does not have the aspiration to provide a complete and detailed technical overview. This subsection presents only systems, which not use IoT technology. IoT will be handled in the next subsection and after this, the two subsections with their different processes are compared to identify concrete benefits and advantages using IoT. Table 4 shorten summarizes the essential findings of this subsection. As mentioned, the author critically evaluates all in this subsection provided logistic processes based on the following criteria:

- Gaining economic benefits for the company using a food tracking system with cold chain management
- Gaining ecologically improvement using a tracking system
- Reduce waste using a food tracking system, because of e.g. better food safety and quality, better detection of faults for further transports, etc.

The first result from Kuo & Chen (2010) is their Multi-Temperature Joint Distribution System (MTJD), which should support the food cold chain and gain competitive advantages in the transportation of temperature-sensitive products. The aims of the developed MTJD are the minimization of costs for a logistic service provider and increase of the performance from the whole logistic. Moreover, the authors introduce new materials for supporting the cold chain, like-new cold boxes and cold cabins, where extremely cold food could be safely stored. Furthermore, so-called eutectic plates, which have many improvements in contrast to

[4] Mahajan, P. V., & Frías, J. (2011). Cold chain. *Decontamination of Fresh and Minimally Processed Produce*, 269-484.

conventional cooling systems are used: Eutectic plates can store the cold and gradually transfer the coldness into the environment. They can be charged at night with electricity and during transportation, no need to use fuel for the cooling process exists (Carlsen Baltic, 2019). With these three new cooling technologies, the system from the authors is able to store food products with different temperature requirements in one truck, thus making the transportation process more efficient and reducing the logistic costs (Kuo & Chen, 2010).

- By using the MTJD from Kuo & Chen the logistic costs can be significantly reduced, by aggregating several small and single truck trips into only one truck trip with the help of the MTJD system.
- The MTJD also offers ecologically improvements, because of the aggregation of many trips to only one, the CO_2-emission will be reduced. Moreover, the usage of eutectic plates causes nearly zero-emission, which is an environmentally friendly solution.
- This new system should improve the safety and quality of perishable food, whereby the waste of food can be reduced.

The second system from Galimberti et al. (2013) presents the results from DNA barcoding for better identification of animals and plants. Improved traceability for food-checkers to identify cheap food, which is purposely, wrongly declared as expensive food is also provided. DNA barcoding uses a short section of the DNA sequence, which unambiguously identifies a species. This short sequence includes the four letters C, G, A, and T, which represent the four bases of the DNA. For animals, the section from a mitochondrial DNA gene is used and for plants the section with the chloroplast DNA (Staatliche naturwissenschaftliche sammlungen bayerns, 2019). It is possible to use the DNA barcoding, for example, in the seafood traceability. Each fish has unique characteristics in their DNA sequence, whereby the tracking and tracing of seafood are easily, also after processing. DNA barcoding is also possible to trace meat, dairy products or edible plants. A decisive advantage over other methods, like the protein-based methods, is, that DNA barcoding is more resistant to industrial processes and it is much faster (Galimberti et al., 2013). One important condition for using DNA barcoding is the existence of an online database, which can automatically compare the letter code with the data inside the database. Without the data of the database, the barcode method is not able to function (Staatliche naturwissenschaftliche sammlungen bayerns, 2019). So, compared to other methods, DNA barcoding is more sensitive, fast, cheap and reliable for tracking and tracing food (Galimberti et al., 2013).

- By using DNA barcoding the economic benefits for a company can be improved because the detection of a commercial fraud from a supplier or manufacturer inside the supply chain can avoid financial damage. So, when food scares or frauds come not into the public, the customers continue to trust the company and cause no damages.
- Gaining ecologically improvements is unlikely because the transportation process is the same as before. But for example, when maggots are found in fruits it is possible to identify the exact species, which is the same as maggot and as an adult animal, to determine the place of the contamination, e.g. at the manufactures or in the trade.
- DNA barcoding is not able to reduce food waste, because when food-checkers find falsely declared food products they will punish the manufacturer and probably he will not do it again. Through the fact that the transportation process is the same and checking food products, whether they are declared right or not, helps only to identify commercial fraud but the waste is the same.

Đorđević et al. (2016) provided in their paper the “Food Refrigeration Innovations for Safety, consumer’s Benefit, Environmental impact and Energy optimization along the cold chain in Europe” (FRISBEE), which was a project from the European Union during the years 2010 to 2014 with 26 partners from 12 EU members. Several aims of the project were the following: Firstly, a significant improvement of the food safety and quality for the cold chain through better temperature control. This was realized by the development of new refrigeration models. For example, Phase Change Materials (PCMs) for special food packaging, which can guarantee the safe transport of cooling sensitive products by absorbing heat in the environment and protecting the packaged food at the same time. Moreover, a Cold Chain Database (CCD) was developed as a web-based tool with more than 14,000 profiles, to identify weak links of the cold chain for many products with new simulation tools for predicting the building of ice, etc. Another very powerful invention during the FRISBEE project was Vacuum Insulation Panels (VIPs), which can preserve extremely temperature-sensitive products by difficult conditions at the same temperature level. VIPs are also reusable, recyclable and nontoxic, thus making them perfectly fitting for fuel-efficient transportation. A last very useful technology is the so-called superchilling/supercooling technology (Đorđević et al., 2016; European Commission, 2017; Frisbee european project - Home, 2019). This technology uses as well as cold storage and frozen storage and can, therefore, achieve about -1°C to -1.5°C which is by normally technologies -3°C. Only on the surface of the food, a small ice layer exists, offering food significant longer shelf life (Sozialministerium, 2014).

- By using the Vacuum Insulation Panel, a company can gain enormous economic benefits, because the certainty that extremely sensitive food products are safely stored, also in a difficult environment can save many costs when the products are not damaged during the transportation procedure.
- Gaining ecologically improvements for companies is possible with the help of Phase Change Materials for the food packaging, as it can save a lot of energy.
- Superchilling technology is perfect for reducing food waste. When food products are fresh and more durable than usual, their wastage is reduced also.

6.3 Food Transportation Systems with IoT

This subsection is very similar to the previous one, but one big difference is the providing of four systems from different researchers with their logistic food systems with the usage of IoT in the cold chain. Table 4 provides a brief overview of the presented systems in this subsection. After a description of the systems provided in the different papers, I evaluate them based on the following criteria:

- Gaining economic benefits for the company or industry using a food tracking system in cold chain management with IoT
- Gaining ecologically improvements using a tracking system, like the reduction of CO_2, because of less empty runs from cooling trucks
- Reduce waste using IoT, because of e.g. improvement of food products in terms of food safety and quality, real-time detection of faults where the driver of the cooling truck can react to avoid food waste, etc.

Abad et al., (2009) present an RFID smart tag system for real-time traceability of chilled food, like seafood, for the cold chain management using cooling trucks. The system uses an RFID smart tag, which consists of several sensors, a microcontroller, a memory chip, low power electronics, and an antenna. The sensors enable the system to track the chilled foods lightly, temperature and humidity, while the memory chip can store the food traceability of the products to provide transparency during the whole transportation process. The author's paper concentrates on the tracking of seafood, which is normally done with strip chart recorders or temperature dataloggers. These technologies have the disadvantages, that they are expensive and not automated what means, that the person must check the foods quality and safety manually by opening the cooling boxes or containers inside the truck. The RFID smart tag system with its reader can process the gathered information about the food and transmit it to a computer with a USB port. Moreover, the system has a fully automated reading phase, therefore opening the box where the seafood is stored is not necessary. Furthermore, the smart tags measure every two minutes the condition of the food while storing the values on the memory chips. Because the whole transportation process from the capture of seafood to the consumer can take about three days, a complete safety tracking and monitoring of the food is indispensable.

- The RFID smart tag system can help to improve the economic situation of a company because the real-time monitoring of important food quality criteria increases the food quality, which saves money and strengthens the competitiveness of the company.
- This system uses the same cooling truck technologies with the same polystyrene boxes. Only a smart tag is placed inside the boxes. Of course, enabling real-time monitoring and storing these data is important, but this helps not to gain ecological benefits.
- But the system can reduce food waste, because of two reasons: Firstly, the monitoring of temperature, light and humidity help to keep the seafood fresh and safety. And secondly, even if the food is spoiled, it can still be detected later with the memory chip to find the concrete cause of negatively influencing the food safety.

The second system in cold chain with the usage of IoT from Luo et al. (2016) is a so-called “Intelligent tracking system for the cold chain” and combines the characteristics of IoT with new tracking technologies. The main technology is a Wireless Sensor Network (WSN) built on Zigbee with monitoring applications and the authors use the three-layer-architecture. The first layer is the sensing layer with RFID readers, Barcode readers, Wireless monitor nodes, sink nodes, GPS nodes, etc. to gather real-time data of the transported food in the cooling trucks. This data includes the actual temperature, the humidity status and the exact position of the food. All this data is provided in real-time with the help of the network layer and its WSN, where each node can run independently at the lowest cost as possible and is sent to the upper network layer by sink nodes. The nodes use different cellular technologies, LTE Advanced (4G) and UMTS (3G) for a fast-mobile telecommunication data transfer. But the system uses also the GSM (2G) technology, for regions which are underdeveloped. The last layer, the application layer, processes the data received from the network layer to provide a real-time data interface management, which offers different functions like temperature, humidity monitoring, etc. Of course, the application layer is made up of servers and software, which are installed in the monitoring center and management workstations. So, the system offers several functionalities to monitor and track food with their temperature, position and historical data about the food are archived for more transparent food transportation.

- Using the intelligent tracking system from Luo et al., a company can earn enormous economic benefits because the WSN works at low cost with reliable data transmission and simple protocols. Moreover, the real-time monitoring and tracking of the food enable a fast reaction to keep the food product’s quality high to earn much money.
- Gaining ecologically improvements for companies using the system is pretty sure, because of the generating alert function. When the temperature reaches a predefined

value, the system will generate an alert for the truck driver and the central, so that for example an inefficient cooling system can be detected and replaced to save energy.

- One of the most important aspects of the system is the reduction of food waste. The monitoring of perishable food in real-time and the fast reaction to alerts is a very effective way to keep the food fresh. Moreover, it is possible when damage comes to the food products that the reasons can be identified in retrospect. All these functions help to keep the food products quality at a high level and to reduce food waste.

The next author Want (2018) provide a system, which is a combination of a time-temperature indicator (TTI) and an integrated sensing and communication module (S&C). The TTI uses labels for smart packing, while the S&C monitor the food quality continuously with the help of radio to be embedded in smart packets. The system can perform online data, which can be collected and analyzed to react fast. Reactions could include the distribution of food to the local market when the quality has deteriorated or the reorganization of the transport process. The procedure of the system in-detail is the following: The S&C module is placed into each box with foodstuff and can monitor the temperature, humidity, gas concentration and the box exact position. When the boxes pass during the transportation process a warehouse, the warehouse uses his long-range communication to communicate with an analytics and operation center from the company. Moreover, the need for medium range or short range to transmit the data from the S&C module inside the boxes to the local hub is found, where a Wi-Fi or WSN network could be used. To transmit the data from one box to another the system requires multi-hop communication. Each S&C module has an integrated battery with a lifetime of several years, which only activates every 30 minutes to monitor and transmit the data, so the rest of the time the modules use sleep mode and save energy.

- With the help of the combined TTI and S&C system from Want (2018), a company can gain economic benefits, because the S&C module detects possible contaminations or deteriorating quality, whereby the truck driver can fast react by transporting the food locally or spatial separation of contaminated from non-contaminated food.
- Ecologically benefits are also possible by improving the whole transportation efficiency process. E.g. when the truck driver is conscious about the reducing quality of food, he stops his original transport and sell it locally, thus reducing unnecessary drive time and CO_2.
- Of course, the system can reduce waste of food by detecting possible contaminations and monitor the foodstuff's temperature to decrease illnesses causing of rotten food.

Eventually, Wei & Lv (2019) with their "Distribution System of Agricultural Products Cold Chain Logistics", which focusses on a cold chain logistics distribution system for fresh, low-temperature agricultural products. This include eggs, meat, milk, etc. to provide more information and transparency in the whole transportation procedure with cooling trucks. With the help of the system, the quality and safety of fresh food products can be improved and simultaneously reduce waste. Because of several cases of abuse from the traditional cold chain logistic, like inadequate drive path selection, which causes in time waste, this system uses the RFID, Global Position System (GPS) and Geographic Information System (GIS) technologies. Temperature and humidity of the food can be recorded with the help of different sensors, which are placed by the products and inside the cooling truck, and RFID labels, which are placed on the product packing. The gathered data from the RFID label is transferred to a remote monitoring center via General Packet Radio Service (GPRS). When values reach the threshold of e.g. temperature, an alarm is generated at the monitoring center and the employees can notify the truck driver to react fast. Using GPS, the exact position of the truck, his running status and condition can be easily tracked for ensuring timely delivery. The GIS technology can give an overview of the road information in real-time, where the monitoring center can inform the driver about an incoming traffic jam and directs him to another route for staying in time.

- The provided cold chain distribution system can definitely gain an economic value for a company, because of the improving transportation efficiency by detecting traffic jam and reducing logistic costs. Moreover, the reduction of food damage with better food quality and safety reduce also costs and save money. Furthermore, a company using the system will stay in time for higher customer satisfaction, more orders and more profit.
- By avoiding unnecessary additional time staying in a traffic jam for more effective transportation of the food, the system can enable ecologically benefits.
- Finally, the enhancement of food safety and quality, the more efficient and in-time transportation process causes better avoiding rotten food and reduced food waste.

6.4 Advantages through using IoT

Finally, this subsection presents a comparison of the provided food transportation systems from the subsections 6.2 and 6.3 and identifies which systems are unsuitable for the cold chain transportation procedure. An overview of the results from the two subsections is provided in Table 4, which briefly summarizes the main findings. During the two subsections, I contributed that providing food safety, food quality, and sustainability and simultaneously a resource-efficient, environment-friendly transportation is the base to guarantee, that foodstuff can keep fresh for the consumer by bringing money to the company (Aung & Chang, 2014; Atzori, Iera, & Morabito, 2017). Because of several problems like the high percentage of food waste during the transportation process from the farm to the end-consumer, which is often 30 percent or that the temperature in cooling trucks in one-third of the control exceeds the maximum, the logistic industry should change their systems. Seven different systems were presented in the subsections 6.2 and 6.3, five of which have the potential to improve the cold chain transportation of food positively.

Already existing systems are available without the usage of IoT, which can bring benefits for the transportation process. The provided Multi-Temperature Joint Distribution System and the EU project FRISBEE meets the three benefits (economic and ecological benefits, reducing food waste) in an efficient way. The DNA Barcoding method only helps to reduce public damage for the company by detecting frauds, but ecological benefits or reducing food waste is not possible, which makes the system unsuitable for the logistic. Four systems with usage of IoT were provided, only the RFID Smart Tag System was unable to fulfill earning ecological benefits for the company. The other three presented systems, however, all meet the criteria. Apart from the DNA Barcoding and RFID Smart Tag System, the other five systems can gain benefits and reduce food waste.

Thus, using new technologies can have several advantages for a company like reducing truck trips, because of storing different temperature depending products into one cooling truck, which saves money and reduce CO_2. The use of new improved smart packaging for keeping foodstuff fresh and save from damages is another improvement. New technologies like the supercooling method to extend the life of food can gain enormous advantages too. Real-time monitoring of food recognizes possible contaminations, having alert functions for a fast reaction in case of an emergency or enables more efficient transportation. Staying in-time for fresh food are possible advantages using IoT in the transportation process with cold chain for cooling trucks.

Table 4 Comparison of food transportation systems with and without using IoT (Source: Own Presentation)

Transportation System without the usage of IoT				
Criteria / **System**	**Economic benefits**	**Ecological benefits**	**Reducing food waste**	**Suitable for a company?**
Multi-Temperature Joint Distribution System (MTJD)	Fewer truck trips, Save money	Aggregation of many trips, Reduce CO_2	Eutectic plates store cold better, Reduce waste	✔
DNA Barcoding	Detection of fraud, Less public damage	Same transportation process, No benefits	Only punish the responsible, No benefits	✘
FRISBEE	Vacuum Insulation Panel reduces food damage, Reduce costs	Phase Change Materials for better food packaging, Save energy	Supercooling for longer food shelf life, Reduce waste	✔
Transportation System with the usage of IoT				
RFID Smart Tag System	Real-time Monitoring, Save money	Same cooling truck technologies, No benefits	Higher quality, better detection, Reduce waste	✘
Intelligent Tracking System for the Cold Chain	WSN works at low cost, Save money	Alert function for fast reaction, Save energy	Protect food safety and quality, Reduce significantly waste	✔
Time-Temperature Indicator (TTI) & Integrated Sensing and Communication Module (S&C)	Contamination recognition, local transportation, Save money	Declining quality detection, Reduce CO2	Monitor temperature and faster rotten food detection, Reduce waste	✔
Distribution System of Agricultural Products Cold Chain Logistics	Higher customer satisfaction, Save money	Avoiding traffic jam, Reduce CO2	In-time transportation, Reduce waste	✔

7 Discussion and Conclusion

Internet of Things (IoT) is a fast-growing technology that offers many possibilities of how people can use it for improving whole processes or just automate single tasks for more comfort. These possibilities range from the use of intelligent buildings, over medical improvements, to the monitoring of whole transportation processes and make them more efficient. Due to the huge number of different architectures and technologies, the exact choice that fits the particular application context of a company is not easy. This bachelor thesis concentrated on two main concepts: The first one was a detailed overview of the IoT technology, which included characteristics, elements, technologies, application areas, etc. The second concept included a specialized view of the food transportation topic with cold chain management. The following subsections summarize the procedure during the thesis with its main findings and my view of a theoretical 'ideal' system for the food transportation sector. Afterward, a critical assessment of this work with its focuses and limitations is provided. Subsection 7.3 includes topics and areas where still gaps in research exist and therefore further research is needed and finally, a brief outlook on how my findings can impact further research.

7.1 Summary

On the one hand, this bachelor thesis conducted in chapters four and five the most important information, which relates to the topic Internet of Things in general. For this purpose, a first comprehensive literature review was made, which included 57 different sources from authors, researchers, etc. and several internet articles. The main findings of this review were the following: No generally accepted definition about IoT was found in the literature, each researcher focused on different aspects like economic, technical or ecological. My definition of IoT, which was an attempt to unite the essential characteristics in one definition, was the following:

> Internet of Things (IoT) refers to a global network, including trillions of interconnected devices and smart objects, which share information and communicate with each other. This network enables things, supported by their sensors and actuators to provide information at any time, from anywhere, for anyone and anything. IoT is a revolution of the internet and it is already radically transforming our lives.

The identification of key characteristics like interconnectivity, scale, and self-configuring as well as common elements e.g. identification, sensing, communication, etc. was found out through the literature review. Furthermore, several technologies like RFID, Bluetooth or Cloud Computing were described how they can fulfill the user's requirements. The presentation of various architecture options finished chapter 4. In chapter five, some application areas where IoT can improve processes, systems or just provide more comfort for people were described. With this literature review, conducted in chapters four and five, the first aim of this bachelor thesis was successfully fulfilled.

On the other hand, this bachelor thesis specialized in the subject of food transportation and traceability with cold chain management using cooling trucks. For this purpose, a second literature review was made, which focused on foodstuff, cold chain management, and cooling trucks. After an overview of the topic in general, concrete systems or processes from authors and researches were described and personally evaluated based on three criteria: Economic benefits, ecological benefits and reducing food waste. The main findings and advantages through the comparison of the different systems were, that using IoT in the transportation process could enable the real-time monitoring of food. Faster reactions, because of alert functions and a more efficient truck drives by being connected to monitoring centers are able. But also, the usage of new technologies without IoT can improve the logistic, like using new and better packaging or the supercooling method for significantly increasing the food products shelf lives. The findings were also summarized at the end of the chapter in Table 4. So, by the comparison of several systems and processes the second aim of this bachelor thesis, identify advantages using new technologies with and without IoT, was reached.

For answering the last aim of this work, the question of how a theoretical 'ideal' system with its technologies for the transportation of foodstuff in the cold chain could look must be answered. I present my view of such a perfect system. My proposal is based on the insights gained during the two literature reviews and the comparison of the different systems. It is extremely hard to define one theoretical 'ideal' system, because this depends on the transported food class, the overall distance of the drive, the number of intermediate stops, use of other transportation methods like ships, etc. But generally, in my opinion, the optimal system for food transportation involves a real-time monitoring component, consisting of a WSN with hundreds or thousands of sensors placed inside a multi-temperature truck. This sensor assisted cooling function should include, an alarm function when exceeding the temperature, which informs the truck driver either via a special designed IoT cellphone or a monitoring center to avoid food waste. The monitoring center has the additional advantage, that it can inform the truck driver of an upcoming traffic jam and navigates him to another route to stay in-time using GPS. Moreover, the logistic process must use as efficient packaging as possible, which can include eutectic plates which are maintenance-free and have an efficient system performance of over 8 years. The last important characteristic which the system should also use is the supercooling function, which is suitable for several food classes/types. The foodstuff rises to its individual freezing temperature and then freezes in a very close temperature range, which is perfectly constant. The results of chapter six have shown, that not only the usage of IoT can improve the transportation process, but also new technologies. In my opinion, the reasonable combination of both areas, with and without IoT, is the best combination to reduce or avoid food waste.

7.2 Critical Reflection of the Work

This bachelor thesis has shown a detailed view of the whole topic of IoT with its main characteristics, elements, technologies, and architectures. Moreover, several application areas, where IoT can improve processes were briefly described. In the second part of this work, I provided an in-deep topic, which handled with foodstuff transportation in cold chain management. Although this work combined a comprehensive overview of the topic IoT with the deepening topic of foodstuff, it has limitations. One limitation is the missing in-depth technical view. I sometimes mentioned the exactly used technologies or systems, but the concrete used sensors, actuators, etc. are not provided in this work. Another limitation is the consideration of only six application areas in this work. But due to the limited space of a bachelor thesis, this is not possible otherwise. One limitation, which often occurs in scientific works, refers to the target group of the audience. But my work is suitable for both target groups, because of the wide overview of the topic which is interesting for beginner and the foodstuff topic for advanced readers. Therefore, this work is worth reading for both target groups.

7.3 Identification of Research Gaps and Future Research Needs

The results of this bachelor thesis reflect the current state of research. Very often, current scientific sources for the literature reviews were used and combined with numbers from web pages. During my two reviews, I have identified research gaps, which should be closed. Regarding the historical evolution of IoT with its three generations, only one work from Atzori, Iera, & Morabito (2017) was found in this work, which handles the topic. Other researchers should also work on this topic and revise the work from the authors. Other research gaps refer to the food transportation topic with cold chain management. During the second literature review, only a few authors provide a system or whole process with cold chain in cooling food trucks and the use of IoT. Very often, only a system to improve the cold chain was described. In this case, future research is urgently needed, because innovative systems, which improve the transportation process and reduce food waste are indispensable in the future for tackling the amount of annual food waste. As a final point, I must stress that no indication exists, how much the new food systems can reduce food waste or improve the overall transportation process. Neither tables with numbers, which compare the reduction, nor percentages or estimations were made. Therefore, future research should provide these numerical comparisons for better visualization of the usefulness.

7.4 Outlook

My work can act as a good base for future research, because of the presented systems in subsections 6.2 and 6.3. These systems could be enhanced with more technical aspects and context. Moreover, Table 4 at the end of chapter six, provides an overview of the three criteria economic and ecologic benefits and the reduction of waste. More criteria can be added for a better decision whether the system is suitable for companies or not. As mentioned in the previous subsection, numbers or indications of the reduced percentage of food waste is necessary for a better view. Future work might be able to realize my theoretical presentation of a theoretical 'ideal' system in practice on the base of my work. I strongly want to emphasize that, the Internet of Things will become more and more important, penetrating nearly every aspect and area of life. Possibly, not only smart cities but a whole smart planet, using the IoT will be created.

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