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The impacts of Internet of things on the supply chain activities

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Acknowledgement

“Success isn't about the end result*;* it's about what you learn along the way”, ***said Vera Wang.***

Three years ago, I graduated in engineering from the University of Balamand in Lebanon. I didn’t want to compete with other fresh graduates, I wanted instead to gain a competitive advantage over everyone else. Therefore, I chose to go for the difficult path, and I applied to the Polytechnic of Turin. I was more than grateful when I was accepted and that’s exactly when the adventure started. It was a never-ending learning pathway on the personal and professional level.

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On another level, I’m blessed to have childhood friends that pushed my limits in every step of the path. Moreover, I am grateful for the friends I met here in Turin during my stay. They were for me a new family with whom I shared unforgettable moments. You were my constant source of encouragement during these years.

Finally, I’m satisfied with everything I reached, and this is just the beginning.

Abstract

"Internet of things" is the interconnection, by means of internet, of different computing devices inserted in regular or physical objects. Dumb physical objects equipped with smart sensors will be capable to accomplish complex tasks that necessitate a great degree of intelligence. These smart objects are therefore able to sense the external environment, collect information accordingly, and share the collected data. The collected information need to be processed, analyzed and stored in order to deliver values and services to the user. Since, data processing and storage are generally done in a remote server, data needs to be transported from the sensors to the servers. In this thesis, different types of sensors are discussed as well as their benefits, various connectivity forms are presented, and two data processing options are analyzed. In the forthcoming years, "internet of things" technology is going to change the way individuals live by offering high levels of services. Financial services, manufacturing, healthcare, communications, retail, transportation, smart cities, smart warehouses, and agriculture are just few examples where IoT technology is having an impact. In the manufacturing industry, IoT technology is transforming, improving, and empowering the supply chain activities. In this thesis, the benefits of IoT technology in inbound logistics, production, warehouse activities, and transportation are discussed and analyzed. The analysis shows that the benefits of IoT technology are incomparable and therefore, despite IoT implementation challenges, many manufacturers are spending or will expend money on this astonishing technology in the near future.

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1. Introduction

Today the internet is omnipresent, is touching each corner of the world, and is influencing human life in unbelievable ways. However, such influence is far from over. We are now going toward an era of more prevalent connectivity where a variety of things will be connected to the internet. We are going toward the “internet of things” era. “Internet of things” (IOT) is the interconnection by means of internet of computing devices inserted in regular objects, empowering them to send and get information. These “smart” objects are therefore capable to accomplish complex tasks that necessitate a great degree of intelligence. For this interconnection and cleverness, objects are equipped with sensors. Sensors are devices, which interact with the environment and collect data. The data collected is to be stored and processed in order to develop valuable inferences. The storage and processing of data is generally done in a remote server. Once data processing is done, the derived inferences are used to advance the quality of life. “Internet of things” applications are being used in numerous sectors including agriculture, manufacturing, health care, education, energy conservation, transport systems, smart buildings, safety and security, smart environment, and etc. This trend is likely to increase in the future, since the economic impact of “internet of things” applications is to be at least around 2,300,000,000 US dollars each year up to 2023[1] [2].

Different IoT system architectures have been suggested by diverse researchers. The simplest architecture is shaped by three layers: perception layer, network layer, and application layer. The perception layer, known as physical layer, has sensors/devices for detecting and collecting data about the surroundings. The network layer is in control of transmitting collected data to servers through a network. In addition, the network layer is in charge of data storage and processing. The application layer is in charge of delivering services and values to the user[1].

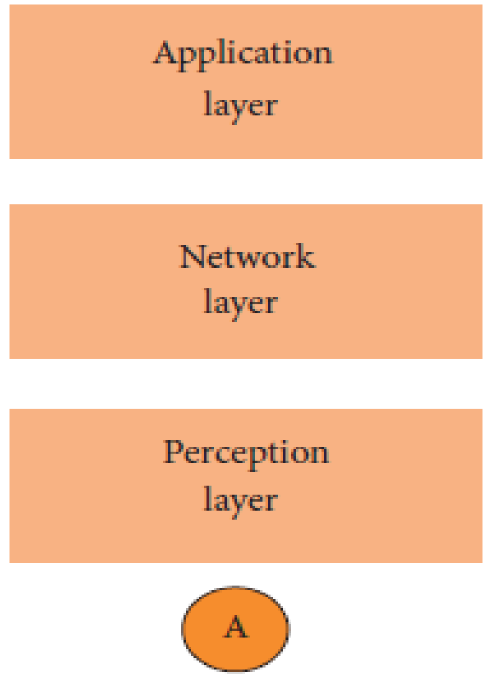

Figure 1: Three-layer architecture

The discussed architecture only presents the general idea about IoT. It is not sufficient because researchers focus on finer features of the "internet of things". That is why, more layered architectures are proposed. An architecture which additionally contains processing layer and business layer is known as five-layer architecture. The five layers are: perception layer, transport layer, processing layer, application layer, and business layer. The perception and application layers in the five-layer architecture have the same role discussed in the three-layer architecture. The transport layer is responsible of transmitting data between perception and processing layer. The processing layer, known as middleware layer, is in charge of data storage and processing. The processing layer employs various types of technologies such cloud computing, databases, and big data processing elements. The business layer controls the whole IoT system. It is about gaining money from the service delivered[1].

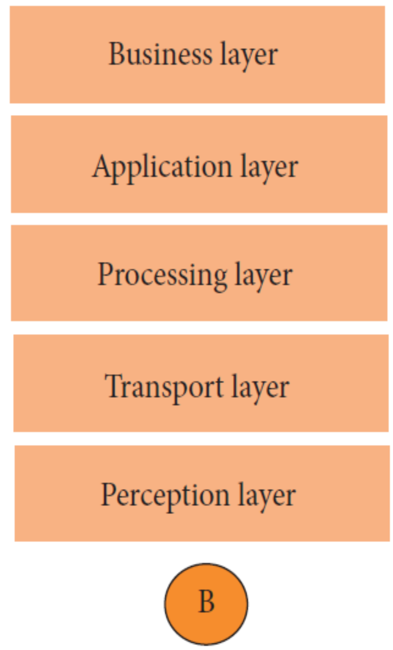

Figure 2: Five-layer architecture

The main idea about "internet of things" is to collect, process, analyze, and store data in order to deliver values and services to the user. Generally speaking, data processing is done by centralized cloud computers. Despite the fact that cloud computing has various advantages, it is insufficient to meet the requirements of many "internet of things" applications. Cloud computing does not meet the requirements of applications where smart devices are moving, real time actuation is crucial, and power is constrained. When smart devices are moving, network condition is changing and it will be difficult to communicate with the centralized cloud computers. Transmitting data to the cloud computers and getting back replies takes time. So, applications where immediate responses are required cloud computing is not the best solution. Communication between smart devices and cloud computers consume a great amount of energy. So, smart devices, which are power constrained, will not have to capability to efficiently communicate with the cloud computers. To solve these problems, some data processing resources are brought to the edge of the network. This concept is called fog computing or edge computing. Smart gateways, which act as links between sensors and the cloud, are employed to realize fog or edge computing.

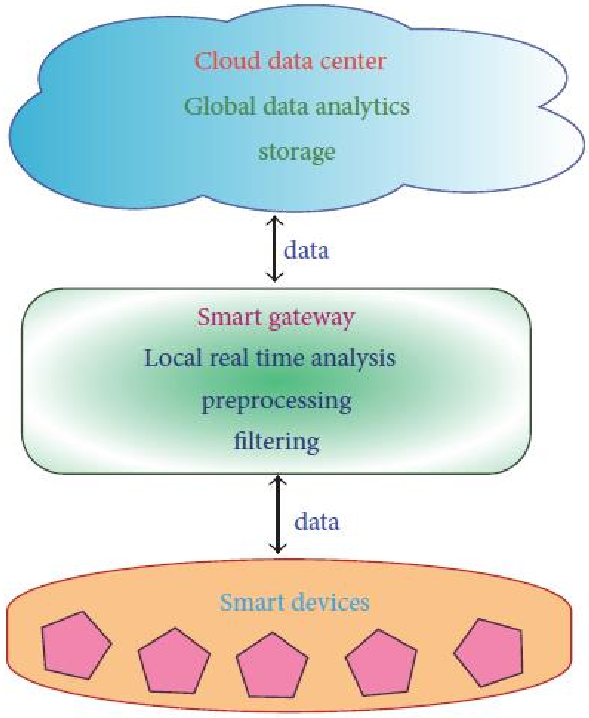

Figure 3: Smart gateways used for preprocessing

The implementation of smart gateways and fog computing has brought many advantages. By applying fog computing, data will not be required to pass all along the network to be processed by the cloud computers, but instead some data will be processed in the smart gateways which results in lower latency and immediate responses. In addition, numerous smart gateways can be implemented in different geographical areas to support applications where smart devices are moving. As smart devices are moving, they can transmit data to the nearest smart gateway available. Moreover, data received by the smart gateway can be filtered and only what is essential to the cloud is sent. The fog computing concept has introduced what is known as fog architecture.

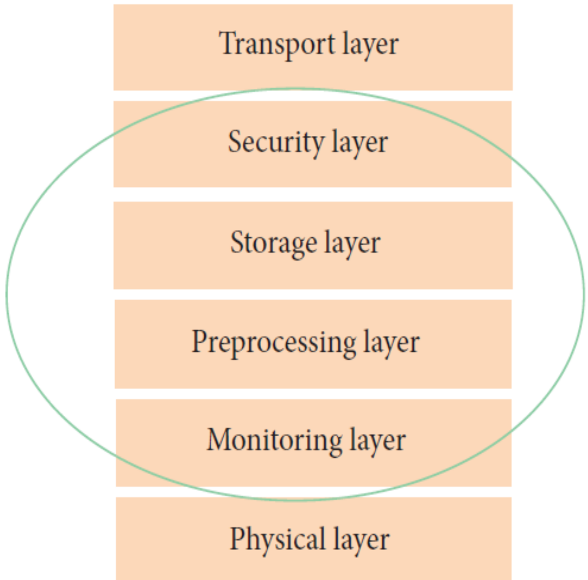

Figure 4: Fog architecture

Security layer, storage layer, preprocessing layer, and monitoring layer are inserted between the transport layer and the physical layer. The inserted layers summarize the role of the smart gateways. Monitoring layer is responsible of monitoring the power consumption of the "internet of things" devices as well as their activities and services. Preprocessing layer is in charge of filtering, processing, and analyzing sensors data. Storage layer is responsible of temporary data storage. As its name announces, security layer is in charge of ensuring security of data[1] [3].

The implementation of the "internet of things" in the industry has led to a significant transformation concerning the way we produce goods. This transformation is being titled Industry 4.0 to characterize the fourth revolution in the industry. The industrial production went through three main revolutions: the inclusion of mechanical machines, the introduction of electric power, and the insertion of electronics in the manufacturing processes. In this paper, we will present, in the first section, the sensors that are being used by the manufacturing companies. In the second section, we will explain how the sensors data are being sent for processing and generating inferences. Finally, in the third section, we will present the benefits of implementing "internet of things" systems in the industry [1] [2].

2. Data collection

2.1. Barcode system

Automatic Identification and Data Collection(AIDC), is the universal name of technologies that help automatic data entry in a way to eliminate human error and to increase time and labor efficiencies. Barcoding system, one of these technologies, enables easy, fast, and precise data entry of the product labelled. The barcode system is composed by four major components: barcode printer, barcode label, barcode scanner, and database for data storage[4].

2.1.1. Barcode components

2.1.1.1. Barcode printer

As the name announces, a barcode printer is a device able to print barcodes. There are four typical types of barcode printer: ink jet, laser, dot matrix and thermal. Thermal barcode printer in its turn is divided into two types: direct thermal, and thermal transfer. Each barcode printer type has its own characteristics. The main characteristics describing each printer's type are shown in the table below.

Technology	Print Quality	Scanner Readability	Initial Installation Cost	Long-Term Maintenance Cost
Dot Matrix	Fair	Low	Low/Moderate	Moderate/High
Ink Jet	Moderate	Low/Moderate	High	Moderate/High
Laser	Moderate	Moderate	Moderate/High	Moderate/High
Direct Thermal	Moderate/Excellent	Moderate/Excellent	Moderate/High	Low
Thermal Transfer	Excellent	Excellent	Moderate/High	Low

Table 1: Different characteristics for each type of barcode printer

2.1.1.2. Barcode label

Before speaking about barcodes, one must know the difference between code, symbol and symbology. The symbol can be defined as the arrangement of bars and spaces or squares and spaces organized in a manner to encode data or information. The code is the data or information that can be acquired from the barcode symbol. This data can be numbers, letters, or combinations of numbers and letters. Symbology is the methodology used to arrange the symbol. Subsequently, using a predefined symbology, barcode is a symbol that contains a series of bars and spaces or squares and spaces arranged in a way to encrypt data known as code. These bars, squares, and spaces can be with different widths and lengths. Some special patterns of lines and spaces can be set in order to recognize the beginning and the end of the barcode symbol known respectively as the star and stop characters. A device, known as the barcode reader, is able to decode the information encrypted in the barcode symbol using a methodology that will be discussed in the following. Therefore, we can say that barcode by itself does not represent a system but rather, it is an identification tool[5].

Generally speaking, there are two different types of barcodes: One-dimensional or linear(1D) and two-dimensional(2D) barcodes. They can be found in different kinds of applications, and they are scanned by means of different kinds of devices. The symbology and the storage capacity are the most important differences.

2.1.1.2.1. One-dimensional barcode label

Most people, when talking about barcodes refer to the linear barcodes. One-dimensional barcodes are frequently found on consumable products. 1D barcode is made by a set of vertical bars and spaces with variable width where the data is encoded horizontally. The data that can be encoded in such type of barcode is limited, up to some characters, and is alphanumeric. The barcode gets longer if additional information needs to be encoded. That’s why systems using this type of barcodes are usually linked with a back-end database. Once the barcode is scanned, the acquired information is linked to a database in order for the user to get more information about the labeled product. Therefore, this type of barcode addresses “product identification”. For example, since the product identification number in most of the cases is the only encoded information, 1-D barcodes are the best fit when additional information of the product labeled may be subjected to changes. If the price of the product has changed, the user can access the database and directly change the price of the specific product number; this is not the case where the price is encoded in the barcode and consequently, the barcode needs to be replaced[6].

Figure 5: One-dimensional or linear barcode

2.1.1.2.2. Two-dimensional barcode label

Two-dimensional barcodes are made by a set of square, dots, or hexagons along with spaces where data is encoded in both vertical and horizontal directions. Due to this symbology, 2-D barcodes can encode much more data or information while being physically smaller compared to 1-D barcodes. The data encoded can contain a full description of the product labelled. The information encoded are not just numbers or characters, like in the case of 1-D barcode, but in some cases the data encoded can take the user, scanning the barcode, to a website containing videos and images. That means you can take advantage of the data without being linked to back-end database. Therefore, this type of barcode addresses “product description”[6].

Figure 6: Two-dimensional barcode

2.1.1.3. Barcode scanner

In the information collection stage, scanners are used to instantly and precisely read, catch and translate the data encoded in the barcode symbol. Scanners detect data much quicker than people and with zero error, and thus increasing the operation efficiencies. Barcode scanners can be categorized as either contact or contactless type. Barcode scanners can as well be classified into fixed or moveable type[7]. Considering the data detection mechanism, barcodes scanners can be subdivided into four major types: pen, laser, charge coupled(CCD), and 2-D camera barcode scanner. Independent of what type is used, and generally speaking, a barcode scanner consists of three main components: lighting system, sensor/converter, and a decoder. The lighting system of the barcode reader starts lighting the symbol. The sensor detects the light reflection intensity and consequently an analog signal is created. The analog signal is transformed into a digital signal by the converter. The digital signal is fed into the decoder which is able to interpret and translate this signal into useful information[8].

2.1.2. One-dimensional barcode

There are many types of one-dimensional or linear barcodes, but the most important are: Code 39, Code 128, Interleaved 2 of 5, Universal Product Codes(UPC), International Article Number(EAN), and Coda Bar. Each barcode type has its own characteristics such as: defined symbology, characters or features that can be encoded into the symbol, and the barcode size. Depending on the barcode characteristics and the company requirements, a barcode type can be selected. Not to go into further details, I would emphasize on the UPC barcode systems and how it functions. The UPC barcodes can be found in retail stores or distribution centers. They consist of 95 evenly spaced columns that are either black or white. When a barcode scanner is scanning a barcode, it is checking whether each column is reflecting light or not. Opposite of what you might expect, each column that reflects no light is converted as “1” by the system, and each column that reflects lot of light is converted as “0”. So after scanning the barcode, the system is left with 95 digits of zeros and ones. These digits are grouped into 15 sections as it is shown in the figure below. The three guard sections are used to identify beginning, center, and the end of the barcode. The digit sequence of each of the left or right guard is “101”, which is represented by two black columns embracing a white column. The center guard's sequence is "01010", where each "0" is represented by a white column and each "1" is represented by a black column.

Figure 7: UPC barcode

We are left with 84 columns that are grouped into 12 sections of 7 digits each. Each section encodes a character, or in this case a number. Each number is identified based on the section's sequence of digits. Since a barcode scanner needs to know whether it is reading a barcode from left to right or from right to left, each section on the left contains an odd number of "1s", begins with "0", and ends with "1"; while each section on the right contains an even number of "1s", begins with "1", and ends with "0". For example, if a barcode scanner detects sections with even number of "1s" on its left, this means that the barcode is being scanned upside-down, and therefore the barcode scanner start decoding from its right. In this way, it is guaranteed that the system is decrypting the right information. Consequently, the sequence that is used to represent a specific number on the left side is different than the sequence list that is utilized to represent the same number on the right side. For example, the sequence "0011001" represents number "1" on the left side, while a dissimilar sequence "1100110" represents "1" on the right side. The sequence lists used to represent each number on each side and an example for number "9" are presented in the figure below.

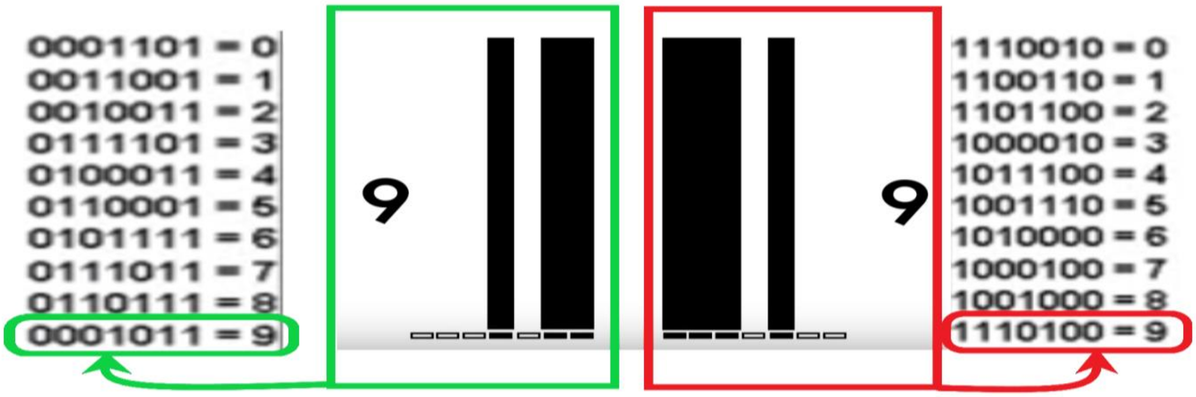

Figure 8: Sequence list for number's representation

Based on these sequences, a series of 12 numbers is identified. These numbers are similar to the numbers that are generally written below the barcode symbol as the figure below shows. Generally, the first number, “0” in our case, is used to identify the type of the product labelled. This number is outside the barcode symbol on the left. The next 5 numbers are used to recognize the manufacturer of the product; these 5 numbers are kwon as the company’s code. The second set of 5 numbers represent the product’s id number; these numbers are known as the product code. The last number, which is “7” in our case, is known as the modulo check character. This number is located outside the barcode symbol on the right, and is used by the barcode system to verify that the barcode has been scanned effectively and without error. These 12 numbers are then sent to a linked database, as discussed above, in order to catch more information about the labelled product.

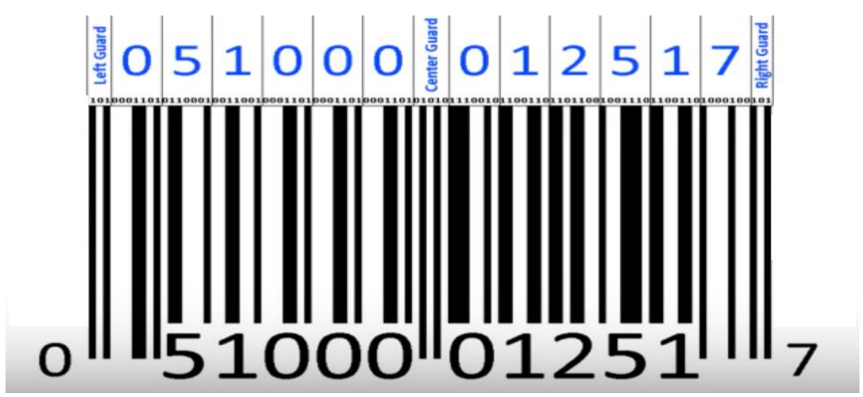

Figure 9: The identified numbers

2.1.3. Two-dimensional barcode

There are many types of two-dimensional barcodes such as: data matrix, QR code, PDF417, maxi code, and aztec. These two-dimensional barcodes could store a large amount of data such as: email addresses, names, product details, SMS messages, Dates, website URLs, and etc. Due to the complexity of the 2-D barcode symbol, the steps done by the barcode reader to decode the information are much more complicated than the steps done when decrypting a 1-D barcode. Therefore, a 2-D barcode scanner is more expensive than a 1-D barcode scanner. But, due to the new capability of smartphones to decode data stored, 2-D barcodes are becoming recognized and well-known. The quick response code, known as QR code, is being used in the industrial field.

Figure 10: QR code

2.1.4. Benefits of barcoding

Technical capabilities of the barcoding system have improved over the years. These improvements have led companies to implement barcoding systems in their supply chain. The simplicity of barcoding systems is a major reason for their success. Ink and paper are the only two constituents needed to produce barcodes. Continuous enhancements have resulted in cost reduction even of the barcode scanners which contribute to a major cost in the barcoding systems. So, implementing barcoding systems is not expensive compared to other technologies with the same purpose. Ease of use is as well a major reason for barcoding success. Implementing an appropriate software and hardware, simplifies data collection and processing.

Moreover, even expert operators when collecting data are subjected to roughly one error for every 300 records. Since accuracy in manufacturing industries is crucial, implementing barcoding systems is essential. Barcoding systems lead to higher speeds of operations without sacrificing accuracy. For example, Zebra technologies in their studies about barcoding systems demonstrate that accuracy can reach about 99.99%, or in other words, one error every one million records. Therefore, by simplifying data collection, accelerating operations, and reducing human errors companies can achieve higher profitability and productivity[9].

2.1.4.1. Barcoding in asset tracking

The use of barcoding systems to track manufacturing tools and equipment is common in many industries. Companies, before the implementation of barcoding systems, were not able to identify which operator is responsible if a tool disappeared. Since a special tool can cost up to 35000 dollars, companies had to pay a great amount of money for tools replenishment. By implementing barcoding systems, companies are capable to recognize and charge the operator responsible for tool loss. Consequently, the number of tools disappearing decrease and therefore, the companies can save a large amount of money. In addition, many products need to be packaged in special reusable containers for delivery. When these containers are not well managed, they may in most of the cases be lost in the customer facilities. Company needs to buy additional reusable containers to maintain a proficient supply chain if the containers are not returned. Therefore, this contributes to a major loss for the company. By using barcode technology, company is capable to decrease this loss, by scanning containers to record location details as they pass by the outbound gates[9].

2.1.4.2. Barcoding in receiving goods and stocktaking

Before accepting any delivery, operators must guarantee that the received goods meet the requirements. Goods' accepting process, without the use of barcoding systems, is time consuming. With the use of barcoding technology, operators at in the inbound gates scan each product's barcode by wireless barcode readers. Information decoded by the barcode readers are linked with a back end database. Information regarding the received products can therefore be checked by the receiving goods department. If the received products are compatible with the purchase order, operator will automatically be informed to confirm and finish the accepting process. After confirmation, forklift operators transport the received goods from the receiving area to the warehouse. Next, forklift operators scan the barcodes of the products as well as the barcode on the shelf in order to record the storage location of each product in the system. After checking the received goods' compatibility with the purchase order and defining the storage location of each product received, receiving process is completed efficiently. In the long term, due to some errors, the quantity of products on the shelfs will be different than the quantity registered in the system. So in many cases, stocktaking is an indispensable process done to correct any error. Without the use of barcoding systems, operators must find the location of the products which the company is willing to check. Next, operators must manually collect information about the quantity of the products. This information is then sent to the warehouse manager in order to correct the errors that may have occurred. This process is time consuming and may be subjected to human errors. With the use of barcoding systems in stocktaking, operators are informed about the location of the products. Operators only job is therefore to scan each product targeted. The information collected by the scanning process is automatically sent to the backend database. As a result, the warehouse management department can easily correct any error in the system. As a conclusion, barcoding systems help the warehouse management to save time and money, without sacrificing accuracy, in the receiving and stocktaking processes[10].

Figure 11: Stocktaking process using barcode technology

2.1.4.3. Barcoding in inventory management

The use of barcoding technologies in inventory management has led companies to perfectly manage their inventory levels. The real time data provided by the barcoding systems allow companies to take decisions based on existing, concrete, and exact information. Using barcode technologies, information about the location and quantity of each product in the warehouse can be directly retrieved. This allows companies to decrease the searching time, and to accurately identify when they will run out of goods. With these capabilities, companies are therefore able to employ just in time(JIT) practices. JIT practices mean that the companies make order for stock replenishment just when they identify a low stock level. This JIT management, as stock level is decreased, allow the companies to have more spaces available in the warehouse and to increase investments in other areas. So, implementing barcoding systems in inventory management lead to huge savings. For example, a baking company succeeded, one year after implementing barcode systems in the warehouse, to reduce the inventory management costs by 3 million dollars[9].

2.1.4.4. Barcoding in picking and shipping goods

In addition, barcoding systems increase the efficiency of picking and shipping processes. In the absence of barcoding technologies, when orders are released, operators must search for the requested products, count them, and update manually the stock levels. While in the presence of barcoding systems, operators are informed about the locations of the products requested. Operators just have to scan the barcodes on the requested products as well as the barcodes on the shelfs, and subsequently the stock levels on the system are automatically updated. Operators are then informed about the orders' sequence, as well as the products requested by each order. Consequently, operators can efficiently prepare each order and make it ready for shipping according to the sequence given. As a result, less operators are needed for these operations, and higher efficiency can be attained[10].

2.1.5. Conclusion

By implementing barcoding technologies, labor efficiency is increased and time needed for operations is decreased. As labor costs are significant in any warehouse, the use of barcoding systems to automate and speed up processes is inevitable. Around 80-90% of the best 500 companies in the world have implemented barcoding systems in their warehouses; a fact that shows the importance of barcodes. Some examples are presented in the following to show the benefits of barcoding. The United Postal Service(UPS) company claimed that 600 million US dollars were saved each year after implementing barcoding systems. General Motors company has magnificently reduced errors, such as mounting the incorrect parts, to 0%. Kimberly-Clark company has succeeded to reduce the distribution errors by 50% when using barcoding technologies[9].

2.2. Radio Frequency Identification

Automatic Identification and Data Capture (AIDC) group is a group of technologies that repeatedly distinguish objects, gather information about them, and enter that information legitimately into a database with practically zero human mediation. Radio frequency identification(RFID), one of this group of technologies, uses radio waves to achieve its job[11].

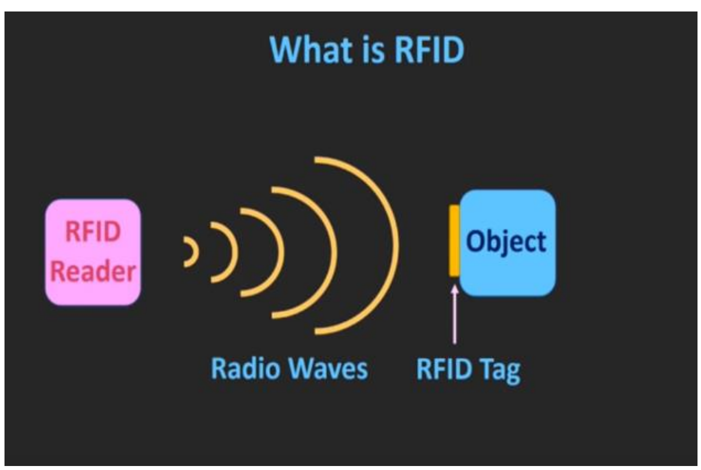

Figure 12: RFID radio waves being transmitted

The RFID system consists of three basic components. The first component is the RFID tag that will be attached to the object or the product. The RFID tag holds information about the object. The second component is the RFID reader or the RFID interrogator that will interact with the RFID tags. The last component is a backend system that decodes the information sent by the RFID tags. After the information has been decoded, it will be stored in a database[12].

2.2.1. Passive and active RFID tags and their differences

There are two main types of RFID tags: passive RFID tags and active RFID tags. They are different when talking about data storage, range, power source, size, cost, environmental constraints, life spam, tracking, and the way they function.

2.2.1.1. Characteristics

A passive RFID tag can store up to 128bytes of information, the tag can be seen within the range of 5 meters. The passive RFID tag has not a power source but instead it will use the energy coming from the radio waves transmitted by the RFID readers as will be discussed in the following. Since it has no battery, a passive RFID tag can serve up to 20 years, it costs only about 10 to 50 cents, and it can be installed easily even in harsh environments. While active RFID tag can store up to 128Kb of information, the tag can be seen within the range of 100+ meters. The active RFID tag has a battery as a source of energy therefore it can serve up to 5 years, it costs up to 20 dollars and more, and it cannot be installed easily in any environment[13] [14].

Figure 13: Size difference between passive and active tags

Moreover, when talking about items tracking or identifying location these two systems differ. A passive RFID system tells you if a RFID tag is in the reading field or not but does not tell you the exact location. This passive RFID system is nowadays being used with what is called a received signal strength indicator(RSSI). The RSSI does not tell you the exact location of the tag but it can inform you if the tag is getting nearer or further based on the signal strength received by the reader. In contrary, an active RFID system can be used along with real time location systems(RLTS) to detect the exact location of the tag based on triangulation. Moreover, an active ultra wideband(UWD) can state the exact location of the tag[15] [16].

2.2.1.2. Functioning mechanism

Talking about the difference in the way each system works. To begin we will briefly discuss the RFID system with a passive RFID tag. The RFID reader consists of three components: The RF signal generator, the receiver/signal detector, and the microcontroller. The RFID tag is formed by: the transponder, the rectifier circuit, the controller, and the memory.

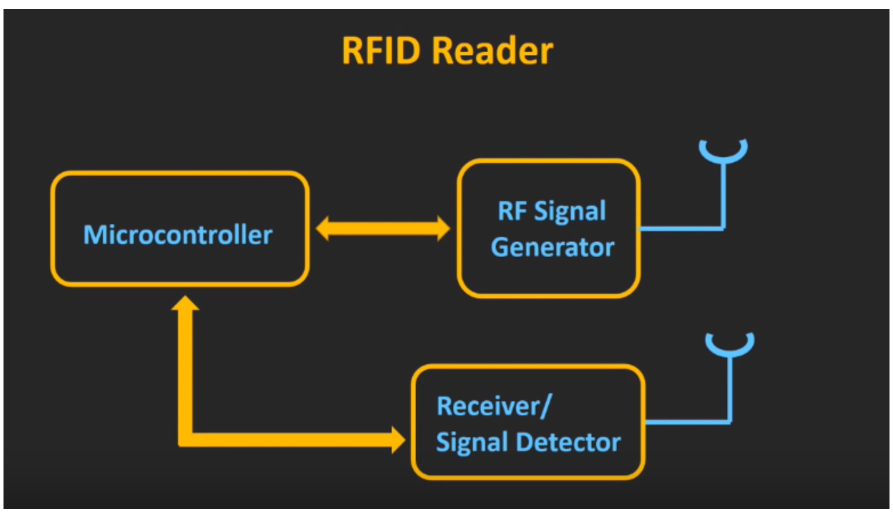

Figure 14: RFID reader components

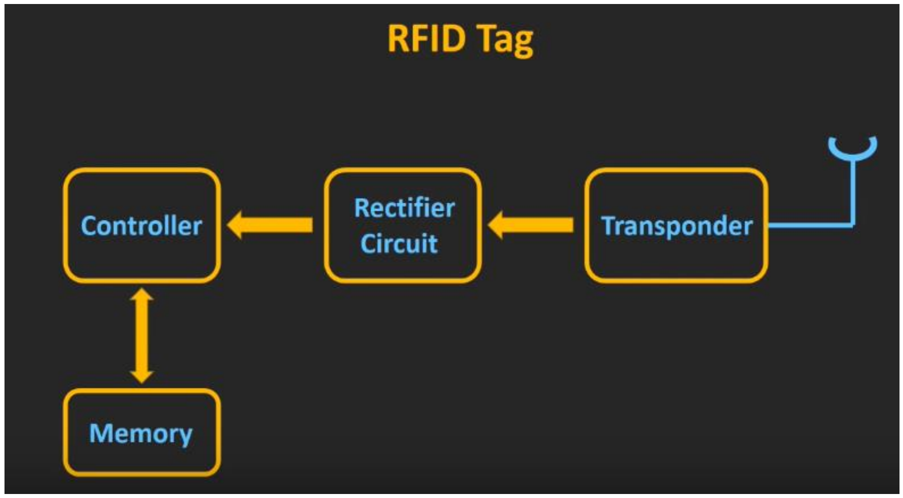

Figure 15: RFID tag components

The RFID reader transmits radio waves by the RF signal generator. Once the RFID tag is inside the electromagnetic zone, the transponder receives the radio waves. Since the passive RFID tag does not have any source of energy, it converts the radio waves into voltage through the rectifier circuit. This voltage will be used by the controller and to transmit feedback radio waves. These feedback radio waves transmitted by the RFID tag will be received by the receiver/signal detector of the RFID reader. In order to decode the information that has been sent by the RFID tag, the RFID reader has a microcontroller.

In contrast, while talking about active RFID systems we need to distinguish between two types of active RFID tags: transponder and beacon. Transponder tag wakes up once it receives the signal transmitted by the RFID reader. Using the battery imbedded, the transponder tag sends the tag information to the reader. The information detected will be decoded and sent to the database. Beacon tag does not wait to receive the RFID reader's signal, but the bacon tag on the contrary is continuously sending signals containing RFID tag's information. The rate by which the Beacon tag is transmitting signals will define the battery life. As expected, accuracy level is increased by increasing transmission rate. Once the beacon tag is in the reading zone, the RFID reader will detect the signals sent by the tag. The information detected will be decoded and sent to the database. Therefore, as expected, transponder tag is more efficient than Beacon tag since it conserves its battery when it is not inside the reading range[12] [17].

2.2.1.3. Conclusion

Generally speaking, the advantages of a passive RFID tag are: it is small, it is cheap, it is more flexible, and it can stand a lifetime. While the advantages of an active RFID tag are: it can be detected from really long range and it can be partnered with other technologies (humidity sensor, temperature sensor, etc.) and so its ability is increased[17].

2.2.2. RFID classes

Another way to distinguish between tags is by their capabilities to read and write data. We can subdivide RFID tags into five different classes:

Read-only tag is classified under the class 0. This tag holds an id number that is inscribed just once during manufacturing. The information in the memory cannot be updated. Write-once read-many tag is classified under the class 1. This tag is manufactured without any data in the memory. The user is therefore capable to introduce information in its memory just once. This tag is also called simple identifier. Read-write tag is classified under the class 2. This type of tag is the most flexible since it allows the user to read and write information into the memory. This tag's memory space is larger compared to the above tags' classes. A read-write tag installed along with a sensor will be classified under the class 3. The sensor records data such as temperature, humidity, motion, or pressure and saves the recordings into the tag memory. Since sensor recordings may be taken outside the reading range of the RFID reader, which is the only source of power for the RFID tag in a passive RFID system, the RFID tag must be active. A read-write tag installed along with a transmitter will be classified under the class 4. In the presence of a transmitter, the RFID tag will be able to communicate with other RFID tags and devices. Therefore, this type of RFID tag must be active with its own power supply. The different types of RFID tags are shown in the figure 5. In addition, RFID readers can also be classified: read-only or read-write readers. Read-only RFID reader, as the name announces, can only read information from the RFID tag. While the read-write RFID reader does not only read information from the RFID tag, but also can write information into the tag memory[18].

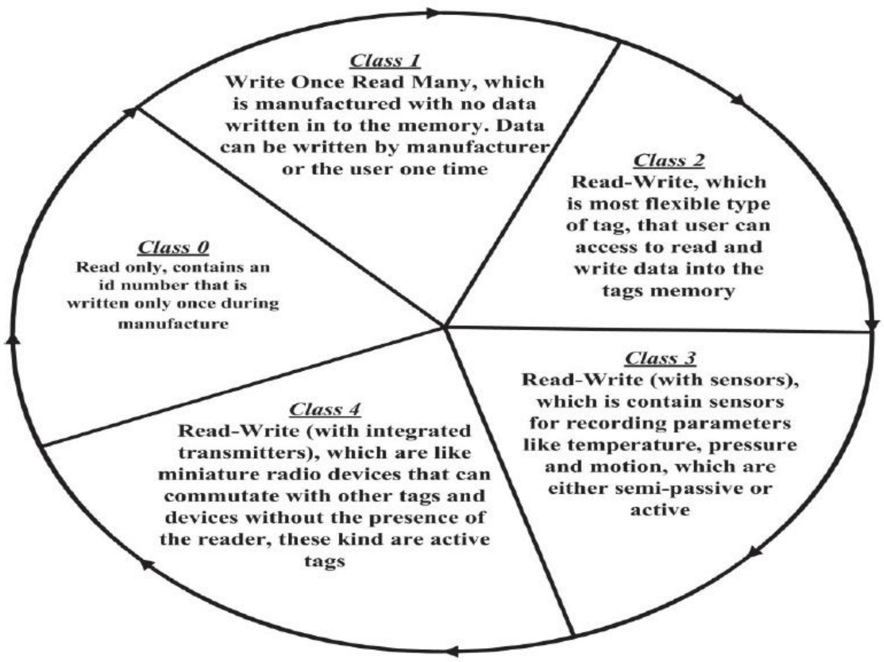

Figure 16: Classification of RFID tags

2.2.3. Influence of the frequency on the wave

Electromagnetic waves have recognizing qualities that impact how they propagate through vacuums and through various kinds of materials. When talking about RFID systems, frequency of the wave is the most significant. Figure 6 shows a standard pattern of a radio wave. The wavelength, λ, is the distance between two peaks of the wave. The recurrence of a wave is the number of peaks that pass a stationary point in a given timeframe.

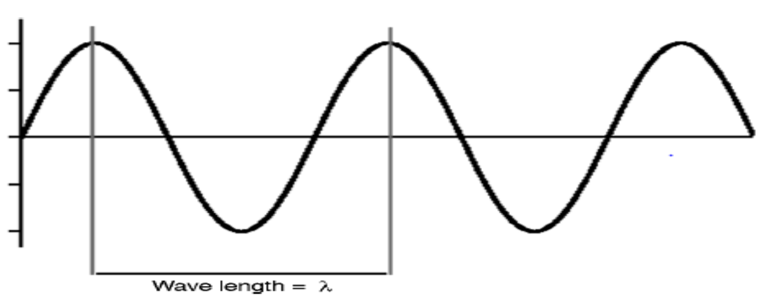

Figure 17: Radio wave pattern

For example, 20.000 wave peaks pass through a stationary point in one second with a wave frequency of 20 KHz. Wavelength is then calculated by the following equation: $\lambda = c/f$. Where 'c' is the speed of light which is around 300.000.000 meters per second, and 'f' is the wave frequency. The table below illustrates the abbreviations used for frequency's magnitude.

Abbreviation	Cycles per Second
1 Hz (hertz)	1
1 kHz (kilohertz)	1,000
1 MHz (megahertz)	1,000,000
1 GHz (gigahertz)	1,000,000,000

Table 2: Abbreviations used

Radio waves transmitted at different frequencies will present different characteristics. There are three significant characteristics of a radio wave when talking about RFID systems: data rate, permittivity, and distance.

2.2.3.1. Data rate

Data rate is the amount of information that a radio wave can hold. A single portion of data can be encrypted between two peaks of the wave length. When higher frequency is used, higher number of peaks will be sent in the same timeframe than would happen with lower frequency. The reader will be able to detect more wave peaks, and therefore the reader will be able to acquire more information. So, as expected, data rate increases with the increase of frequency. For example, where tags mounted on products are moving by a conveyor belt at high speeds, high frequency is needed in order for the tag to send all the information needed by the reader before quitting the reading range.

2.2.3.2. Permittivity

When implementing RFID systems, designers must take into consideration the material in the close vicinity of the tags. The density and the atomic structure of each material are responsible for the material absorption of a certain frequency. This absorption will weaken the propagation of the wave through the material. RFID systems confront signal weakening difficulties when placed in the proximity of material that absorb radio frequency energy. RFID systems that work with extremely high frequency for example should not be implemented in environments that contain water since the extremely high frequency are not able to propagate through water. And therefore, the energy transmitted by the wave will not reach its destination, but in contrast it will be transferred to the water.

2.2.3.3. Reading range

The quantity of energy that can be taken from an electromagnetic wave is proportional to the frequency used. Higher energy absorption capabilities mean higher read ranges. Therefore, read range is directly proportional to the frequency in use[19].

2.2.3.4. Conclusion

As a general, a low frequency system has low data rate, short read range, but it is more efficient for reading next to unfriendly RFID environments. While in contrast, a high frequency system has high data rate, long read range, but it has limited capabilities in reading next to unfriendly RFID environments[17].

2.2.4. Frequency bands

Frequency spectrum in his turn has its own classification. The classes or the categories with their names are shown in the table below.

	Designation	Frequency
ELF	Extremely low frequency	3 Hz to 29 Hz
SLF	Super low frequency	30 Hz to 299 Hz
ULF	Ultralow frequency	300 Hz to 2999 Hz
VLF	Very low frequency	3 kHz to 29 kHz
LF	Low frequency	30 kHz to 299 kHz
MF	Medium frequency	300 kHz to 2999 kHz
HF	High frequency	3 MHz to 29 MHz
VHF	Very high frequency	30 MHz to 299 MHz
UHF	Ultrahigh frequency	300 MHz to 2999 MHz
SHF	Super high frequency	3 GHz to 29 GHz
EHF	Extremely high frequency	30 GHz to 299 GHz

Table 3: Classification of the frequency spectrum

RFID systems use only three categories out of the categories presented in figure 8. The categories used are: low frequency(LF), high frequency(HF), and ultrahigh frequency(UHF). These categories have respectively the following frequency ranges: 30 KHz to 299 KHz, 3 MHz to 29 MHz, and 300MHz to 2999 MHz. The pattern difference between these categories is shown in figure 9.

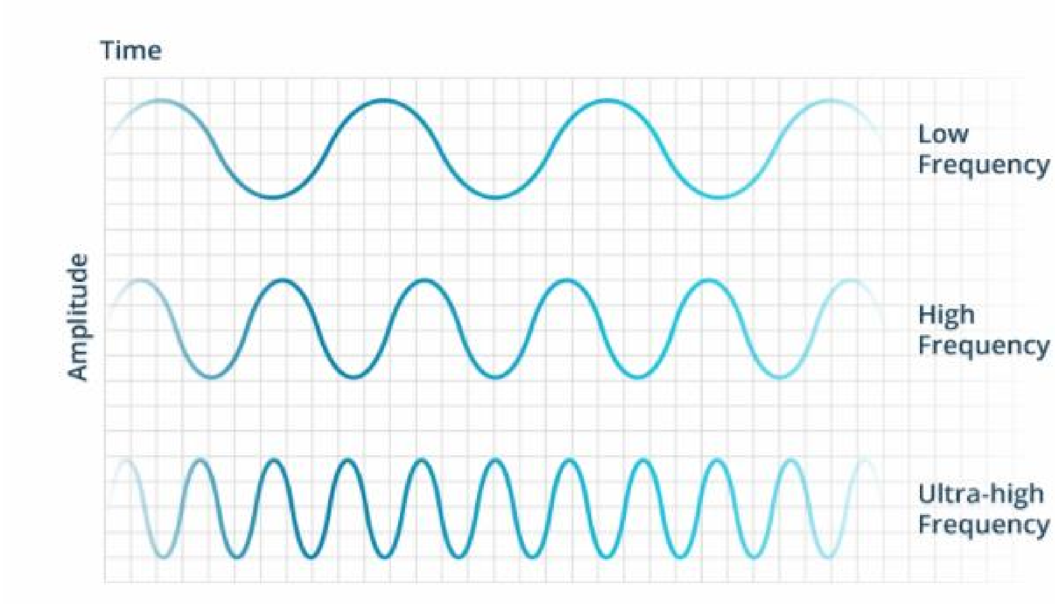

Figure 18: Pattern difference of 3 different frequency categories

Passive RFID tags do not all work using the same frequency. Passive RFID tags can operate with three main frequencies or ranges: 125-134 KHz, 13.56 MHz, and 865-960 MHz. These frequencies or ranges belong respectively to the low frequency, high frequency, or ultrahigh frequency range. Passive RFID tags that use 125-134 KHz frequency range can be detected within 1 to 10 centimeters. While for the ones that use 13.56 MHz frequency have a reading range of about 1 meter. Finally, RFID tags that work with 865-960 MHz frequency range have the greatest range that can reach up to 5-6 meters when talking about passive tags, but they are the most sensitive to unfriendly RFID environments as discussed above. Active RFID tags operate with two main frequencies that belong to the ultrahigh frequency category: 433 MHZ and 915 MHz. These systems have a reading range that can be more than 100 meters. Companies prefer to choose systems that operate with 433 MHz frequency since these systems have more capability to work in an unfriendly RFID environments[17] [19].

2.2.5. Benefits of RFID

Independent of whether we are using active or passive RFID systems or which frequency is used, we will discuss some of the applications of the RFID systems.

2.2.5.1. RFID in manufacturing

Manufacturing can be divided into four main operations: receiving the raw materials, production of products, storage, and delivery of these products. Figure 10 shows the different main operations of a manufacturing plant.

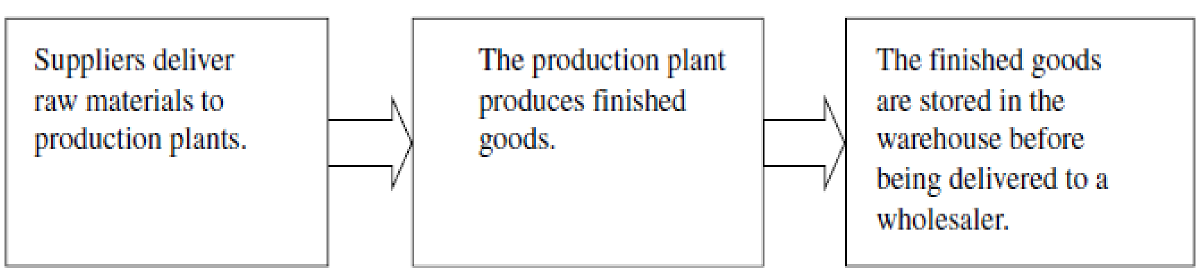

Figure 19: Operations of a manufacturing plant

2.2.5.1.1. RFID in inflow of raw materials

When a delivery arrives to a plant, its content must be checked and verified. Operators must confirm the status, price, and quantity of raw materials. This task is time-consuming and is exposed to human error. This task can be worse if the delivery contains multiple types of raw materials with different quantities. RFID system facilitates this task and makes the operation more efficient. As a pallet arrives at the inbound gate, the RFID reader installed detects information sent by the RFID tag installed on that pallet. These information contains: status, price, and quantity of each raw material placed on the pallet. This ability permits instant verification of all the contents of the delivery and eliminates the time consuming task that can be subjected to errors. The information is then sent to the enterprise resource planning(ERP) or warehouse management system(WMS). Utilizing this information, forklift operators can be instantaneously instructed to transport the pallets to their exact locations. So the implementation of RFID increases the material acceptance efficiency, eliminates human error, and rises material handling equipment productivity[19].

Figure 20: RFID reader receiving the information sent by the RFID tags at the inbound gate

2.2.5.1.2. RFID in production line

RFID system can be used in manufacturing processes to recognize the item that is being assembled or worked as well as the parts that are to be mounted into the item. Each item inside the manufacturing processes is equipped by a RFID tag. RFID tag contains information about the item. During the process, RFID reader installed at each station detects the information sent by the RFID tag to present what operations should be done, what parts need to be mounted into the item, and whether the parts that are introduced are the right parts. Before the item leaves the station, RFID reader updates the information on the tag memory and a new item status is set. Therefore, not surprisingly, RFID system plays an enormous role in maintaining the quality of the final result particularly when the item is greatly customizable. Consequently, this RFID system in manufacturing processes can shorten the time for checking or identification of items and parts. In addition, this system decreases the errors in the processes and thus reduces the rework costs. Ford Motor for example has been using this system in their companies in Cuautitlan in Mexico as well as in United States for years. Each car's chassis is equipped with an RFID tag. As RFID tag passes through one station to the next, RFID readers read the chassis' requests automatically and thus, installation is done without wasting time and error-free. In addition, not only the products can be tagged but also the production machines. A tag installed on a production machine can store information about its maintenance history, involved operators and parts substituted. Engineers can use a handheld RFID reader to collect this information. Maintenance schedule is therefore directly set. In this way, RFID system helps in decreasing the unexpected machines' shut offs and thus, increases efficiency and productivity[20].

2.2.5.1.3. RFID in the warehouse and delivery processes

The warehouse basic activities are described as follows: receive, store, retrieve the products, and finally prepare any delivery requested. Decreasing the movement costs of products, increasing the space utilization, keeping track of all the products within the warehouse, and preparing deliveries requested in time are the essential tasks for an efficient warehouse. These tasks are labor intensive and contribute to the major operating costs in a warehouse. RFID systems can automate lots of these tasks and thus, decreasing the number of labors. By decreasing the number of workers, RFID system can contribute in a major cost reduction[19].

In todays' operations, every available space in the warehouse must be studied and utilized in a perfect way so that warehouse operators can retrieve, pack, and deliver as fast as possible. Companies can gain competitive advantage implementing RFID system in their warehouse operations. RFID system can enable companies to deliver fast and cost-efficiently through facilitating locating items. This is done by tracking the items movements. As the finished products are moved through the warehouse, RFID readers are continuously detecting information, sent by the RFID tags installed on the products. This information contains the environmental requirement of each product. For example, high value products must be stored in a secured place and harmful products must be placed in a designed location. All this information collected by the RFID readers are continuously processed and sent to the warehouse management system(WMS). If any product is not in the exact place, the system can alert the warehouse manager for corrective actions. Therefore, once a delivery is requested, the warehouse manager can easily find the exact location of the requested products and prepare the delivery. As the delivery is being transmitted from the outbound gates, the reader detects information from the RFID tags to ensure that the right products are being sent in the right order. Inventory level will be updated automatically for precise inventory control[21].

Figure 21: Preparing the delivery

The RFID system used in a warehouse increases inventory visibility. Precise information of the quantity of stock at every area in the inventory network in real-time will allow companies to run a significantly more proficient supply chain. This visibility will allow the company to reduce its safety stocks while conserving or improving customer satisfaction levels (figure is shown below). RFID system in addition can improve inventory accuracy. Inventory accuracy is the discrepancies between inventory that is physically in the warehouse and the inventory recorded in the computer. Usually, the inventory recorded in the computer is larger than the inventory in the warehouse. Using RFID system this difference is mitigated and therefore out-of-stock(OOS) situations are prevented[20].

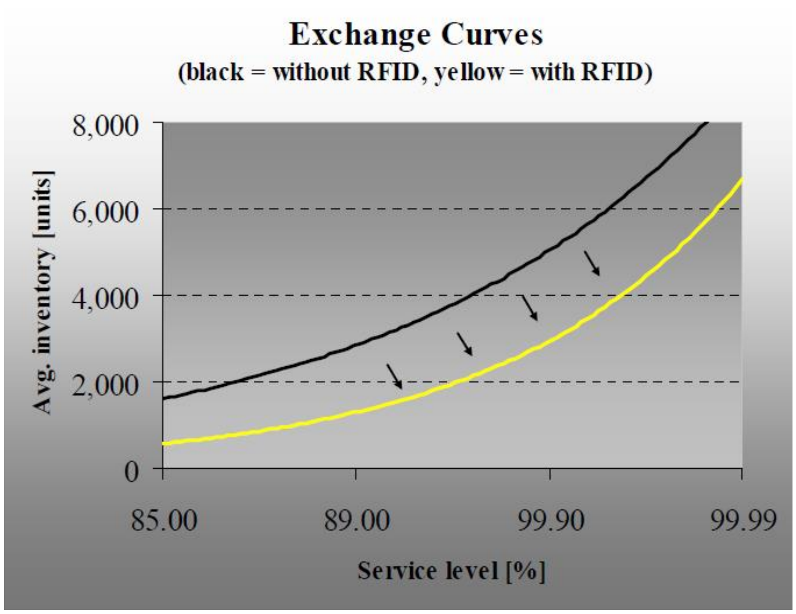

Figure 22: Average inventory versus service level with and without RFID

Beyond products storage, RFID system can be utilized for optimal assets management and utilization. RFID readers installed on the ceiling of the warehouse are continuously detecting information from RFID tags installed on forklifts or on any vehicle. This information may contain speed, location, and the idle time of the vehicle. Therefore, the warehouse manager can easily identify inefficiencies and search for optimized solutions: the warehouse manager can assign a different path for a forklift for time savings or can assign an additional task for vehicles with high idle time. In addition, managers can be warned when a vehicle is being over-used and therefore a predictive maintenance can be done[21].

Figure 23: Forklift information

Moreover, analysis from the Industrial Truck Association(ITA) and the US Occupational Health and Safety Administration finds that there were around 900.000 forklifts in the US only in 2015. These forklifts contributed to several accidents, around 100.000 per year, that led to around 95.000 injuries. Multiplying these numbers on a global scale shows the importance of refining safety in the warehouse. Connecting the workforce and forklifts improves worker's health and safety. This is done by installing RFID system, radar, sensors, and cameras on each forklift. Each forklift is therefore able to interconnect with other forklifts and workers, and consequently is able to be programmed in order to automatically slow when any forklift or worker is around. In addition, forklift will be able to scan the surroundings in order to prevent collision with any hidden objects[21].

2.2.5.2. RFID in transportation

2.2.5.2.1. RFID in electronic toll collection

Electronic toll collection(ETC) is one of the best uses of RFID innovation. ETC is a transport solution that permits the manual in-path toll collection procedure to be automated with the goal that drivers do not have to stop and pay money at the gate. In an electronic toll collection application, each vehicle is equipped with a RFID tag. RFID reader is mounted at the tollgate. When a vehicle passes through the tollgate, the RFID tag and the RFID reader communicate. If the information sent by the RFID tag are valid, payment is spontaneously issued. In the majority of the cases, there is more than one reader; each tollgate lane has its own RFID reader. So, RFID readers are programmed and synchronized in a way to efficiently detect information sent. Due to the ETC technology, logistics providers are able to avoid traffic congestion and increase passage speed through the tollgate. Therefore, ETC technology is a convenient way for the logistics providers to accelerate their transportations[19].

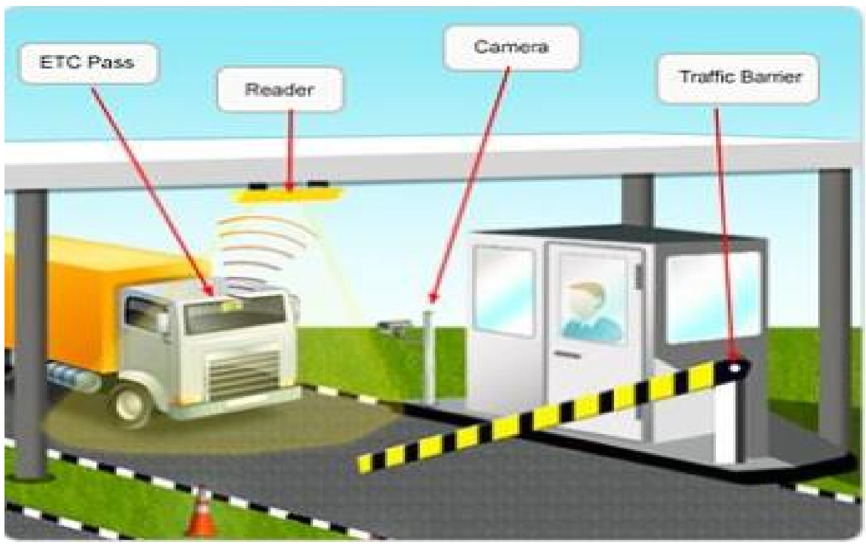

Figure 24: Automatic toll collection through RFID

2.2.5.2.2. RFID in intelligent transportation

RFID readers can be installed all along the routes. When a vehicle equipped by a RFID tag passes by a RFID reader, information about the vehicle can be detected. Therefore, the identity of each vehicle passing by a RFID reader is spotted, location of the vehicle is identified, and the route that the vehicle has traveled is detected. Utilizing RFID innovation, exact information of real traffic flowing through a specific street or highway at any timeframe can be gathered and related. By analyzing this data, precious information about traffic condition can be provided. As a result, plans to avoid traffic jam are easily realizable and achievable. Logistics providers use this information to optimize the routes taken by their transport trucks. So, transportation is speeded up and customers are more thrilled. Therefore, it can be said that RFID technology, with no doubts, helps logistics providers to increase their transportation efficiency[19].

2.2.5.2.3. RFID in counterfeit protection and security

Fake goods are not original, but rather have been made to appear precisely like original ones so as to trick people. So, counterfeiting is a major threat in any business. Companies are always searching for solutions to tackle the counterfeit. Using RFID technology in the supply chain can ensure a great counterfeit protection and security. RFID readers are installed at each corporation in the supply chain, from the manufacturer to the final customer. Each product is equipped with a RFID tag. As a product is moving across these corporations, its tag is detected. An original product will have therefore a record of RFID tag reads that verifies its progress from the manufacturer to the final customer. While a non-original product, inserted at some point in the supply chain, will have an improper record with missing RFID tag reads. Using this approach, called e-pedigree, it is possible to differentiate between counterfeit and authentic products. Since pharmaceuticals are high value products and are easy to falsify, many pharmaceuticals companies are currently using the e-pedigree approach for counterfeit protection. For example, Pfizer is a pharmaceuticals company that is using this approach to attain a secure supply chain[20].

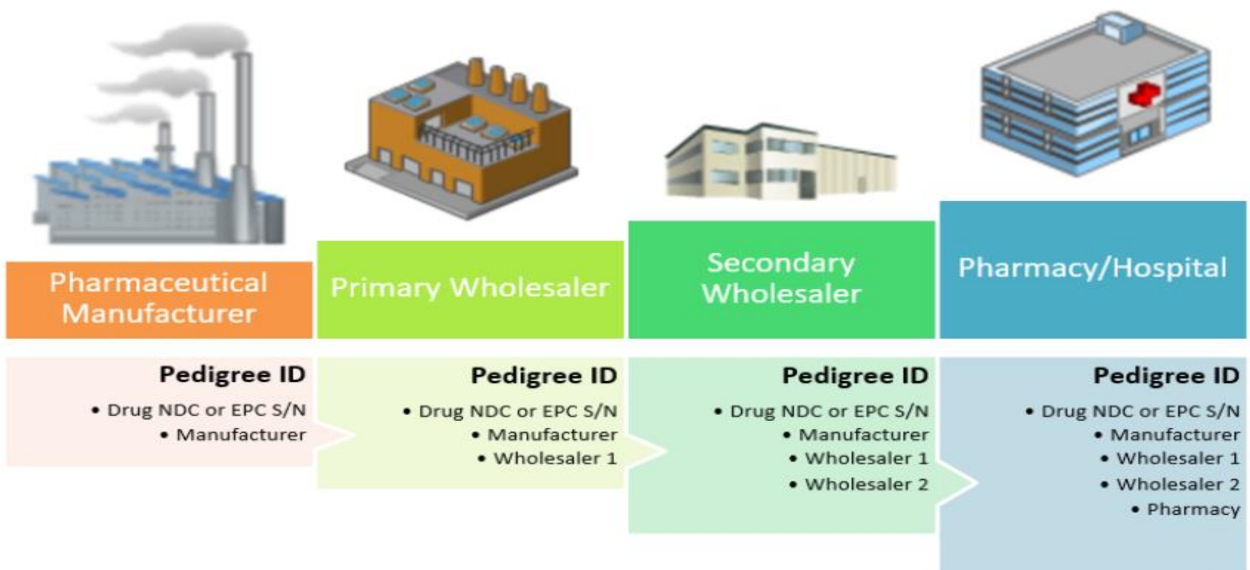

Figure 25: RFID record evolution across the supply chain

2.2.5.2.4. RFID in food industry

RFID technology has improved the food industry. The retailers' approach for replenishing the sales floor has upgraded. Since many perishable products in the food industry must be transported in a cold environment, tracking the temperature from the packaging process to the arrival at the store is important. RFID tag, installed on each product a with temperature sensor, is capable to record the temperature history during the transportation. Upon arrival of the products to the retail store, the retailer uses theses records to decide on cut rate and on adjusting the sequence of replenishing the sales floor. Since products are subjected to different temperature histories, and thus have different expected shelf lives, it is not anymore optimal to restock the sales floor based on "first-in/first-out" approach. But rather, it is more convenient to replenish using "lowest shelf life first" approach. Using RFID technology, retailers are expected to cut their spoilage losses in half[20].

2.3. Global Positioning system

GPS or global positioning system is a navigational system that uses satellite signals to determine a receiver's location on the globe. The GPS system is constituted with three different segments: the space segment, the control segment, and the user segment. The appropriate activity of each of these segments guarantees an exact and reliable operation of the whole system.

2.3.1. GPS segments

The space segment is formed by 32 active satellites orbiting around 13,000 miles above the earth. They are arranged in 6 different orbits. From the 32 active satellites, 24 are the core satellites while the reaming 8 are used for emergency replacements. Each 12 hours a satellite is set to traverse its orbit. With a successful satellites constellation, a receiver on the ground can see at least 4 satellites at a time. A main control station in USA, along with numerous control and monitoring stations around the world make up the control segment. These stations control and monitor the activity of the satellites. The control segment is in charge of spotting satellites that are not transmitting signals properly or satellites that are not in their proper location. In the case where a satellite is not broadcasting properly or is not in its proper location, the control segment sends to this satellite the information needed for a convenient operation. This information may contain the position where the satellite must be located or the data that must be transmitted. The user segment consists of all the receivers that are getting satellites' signals. These receivers are passive, which means that they do not transmit any signal to the satellites, but rather they only receive signals. This is the reason why an unlimited number of receivers can efficiently work at the same time[22].

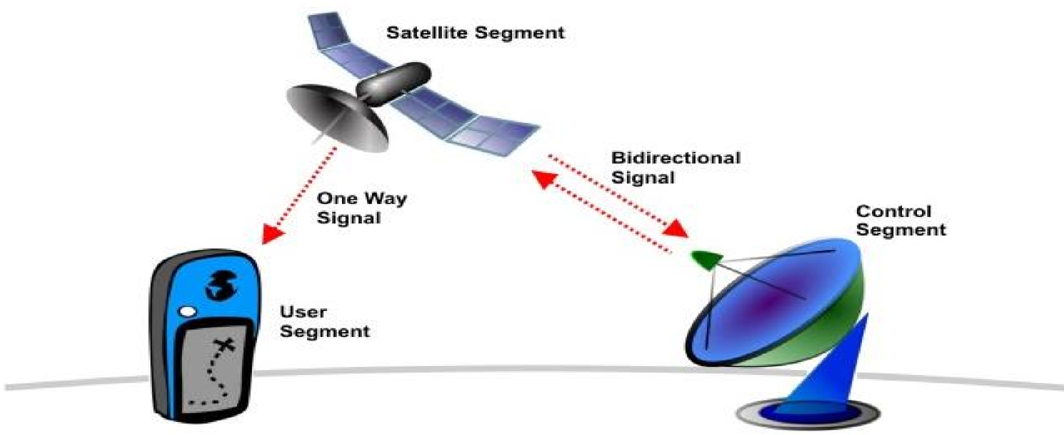

Figure 26: A graphical representation of the different segments of a GPS

2.3.2. Functioning mechanism

The general idea behind global positioning system is the use of satellites to locate any receiver on earth. Satellites are continuously sending radio waves that will be detected by receivers on earth. The distance from a satellite is measured based on the time taken by a radio wave to reach the receiver. Multiplying the time needed by the speed of light, speed at which radio waves propagate, the receiver distance from the satellite is obtained. The receiver may be located at any place on the globe. When the receiver distance from one satellite is computed, the possible positions of the receiver are narrowed to somewhere on the surface of a sphere with radius equals the distance computed.

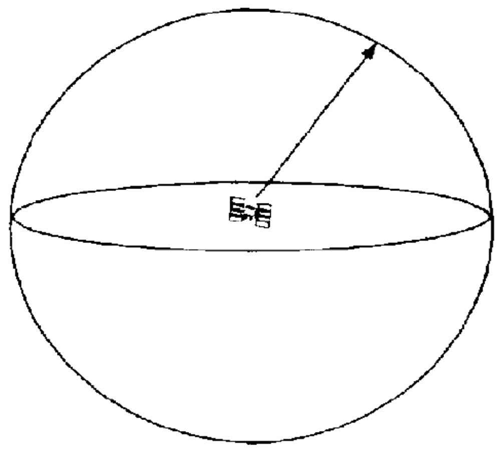

Figure 27: Receiver is somewhere on the surface of this sphere

The receiver distance from a second satellite is subsequently computed. Consequently, the receiver is not only somewhere on the surface of the first sphere, but also on the surface of the second sphere. The possible positions of the receiver are narrowed to a circle. This circle is the intersection of the two spheres.

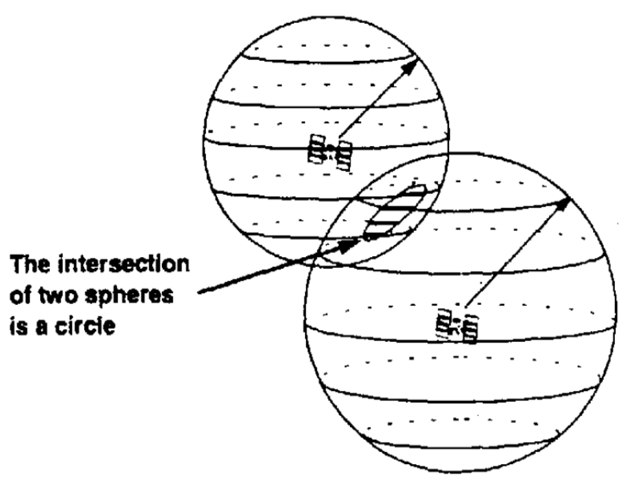

Figure 28: Receiver is somewhere on this circle

When the receiver distance from a third satellite is computed, the possible positions of the receiver are narrowed to two points. These two points, as expected, are the intersection of the three spheres. To detect which of these points is our exact location, the receiver distance from a fourth satellite must be computed. But in most of the cases, one of these points is either underground or out in space and for that reason it can be rejected. Therefore, the exact location of a receiver on the earth is detected using the global positioning system[23].

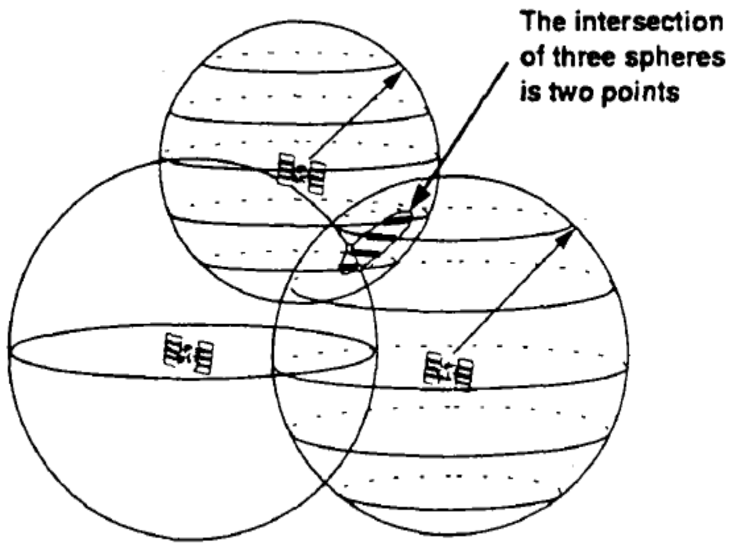

Figure 29: The two possible locations of the receiver

2.3.3. Benefits of GPS

GPS technology is being extremely used nowadays due to its numerous benefits. GPS technology helps companies to improve profitability, productivity, efficiency, and accuracy.

GPS technology supports companies to efficiently monitor their drivers. Using GPS technology, companies have the capability to score performance of each driver based on: braking, acceleration, speeding, and mileage. Companies can inspect every day report cards to recognize undesired behaviors and consequentially distinguish drivers that need training. Companies can teach chauffeurs to drive more consciously for a better fuel efficiency. As fuel is a major cost in transportation, fuel savings is substantial. For instance, drivers can be coached to decrease unnecessary braking and accelerating to increase fuel efficiency. Drivers can as well be coached to drive at a certain speed range for a maximum fuel efficiency. In addition, the increased visibility provided by the GPS technology helps companies to detect doubtful usage of vehicles.

When drivers know that they are being supervised, the unauthorized usage of the vehicles for side jobs or unproductive personal use will certainly drop. Therefore, productivity is highly increased.

Companies using GPS technology have the capability to manage and monitor their entire fleet in real time. This makes the chance to guide all drivers along the most exact routes, while staying away from streets with overwhelming driving traffic or any regions with current occasions that may block the streets. Shorter travel distance and less required time lead to minor transportation expenses. When GPS technology is used along with data analytics, it can recognize which driver is best suited for a given road condition. Therefore, higher operational efficiency can be reached. In addition, punctuality of the deliveries is paramount especially in a market full of competitors. GPS technology supports a company to deliver on time and thus, gain competitive advantage over its competitors. Customer satisfaction is consequently increased and higher profitability can be achieved[24].

3. Connectivity and Data processing

The collected data needs to be processed, analyzed and stored in order to deliver values and services to the user. Data processing is generally done by centralized cloud computers. Accordingly, data needs to be transported from the sensors to the cloud computers. There are plenty of different options for this transportation, which will be discussed after talking about data processing.

3.1. Data processing

Regardless of the fact that cloud computing has various advantages, it is insufficient to meet the requirements of many “internet of things” applications. To solve the problem, some data processing resources are brought to the edge of the network. This concept is called fog computing or edge computing. Smart gateways, which act as links between sensors and the cloud, are employed to realize fog or edge computing. So, the sensors data are sent to the gateways, gateways preprocess the data, gateways send the necessary information to the cloud servers, and finally the cloud servers process and analyze the data to provide inferences to the user [1] [3].

3.1.1. Cloud computing

The cloud is made by interconnected powerful servers and computers that execute services for businesses and for individuals. Back in the days, cloud computers were tremendously expensive and large. So, companies used to rent cloud services from cloud computing providers instead of buying these expensive servers. Microprocessor technology has successfully helped in reducing cost and size of these computing servers. Consequently, companies were able to buy and implement these powerful cloud servers. But, as the internet connection speed has increased, companies are once again renting cloud services from cloud computing providers instead of possessing cloud servers, which need a lot of maintenance. Nowadays, businesses are renting cloud services from one of the largest cloud computing providers: Microsoft, Amazon, or

Google. This can save a huge amount of money because companies only need to pay when they use the cloud services[25].

3.1.1.1. Benefits of cloud computing for IoT

- Processing capabilities: Cloud servers and computers offer unlimited processing abilities.
- Storage capacities: Cloud servers and computers offer limitless storage space. This feature will permit the increasing number of IoT devices to send their information without the risk of storage space shortage.
- Reduced costs: Companies pay to the cloud computing providers only when they use the cloud services. This cost is significantly less than the cost of the computing servers and their continuous maintenance.

3.1.1.2. Drawbacks of cloud computing for IoT

- Security and privacy: Companies private data are sent through universally connected channels. So, not surprisingly, the system is susceptible to cyberattacks or data loss.
- High latency: Transmitting data to the cloud computers and getting back replies takes time. So, applications where immediate responses are required cloud computing is not the best solution.
- Potential crashes: If connection is interrupted in this internet-based system or if a cloud server breaks, the IoT application will not work anymore.
- Battery life: Communication between smart devices and cloud computers consume a great amount of energy. So, smart devices, which are power constrained, will not have to capability to efficiently communicate with the cloud computers[26].

3.1.2. Fog computing

To act against the drawbacks of the cloud computing, some data processing resources are brought to the edge of the network. This model is named fog computing or edge computing. By applying fog computing, data will not be required to pass all along the network to be processed by the cloud computers, but instead some data will be processed in the smart gateways. Smart gateways are mediator between IoT devices and remote cloud servers. Smart gateways or fog nodes receive the sensors data, decide which information must be preprocessed and which information must be sent to the cloud for processing. In this way fog computing aids cloud computing to be more efficient in data storage, processing, and analysis. Therefore, it must be understood that fog computing does not replace cloud computing but rather, fog computing complements cloud computing[26].

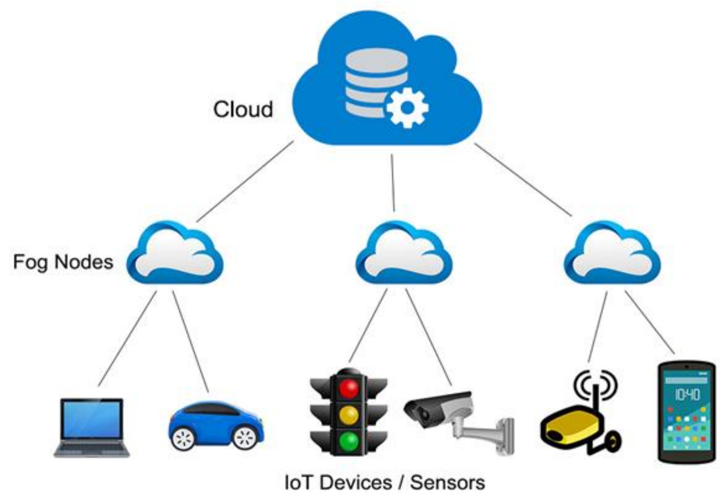

Figure 30: Fog computing architecture

3.1.2.1. Benefits of fog computing for IoT

- Low latency: Some data will be processed in the fog nodes, that are physically closer to IoT devices, which results in lower latency and immediate responses.
- Power efficiency: IoT devices will not consume a huge amount of power while transmitting information because fog nodes are physically closer than cloud servers.
- Impossible to lose connection: Numerous smart gateways can be implemented in different geographical areas. Therefore, multiple interconnected channels can be attained and consequently it is impossible to lose connection.
- High security: Information travels shorter distance in a complex distributed network. Therefore, a higher security can be reached.
- User satisfaction: Immediate responses with no downtimes improve user satisfaction.

3.1.2.2. Drawbacks of fog computing for IoT

- Complicated system: Data is processed and stored not only in the cloud servers but in the fog nodes as well.
- Additional expenses: Companies need to buy and implement smart gateways or fog nodes which results in higher expenses.
- Limited scalability: Data processing capabilities and storage space are limited[26].

3.1.3. Comparison between Fog computing and Cloud computing

	Cloud	Fog
Architecture	Centralized	Distributed
Communication with devices	From a distance	Directly from the edge
Data processing	Far from the source of information	Close to the source of information
Computing capabilities	Higher	Lower
Number of nodes	Few	Very large
Analysis	Long-term	Short-term
Latency	High	Low
Connectivity	Internet	Various protocols and standards
Security	Lower	Higher

Table 4: Comparison between Fog computing and Cloud computing

- A centralized cloud architecture comprises large data centers located far from IoT devices. While a decentralized fog architecture consists of numerous distributed fog nodes located as close as possible to IoT devices.
- Due to its centralized architecture, cloud communicates with IoT devices from a long distance. While the decentralized fog architecture permits the distributed fog nodes to communicate with IoT devices from shorter distance.

- In cloud computing, data processing is done in faraway data centers. While in fog computing, data processing is done in the distributed fog nodes or smart gateways.
- Processing and storage capabilities of the cloud are more powerful than those of the fog.
- The cloud comprises few large data centers. Fog consists of numerous distributed fog nodes.
- Fog computing is used to make short-term analysis to ensure immediate response which is fundamental for applications where time is crucial. While cloud computing is used to make deep long-term analysis.
- By using fog computing, data will not be requested to pass all along the network to be processed by the cloud servers, but instead some data will be processed in the fog nodes which results in lower latency.
- When cloud is used by itself, IoT devices will communicate with the cloud servers through the internet. But, when fog is implemented along with cloud, IoT devices will send their information to the fog nodes or smart gateways using different protocols, and then information is sent by the fog nodes to the cloud servers through the internet.
- Fog provides higher security than the cloud due to its distributed decentralized infrastructure[26].

3.2. Connectivity

The data are sent to the gateways, gateways preprocess the data, gateways send the necessary information to the cloud servers, and finally the cloud servers process and analyze the data to provide inferences to the user. In this part of the thesis, we will discuss how data are transported from IoT devices to the smart gateways. The data transmission from the smart gateways to the cloud servers, and from the cloud servers to the users is done through the internet. To connect IoT devices to the smart gateways, there are numerous number of options. The best connectivity option is the one which has vast range, is able to transmit lots of data, and consumes very little power. Unfortunately, this perfect connectivity type does not exist. Each available connectivity type is a tradeoff between range, power consumption, and size of data that can be transmitted or bandwidth. This permits to divide the several available connectivity types into three major classes. The first class of connectivity is characterized by high range, high power consumption, and high bandwidth. To send a great amount of data over a long distance, it needs high power. Think of your smartphone, which has the ability to send and receive a huge amount of data over long distances, but power is highly consumed. This is the reason why you need to charge your smartphone on a daily basis. Connectivity types in this class include satellite and cellular. The second class of connectivity is characterized by low range, low power consumption, and high bandwidth. To decrease the power consumed while sending a large amount of data, range must be decreased. Connectivity types in this class include Bluetooth and Wi-Fi. The third and last class of connectivity is characterized by high range, low power consumption, and low bandwidth. To improve the range while consuming a small amount of power, the amount of information that you are transmitting must be decreased. Connectivity types in this class are named Low-Power Wide-Area Networks (LPWANs). LPWANs transmit extremely small amounts of information. This allows them to have low power consumption along with a high range. For instance, a temperature sensor used in a farm does not need to transmit a high amount of data, possibly a single number (the temperature) every 2-3 hours. In addition, this temperature sensor must have a long range since agriculture covers a huge area. Finally, the temperature sensor must not consume a high amount of power since, charging it in the middle of the field is not reasonable. Therefore, the best connectivity type for this temperature sensor is LPWAN. LPWANs are enormously useful for different “internet of things” applications. They allow millions of sensors or IoT devices to collect and send information over long distances, while maintaining low power consumption. These applications usually need gateways to efficiently work[27].

3.2.1. Cellular network

3.2.1.1. Mechanism

Cellular networks allow us to connect with friends, access to internet, watch videos, and much more. Cellular connectivity ensures the transmission of a huge amount of data over a long range but it consumes high power. This type of connectivity is therefore good for devices that can be plugged in electricity source or devices which can be recharged frequently. Cellular networks, as all wireless technologies, utilize electromagnetic waves to transmit and receive data. If all wireless communication technologies attempt to use the same frequency for data transmission, there will be interference and clear communication cannot therefore be achieved. Subsequently, the federal communications commission (FCC) sets, for each wireless technology, frequency bands that they are allowed to operate within. Cellular carriers, even with their own specified frequency bands, must take into account interference as will be discussed in the following. It is called cellular network because cellular carriers split areas into "cells". Each cell has its own cell tower that operates with a specified frequency. If two adjacent cell towers are operating with the same frequency, their signals may be subjected to interference. So as general rule, two adjacent cell towers must be operating with two different frequencies to ensure a reliable communication. When hexagonal arrangement is used, it means that you will need seven different frequencies to make sure that the same frequency is not utilized in adjacent cells.

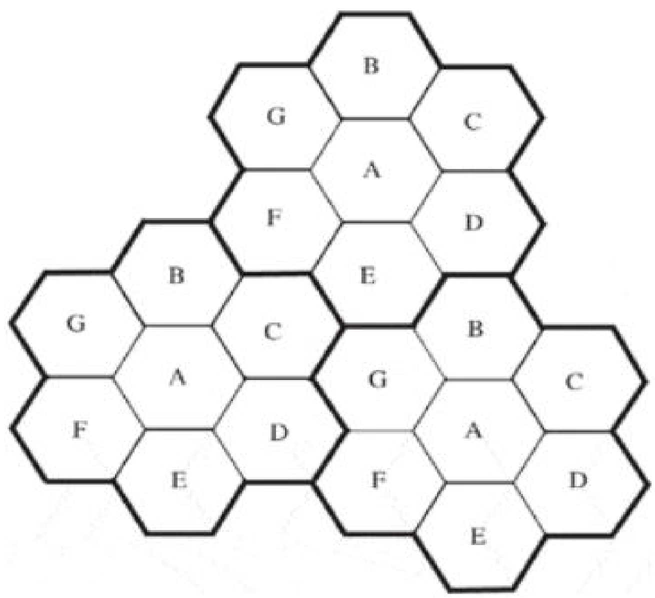

Figure 31: Hexagonal arrangement of cells

In this way, the same frequency can be set and used into different separate cells as it is shown in the above figure; this concept is called "frequency reuse" and helps cellular carriers to increase their quality of service (QoS). The coverage area of each cell tower depends on the usage density. In a crowded city, the coverage area of each cell may be only around half of a kilometer, while the coverage area of each cell may be up to five kilometers in rural regions.

3.2.1.2. Hard hand-off and soft hand-off

When users are moving across the cells, their frequency is changed automatically to switch to new cell towers. This concept is called handoff. There 2 types of hand off: hard handoff and soft handoff. During the hard handoff, as the user is crossing the boundary of a cell, the connection with the corresponding cell tower is broken, and then a connection with a new cell tower will be established; this process can be named “break before make”. During the soft handoff, as the user is crossing the boundary of a cell, the connection with the corresponding cell tower will weaken gradually and a connection with a new cell tower will strengthen gradually. Once the connection with the new cell tower is established, the connection with the old cell tower is broken; this process might be called “make before break” [28].

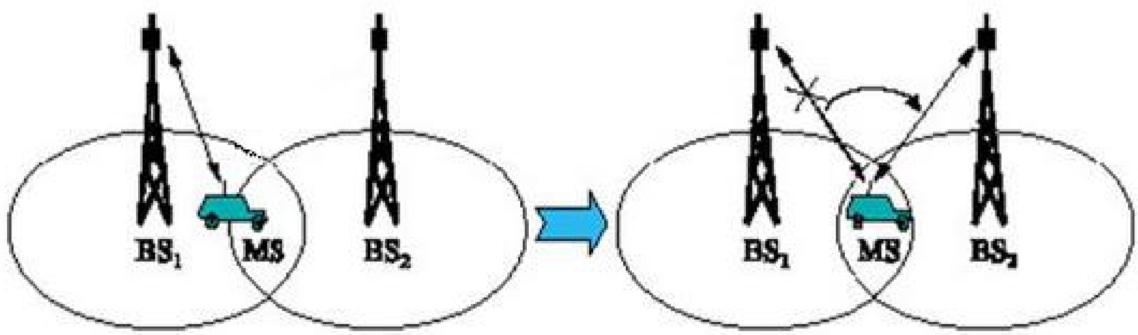

Figure 32: Hard handoff-"Break before Make"

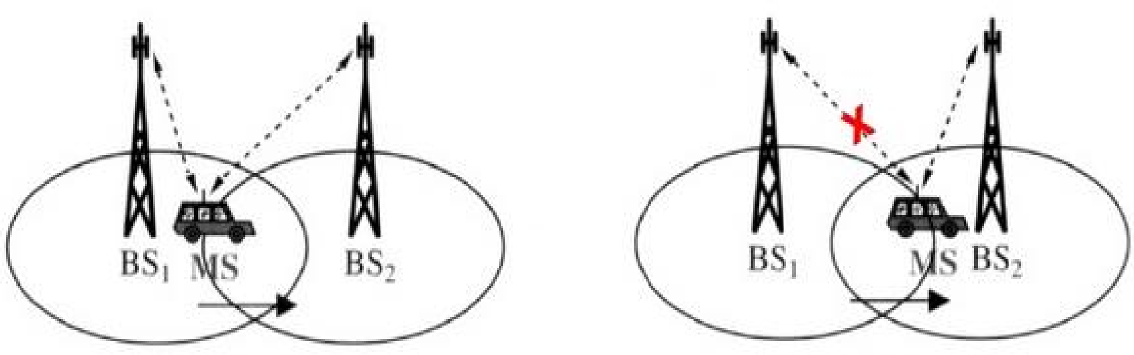

Figure 33: Soft handoff-"Make before Break"

3.2.1.3. Improving capacity

Sometimes the available frequencies allocated for a certain cell are not sufficient. Therefore, it is necessary to know how to increase the capacity. One way to increase capacity is by using what is called "frequency borrowing". If a particular cell is congested, it could borrow available frequencies from adjacent cells. Another way to increase capacity is by using "cell splitting". This is especially useful when there is non-uniformity of traffic. For example, in the center of a city where there is a large number of users, the cells will be congested. So by splitting the congested cells into smaller cells, the capacity will increase and the network will once again be efficient and reliable. However, more cells mean more cell towers, and more cell towers mean more handoffs. So, in order to increase the capacity of some congested cells, handoffs must be well-managed[29].

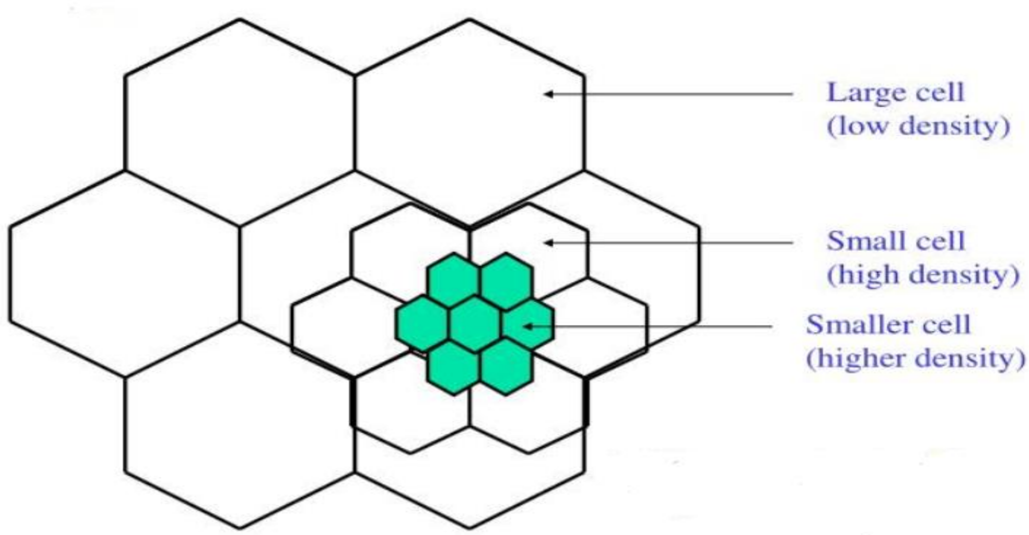

Figure 34: Cell Splitting

3.2.1.4. Cellular "Internet of Things"

As it is sad before, cellular connectivity ensures the transmission of a huge amount of data over a long range but it consumes high power. Therefore, this type of connectivity has not been suitable for "internet of things" applications. But carriers are moving forward with new cellular technologies, aimed specifically to the "internet of things" applications, like NB-IoT and LTE-M. NB-IoT stands for narrow band internet of things, and LTE-M stands for long term evolution category "M". It must be mentioned that the traditional cellular networks used for smartphones are being utilized to empower the new cellular IoT technologies. In other words, instead of building new complex networks to connect IoT devices, they can be connected to the traditional cellular networks with some upgrades. Cellular "internet of things" offers an alternative to Low Power Wide Area Networks (LPWANs) like "Sigfox" and "LoraWAN" technologies. But, unlike LPWANs, cellular IoT operates in licensed frequency bands where cell towers are used as smart gateways. Ericsson, one of the chief providers of communication technologies, predicts that the total number of "internet of things" devices connected to cellular IoT networks is going to increase at a yearly growth rate of 19% until 2023. In other words, out of the 20 billion "internet of things" devices that will be connected by 2023, 3.5 billion devices will be connected to cellular IoT networks. The majority of these IoT devices will be connected in North East Asia, as the figure below shows[30].

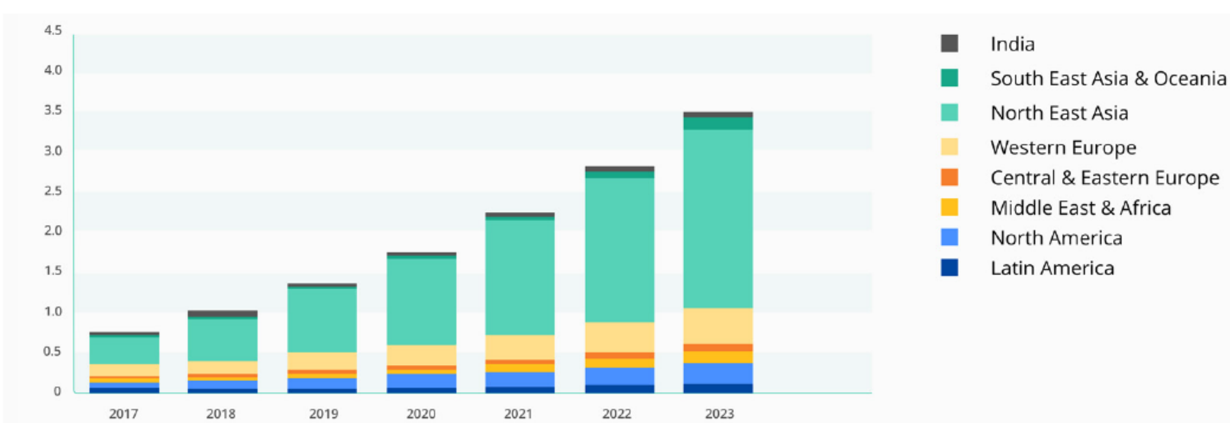

Figure 35: Cellular "internet of things" connections (Billion)

LTE-M and NB-IoT are both great connectivity options for enterprises hoping to exploit Low Power Wide Area Network technology. However, LTE-M and NB-IoT are designed for different use cases and there are some dissimilarities to take into consideration. Latency, speed, power consumption, cost, availability, and mobility are the key differences that differ NB-IoT from LTE-M technology. Latency is the time required for data to reach the server, and for the server to process the data and send back response. In other words, latency is the data round trip time from the IoT device to the server. LTE-M technology has lower latency than NB-IoT technology, and that is the reason why LTE-M technology is used for mission-critical applications. Mission-critical applications mean when real time response is essential. For example, when transmitting precision tracking data or emergency data. Speed is the amount of data that can be pushed into the network in a timeframe. Speed is particularly important when a great amount of data must be transmitted. LTE-M technology has higher speed than NB-IoT technology. This is the reason why LTE-M technology is used for data-intensive "internet of things" applications, and NB-IoT technology is used when small amount of data needs to be transmitted. Nearly all "internet of things" devices are designed to save power when they are not active. Once these devices are active, the ones operating with simpler waveforms will consume less power. NB-IoT technology operates with simple waveform compared to LTE-M technology, and thus has higher power efficiency. Chips supporting NB-IoT technology, unlike chips supporting LTE-M technology, are simple to create and thus they are cheaper. When it comes to availability, it depends whether LTE or GSM is the standard cellular technology in the area. Only Australia, United states, Ireland, and Netherlands have LTE coverage, whereas GSM is the standard in many regions like Africa, and Eastern Europe. If you are deploying in a region where GSM is the standard cellular infrastructure, NB-IoT technology is the best choice. whereas, if you are deploying in a region where LTE is the standard cellular technology, LTE-M is the right choice. LTE-M technology support IoT applications with moving devices, while NB-IoT technology is intended for IoT applications with static devices. After discussing the key differences between NB-IoT and LTE-M technology, it is important to mention that LTE-M can support any kind of LPWA applications, while NB-IoT is designed and intended for simpler type of applications[30] [31].

3.2.2. Satellite

As the name suggests, this type of network utilizes satellites to connect "internet of things" devices to the cloud. Due to its incredible coverage, the satellite connectivity is significant for IoT applications. Only one network of satellites is able to provide coverage to approximately the whole planet. In other words, an IoT device moving across the world would stay on only one network and utilize only one type of connectivity. Satellite's magnificent range give it a preferred position in remote regions where other types of communication such as cellular cannot reach, and in regions that have immature infrastructure, such as the center of the ocean. When talking about satellite connectivity, one must differentiate between two configurations: direct and backhaul. The first configuration, direct, is divided into two modes: dual mode and satellite only. Satellite connectivity in dual mode uses cellular network as long as it is possible, and utilizes satellite network when cellular network is no longer available. Therefore, satellite connectivity in dual mode benefits from the higher amount of data that can be transmitted over the cellular network, and utilizes satellite network for its greater coverage where cellular connection is unreliable or sparse. The perfect example of this connectivity mode is containership, which utilizes cellular network when in port or near seacoasts, but uses satellite network when in the middle of the sea. The second mode of connectivity, satellite-only, as its name announces, uses only satellite network to transport data. This mode is typically used by offshore gas and oil equipment, which are transmitting lots of information from places where cellular network cannot cover. The second configuration, backhaul, uses a tower which acts as a bridge between "internet of things" devices and the satellite. In other words, IoT devices will be connected to the tower using for example one of the LPWAN type of connectivity, and the tower will be connected directly to the satellite. This type of configuration is especially used when there are numerous IoT devices, in remote regions, trying to send small amounts of data. For example, a set of temperature sensors can be implemented in a farm to collect temperature data. The sensors collect temperature data and send it to the main tower using LPWAN type of connectivity, and then the tower sends the data to the cloud using satellite connection.

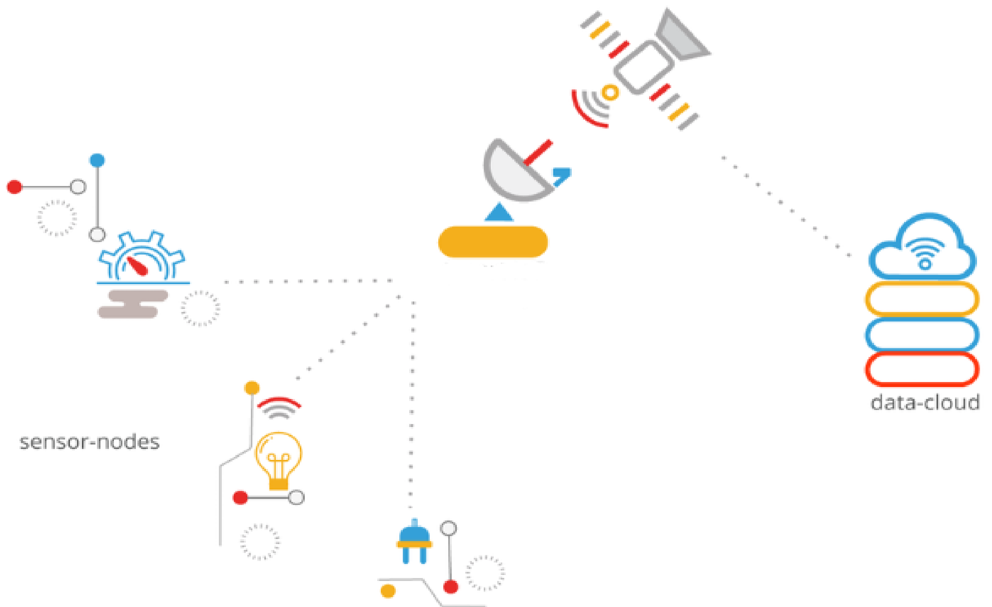

Figure 36: Satellite backhaul mode

Satellite consumes lot of power, and requires larger equipment like dishes for connectivity. This increases the cost of the "internet of things" devices, and makes direct connection of the IoT devices, through the satellite, infeasible for the majority of the IoT applications. Therefore, satellite connectivity is utilized where a tower can be implemented to serve numerous IoT devices as discussed above, high costs of IoT devices are acceptable, or IoT devices are in remote regions and the satellite is the only connectivity option available[32].

3.2.3. Low Power Wide Area Networks

Low Power Wide Area Networks, known as LPWANs, are enormously useful for different "internet of things" applications. They allow millions of sensors or IoT devices to collect and send information over long distances, while maintaining low power consumption. LPWANs transmit extremely small amounts of information which is the reason why they can operate with low power consumption and high range. The figure below displays a classic Low Power Wide Area Network architecture, which is typically analogous to cellular network architecture. LPWA technologies generally use a star topology network. In other words, the edge devices transmit the collected data directly to the base station or the gateway within its range. The data received by the gateway are then sent to the cloud and servers through a backhaul network. And finally the cloud servers process and analyze the data to provide inferences to the user.

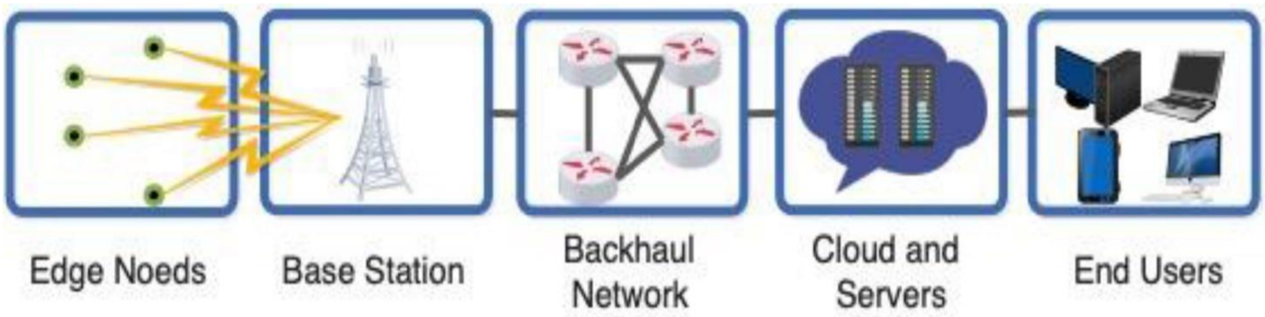

Figure 37: LPWAN architecture

Studies show that around 25% of "internet of things" devices will make use of Low Power Wide Area technologies. The entrance of the LPWA technologies in the market is due to the inability of the short range "internet of things" technologies of transmitting for long ranges and the deployment cost of the cellular "internet of things" technologies is extremely high. The range of the short range IoT technologies is limited, which is the reason why they are not suitable for many "internet of things" applications. Moreover, even though cellular IoT technologies can accomplish long distance communication through the use of mesh network topology, the cost of deployment is too high. In order to decrease the cost of long range transmission, Low Power Wide Area technologies are the solution for connecting enormous number of IoT devices[33].

3.2.3.1. Design goals

LPWA technologies are intended to provide low power connectivity for enormous number of IoT devices over a wide region at low cost. Wide region refers to a long distance data transmission between two "internet of things" devices, which permits the coverage of a village or a town without the use of mesh network topology. Low power indicates the use of an inexpensive power source (two AA batteries as an example) to empower the "internet of things" devices for an extended period of time (10 years as an example). In the following, we will show the design goals of Low Power Wide Area technologies: low power, long range, low cost, and scalability.

3.2.3.1.1. Long range

Wide region coverage is a significant design goal of Low Power Wide Area technologies, that can be accomplished by using particular modulation techniques and exploiting frequencies below 1 Gigahertz. In addition, the environment where LPWA technologies are deployed has a significant impact on the range.

Deployment environment: The range in urban environment is around 5-10 kilometers, this range highly increases in suburban environment to reach 80-100 kilometers. The highest range, 100-120 kilometers and more, can be achieved with direct line of sight.

Using frequencies below 1 GigaHertz: The majority of Low Power Wide Area technologies make use of the sub 1 GHz to provide reliable and high quality communication. In other words, when facing obstacles like concrete walls, the transmitted signal with lower frequency is less attenuated and weakened. In addition, frequency bands below 1 GigaHertz are less congested than frequency bands over 1 GigaHertz, in which many other communication technologies are running. As a consequence, utilizing frequency bands below 1 GigaHertz decreases the risk of interference.

Modulation: In Low Power Wide Area technologies the modulation rate is decreased, at the expense of slowing down the bit rate, in order to place more energy in every transmitted bit. In this way, the receivers are capable of decoding the attenuated signals properly.

3.2.3.1.2. Low power

Low power consumption is as well a key factor to be considered. LPWA technologies must be designed to efficiently work, for an extended period of time, using an unexpansive power source. Since it is tough to replace the power source, the longer is the lifespan of the power source, the more appropriate for LPWA connectivity. In order to decrease the energy consumption, when designing Low Power Wide Area technologies, many aspects must be considered.

Topology: In short range IoT technologies, mesh topology network is being widely used to lengthen the communication range. The mesh topology network will cause the deployment cost to increase. In addition, as the data is forwarded over multiple IoT devices before reaching the gateway, some IoT devices will be more congested than others. Accordingly, their batteries will be depleted rapidly, restricting the network lifespan to just a couple of years. To face these limitations, most of the LPWA technologies make use of the star network topology, where the IoT devices are directly connected to the gateway. In this way, there is no more need for the costly deployment of relays. In addition, IoT devices will no more need to relay data through them and consequently, they save energy[33] [34].

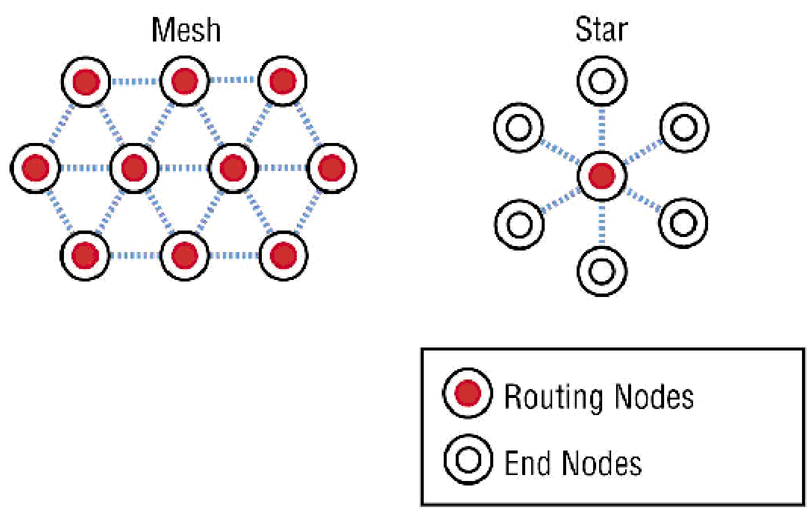

Figure 38: Difference between Mesh and Star network topology

Duty cycling: In order to save more energy, LPWA end-devices are intended to shut down the components that consume a big amount of energy opportunistically. Precisely, the transceivers are turned-off when they are not required. And they are turned-on when the information is to be sent or received. Duty cycling mechanisms are adjusted based on the application type, power source type, traffic pattern, etc. For example, if IoT end-device wants to send data to the gateway, the end-device wakes up its transceiver just when the information is available to be transmitted. And if the gateway wants to send data to the end-device, the end-device must make sure to wake up its transceiver just when the transmission is actually occurring. This can be achieved by approving on a listening schedule among end-devices and gateways.

Offloading complexity: Most LPWA technologies, simplify the design of the end devices. This is done by offloading complex components to the base stations. Therefore, the end devices will no more need to realize complex tasks, and therefore more energy can be saved. By offloading complexity to the base stations, which are less in number than end-devices, allows to lower the deployment cost[33] [34].

3.2.3.1.3. Low cost

Low Power Wide Area technologies have successfully succeeded in connecting enormous number of IoT end-devices. The deployment cost of the LPWA technologies is lower compared to other communication technologies. In addition, the connection quality is ensured. Due to these features, LPWA technologies are competing in a wider range of applications compared to cellular network and short-range technologies. LPWA technologies embrace different measures to decrease the communication and deployment costs.

Reducing hardware complexity: Most LPWA technologies, simplify the design of the end devices. This is done by offloading complex hardwares from the end-devices to the base stations. By offloading complexity to the base stations, which are less in number than end-devices, allows to lower the deployment cost.

Topology: In many communication technologies, mesh topology network is being widely used to lengthen the communication range. In mesh topology network, the data is forwarded over multiple IoT devices before reaching the gateway, therefore each end-device must be equipped with an expensive relay. To face these limitations, most of the LPWA technologies make use of the star network topology, where the IoT devices are directly connected to the gateway. In this way, there is no more need for the costly deployment of relays.

Utilizing license free bands: Several communication technologies, like cellular IoT, operate in licensed frequency bands. Since getting a license is expensive, the operation cost of these networks is therefore increased. To tackle this problem, LPWA technologies operate in the ISM (Industrial, Scientific, and Medical) band. This band is significantly important since this group of frequencies could be utilized without the license charge. The network operation cost is consequently decreased[33] [34].

Range	Center Frequency
6.765–6.795 MHz	6.78 MHz
13.553–13.567 MHz	13.56 MHz
26.957–27.283 MHz	27.12 MHz
40.66–40.7 MHz	40.68 MHz
433.05–434.79 MHz	433.92 MHz
902–928 MHz	915 MHz
2.4–2.5 GHz	2.45 GHz
5.725–5.875 GHz	5.8 GHz
24–24.25 GHz	24.125 GHz
61–61.5 GHz	61.25 GHz
122–123 GHz	122.5 GHz
244–246 GHz	245 GHz

Table 5: ISM bands

3.2.3.2. Sigfox

Currently, there are many different Low Power Wide Area technologies used in "internet of things" devices. Sigfox, Lora, Telensa, Ingenu, and Weightless are noteworthy when talking about LPWA technologies. Each LPWA technology has its particular characteristics and features to realize a low power and long range communication. In this section, I would emphasize my work on the Sigfox technology.

Figure 39: Different LPWA technologies

3.2.3.2.1. Sigfox architecture

Sigfox is a French worldwide network operator established in 2009 that aims to connect wirelessly enormous number of low power devices. Sigfox, one of the Low Power Wide Area Networks, is simple due to its network architecture. In other words, due to the star topology adopted by the sigfox network, huge number of devices can be directly connected to a base station within the range. Each base station installed by the sigfox operators is connected to the sigfox cloud. The sigfox cloud servers are in their turn connected with the customers' servers.

Figure 40: Sigfox architecture

3.2.3.2.2. Sigfox coverage

To take advantage from the sigfox technology, you have to be covered by the sigfox network. Sigfox networks have already covered 70 different countries and regions. Sigfox network operators are aiming to cover 100% of the world in the near future. The regions and countries that are already covered by the sigfox networks are highlighted in the following picture. Due to the long range communication offered by the sigfox technology, only 1200 base stations were needed to cover entire France compared to 50000 base stations for cellular networks.

Figure 41: Sigfox coverage

3.2.3.2.3. Sigfox bidirectional communication

Sigfox communication is bidirectional. This means that data can be pushed in both directions through the network. In other words, data can be sent from the "internet of things" device towards the customer server, and the customer server can push data back to the device. The data sent by the device towards the customer server is known as uplink message. And the data pushed by the customer server to the device is known as downlink message.

Transmitting an uplink message through the sigfox network is pretty simple. When the device has a message to be transmitted, it just creates radio waves to send the data. A nearby base station will receive the data. The data are then pushed by the base station towards the sigfox cloud. And finally, the sigfox cloud servers process and analyze the data to provide inferences to the user. One could think that the same process is done with all radio technologies, but conventional radio technologies are pretty complex. Conventional radio technologies are complicated because a number of hidden negotiations must be done between the sender and the recipient before the real data is transmitted. Sigfox uplink message is very small, which the reason why a sigfox enabled device can work with low energy consumption. In fact, each sigfox uplink message could only carry 12 bytes of data. Even though the device cannot send a big amount of information with 12 bytes, they could be more than enough for many "internet of things" applications. An uplink sigfox message takes about 6 seconds to be sent. So, due to regulations a sigfox enabled device is only allowed to send 6 messages per hour or 140 messages per day, which are as well more than enough for most “internet of things” applications.

Even though the sigfox communication is bidirectional, the communication is always initiated by the device. The flow can be described as follow, the device sends a message towards the customer server requesting a down link message. Only when this message reaches the customer server, the customer can reply by a downlink message. In other words, customer is not able to send messages to the device whenever he wants to. A sigfox downlink message could only carry 8 bytes of data. Due to regulations, only 4 downlink messages per day are allowed to be sent. The fact that the communication is always initiated by the device itself has some advantages. The device is turned-on only when data is to be sent or received, and consequently a big amount of energy can be saved. In addition, since most of the time the device is off, a hacker would not be able to get access to the device information and therefore, a high security level is ensured[35].

4. IoT and the supply chain

4.1. Introduction to supply chain

The supply chain is a system of organizations, people, activities, tools, technologies and resources involved in the formation and sale of an item or product, from the supply of raw materials from the provider to the producer, through to its distribution to the end customer. The supply chain main activities include the procurement of raw materials or components from the provider, production of semi-finished or finished products using the materials purchased, delivery of these products to the end customer. Storing raw materials, semi-finished products and finished products along with ensuring a high level of reverse logistics are supply chain activities that may be added to the main activities.

Figure 42: Supply chain activities

Supply chain management (SCM) has evolved gradually since the 1960s to guarantee an efficient and cost-effective supply chain. Supply chain management is a group of techniques utilized to successfully coordinate providers, manufacturers, warehouses, and depots, so that goods are formed and delivered to the exact locations, at the precise quantities, and at the accurate time. In the case where the supply chain management is properly done, the supply chain costs are considerably reduced while service level requirements and customer satisfaction are enhanced. Supply chain management activities improve customer satisfaction by ensuring that the required products are obtainable at the accurate time. Higher levels of customer satisfaction lead to customer loyalty. In addition, SCM activities reduce the operation costs by decreasing procuring, production, and logistics costs. Lower costs lead to higher profit, which will improve the financial position of a company. The supply chain management processes include supplier relationship management (SRM), customer relationship management (CRM), customer service management (CSM), demand management, manufacturing flow management, product development and commercialization, order fulfillment, and return management. The CRM process defines how the relationship with the customer will be established and maintained. The SRM process defines how the relationship with the supplier will be developed and sustained. The CSM process outlines how services will be provided to the customer and is a part of the CRM process. The demand management is a process in which past data are collected and analyzed. The analysis of these data allows the demand management team to agree upon a demand or forecast plan. The demand or forecast plan includes the categories and quantities of items to be produced. Manufacturing flow management process incorporates all important activities to move items through the plant and to achieve manufacturing flexibility. Product development is the process of converting a new idea or concept into a real product. Commercialization is a process that describes how the product will be introduced to the market. Order fulfillment process allows the company to accomplish customer requests while reducing the total storing and delivery costs. Returns management process permits the company to efficiently deal with returns and repairs[36][37].

4.2. IoT importance and challenges

Among all the rising technologies, the "internet of things" is expected to have the uttermost influence on the industrial economy. The "internet of things" is expected to increase the profit of a company by around 20% by 2022. The "internet of things" will be the reason behind 11 trillion US dollars in annual savings for 2025. In addition, IoT is considered as the foundational innovation for breakthroughs in robotics and artificial intelligence (AI).

In order to better comprehend the present state of "internet of things", Forbes Insights surveyed 500 directors around the globe who are driving IoT activities inside their organizations. When they were asked about the importance of "internet of things" to their companies, 64% of the directors said it is important or very important. Not a single director said that IoT is very unimportant, which means that companies are aware of the importance of the "internet of things" in the future. Surprisingly, around one third (36%) of the directors perceive IoT as unimportant. This high percentage may indicate that some companies did not yet completely understand how "internet of things" may improve their businesses.

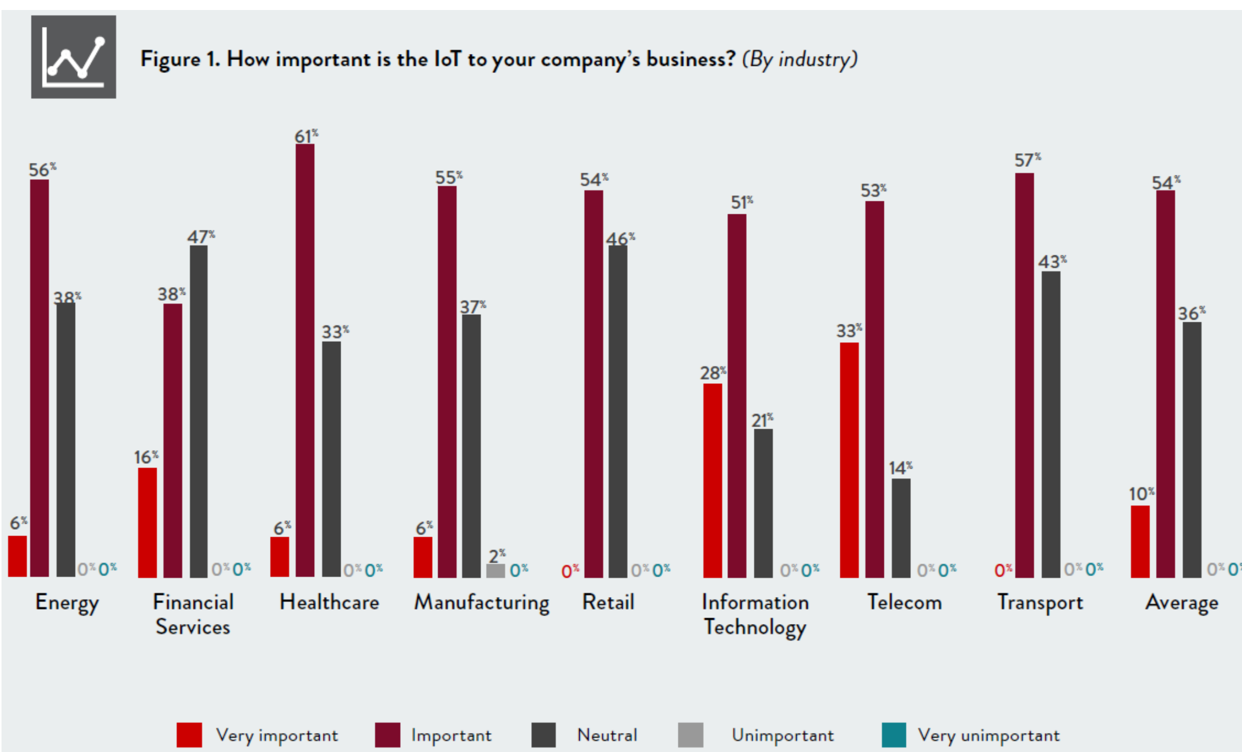

Figure 43: The importance of IoT

This rise of the “internet of things” is shown not just by the number of organizations thinking of it as imperative to their businesses yet in addition by its place in organization priorities. When questioned to rank the importance of numerous different technologies, directors selected IoT in the first place, placing it above artificial intelligence, augmented reality and robotics. This can be due to the lower implementation costs of IoT compared to the other technologies.

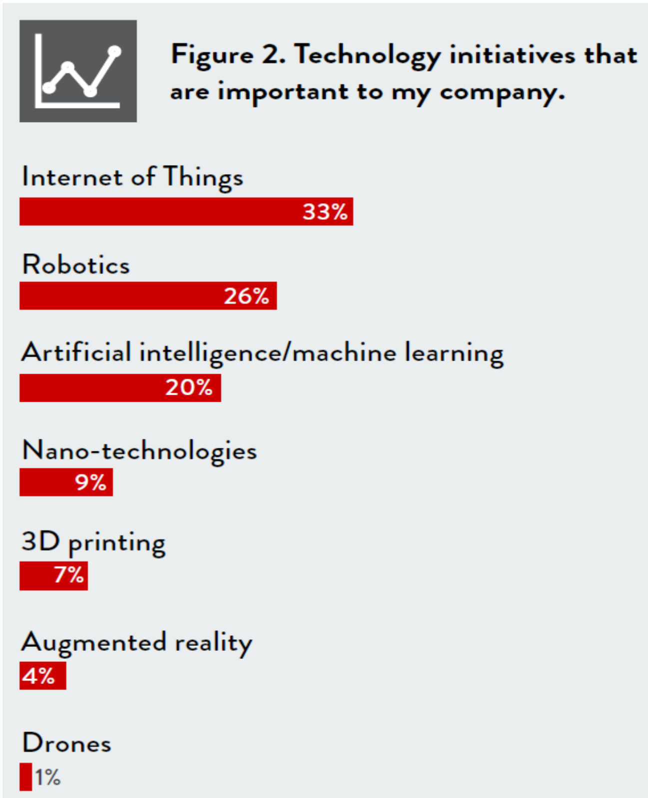

Figure 44: Ranking the importance of different technologies

Every technology has its challenges. “Internet of things” is not an exception. When implementing IoT in their companies, directors are facing different problems. The top five challenges that directors are facing are shown in the figure below[38].

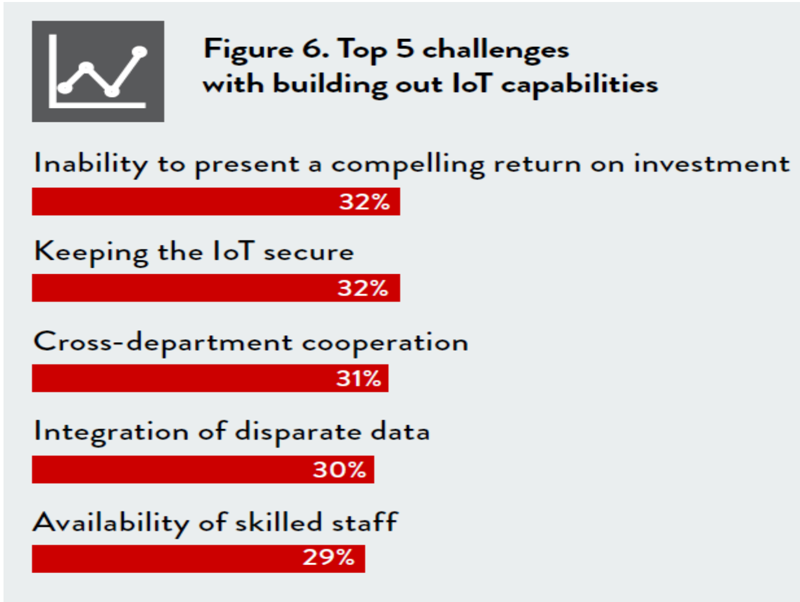

Figure 45: The top five IoT challenges

4.3. Benefits of the IoT in the supply chain

4.3.1. Inbound logistics

4.3.1.1. Tracking deliveries from the vendor

As indicated by IBM, which has already introduced Artificial Intelligence innovation in its supply chain, up to two-thirds of the value of an organization's items or services is gotten from its providers. That is an enormous motivation for the manufacturer to give closer attention on how providers are dealing with the supplies. Higher quality products mean higher customer satisfaction, and higher customer satisfaction means customer loyalty. In addition, by tracking delivery from the vendors, a manufacturer is capable to know well early if a shipment is postponed or delayed, and consequently adjusts the production schedules. To track your delivery from the time it is packed until it reaches your manufacturing plant, an IoT system must be implemented and used. "Internet of thigs" technology in this case is successfully playing an important role in increasing customer satisfaction and manufacturing efficiency[39][40].

4.3.1.2. Receiving goods and stocktaking

Before accepting any delivery, operators must guarantee that the received goods meet the requirements. Operators must confirm the status, price, and quantity of raw materials or components. This task can be worse if the delivery contains multiple types of raw materials or components with different quantities. This task is time-consuming and exposed to human error. With the implementation of “internet of things” technology, as the pallet arrives at the inbound gate, information concerning the quantity, status, and price of the raw materials or components placed on that pallet are detected. The collected information is then automatically sent to the enterprise resource planning(ERP) or warehouse management system(WMS). After checking the received goods’ compatibility with the purchase order and defining the storage location of each item received, warehouse manager completes the receiving process. This IoT ability increases the material acceptance efficiency, eliminates human error, and rises material handling equipment productivity.

Figure 46: Receiving goods

In the long term, due to some errors, the quantity of raw materials or components on the shelfs will be different than the quantity registered in the system. So in many cases, stocktaking is an indispensable process done to correct any error. Without the use of IoT technology, operators must find the location of the products which the company is willing to check. Next, operators must manually collect information about the quantity of the products. This information is then sent to the warehouse manager in order to correct the errors that may have occurred. This process is time consuming and may be subjected to human errors. With the implementation of IoT technology, operators are informed about the location of the raw materials or components. Operators only job is therefore to scan each component targeted. The information collected by the scanning process is automatically sent to the enterprise resource planning(ERP) or warehouse management system(WMS). Consequently, warehouse manager can easily correct any error in the system. As a conclusion, IoT technology helps the warehouse management to save time and money, without sacrificing accuracy, in the receiving and stocktaking processes[10][19].

4.3.1.3. Tracking deliveries around the facility

Operators in some cases are not able to find the pallets delivered, or spend time searching for missing pallets or items. This is due to the fact that truck drivers, delivering the raw materials or components, have practically little or no incentive to certify that goods are delivered exactly to the place where it must be. With the use of “internet of things” technology, operators will know exactly where the pallets have been placed and act accordingly. Therefore, IoT technology is successfully playing an important role in increasing operational efficiency[40].

4.3.2. Manufacturing

4.3.2.1. Asset tracking and management

The use of “internet of things” technology to track manufacturing tools and equipment can be found in many industries. Companies, before the implementation of IoT technology, were not able to identify which operator is responsible if a tool disappeared. Since a special tool can cost up to 35,000 dollars, companies had to pay a great amount of money for tools replenishment. By implementing IoT technology, companies are capable to recognize and charge the operator responsible for tool loss. Consequently, the number of tools disappearing decrease and therefore, the companies can save a large amount of money. In addition, many products need to be packaged in special reusable containers for delivery. When these containers are not well managed, they may in most of the cases be lost in the customer facilities. Company needs to buy additional reusable containers to maintain a proficient supply chain if the containers are not returned. Therefore, this contributes to a major loss for the company. By using “internet of things” technology, company is capable to decrease this loss, by scanning containers to record location details as they pass by the outbound gates. Furthermore, raw materials or semi-finished products inside a manufacturing plant can be subjected to what is called “flat spot problem”, being placed on any flat surface accessible. Losing materials or semi-finished products can slower the production, and lead to worker frustration. Slowing the production means customer dissatisfaction. The “internet of things” technology is capable of providing real-time information concerning the location of the materials. The supply chain manager will be alerted if a material is misplaced or has been moved towards a wrong direction. Using IoT technology, the supply chain manager can easily monitor the raw materials or semi-finished products and ensure that they are placed in the exact location. Therefore, by decreasing what is called “flat spot problem”, IoT technology plays an important role in increasing production efficiency[9][40].

4.3.2.2. Production

“Internet of things” technology can be used in manufacturing processes to recognize the item that is being assembled or worked as well as the parts that must be mounted into the item. For instance, each item inside the manufacturing processes is equipped by a RFID tag, which contains information about the item. During the process, RFID reader installed at each station detects the information sent by the tag to present what operations should be done, what parts need to be mounted into the item, and whether the parts that are introduced are the right parts. Before the item leaves the station, the reader updates the information on the tag memory and a new item status is set. Therefore, not surprisingly, this system plays an enormous role in maintaining the quality of the final result particularly when the item is greatly customizable. This RFID system when used in the manufacturing processes can shorten the time for checking or identification of items and parts. In addition, this system decreases the errors in the processes and thus reduces the rework costs and time. For example, Harley Davidson, having complex manufacturing processes, investing in “internet of things” technology is a simple decision with guaranteed results. Every production step, at the Harley Davidson manufacturing factory in

York, Pennsylvania, is now tracked. The performance and information about each production step can therefore be recorded in real-time. The recorded data are presented on large screens. This information provide operators and managers better visibility on what is happening and what is going to happen in the manufacturing processes. This IoT implementation has led to an enormous improvement. Harley Davidson company successfully decreased the time it takes to create a bike from twenty-one-day cycle to six hours. The company decreased cost by around 7%, improved operator productivity by around 2.5%, and improved net margin by a sensational 19%[20][41].

Figure 47: Tracking production step performance

Another example, Airbus, one of the leading companies in the aerospace industry, is using "internet of things" technology in its manufacturing processes to boost manufacturing efficiency. Planning, building and checking airplane is a requesting task, requiring integration of individuals, procedures and innovation. In airplane construction, there are exact guidelines that determine the sort of screw and the force that must be utilized to join parts. With regards to passenger airplane, there is enormous number of such screws which must be fixed appropriately. Screw on a wing normally requires a different amount of force than a screw on an airplane window. An ordinary subassembly, could have 400000 points that must be tightened. Those points may require up to 1100 different tightening tools. With thousands of guidelines and steps, which must be accurately followed by the operators, a mistake or an error can be easily made. A single mistake throughout the process can cost tens of thousands of euros. To tackle these problems, Airbus has implemented "internet of things" technology in its manufacturing processes. Operators are instructed, through wearable technology, by the exact step that must be done. Airbus tools and machines are equipped with sensors. The position of the airplane is fixed in the hangar. With appropriate connectivity and fixed coordinates, an operator can easily identify the exact location of the required tool. The amount of force that must be exerted is automatically sent to the necessary tool. This approach, has led to about 20-30% increase in productivity and quality rates. Airbus, using "internet of things" technology, has also successfully succeeded in reducing the tools energy consumption by 20%. Moreover, in one particular process, recognized as cabin seat marking, 500% increase in productivity has been achieved with nearly no errors. To conclude, this IoT implementation, made by the Airbus company, has played and is playing an important role in boosting quality and productivity as well as in decreasing costs[42].

Moreover, not only the products can be tracked but also the production machines. "Internet of things" technology can provide the operational manager information about the machine health as well as the maintenance history, involved operators and parts substituted. The operational manager can therefore set a maintenance schedule. In this way, IoT technology helps in decreasing the unexpected machines' shut offs and thus, increases efficiency and productivity[20][41].

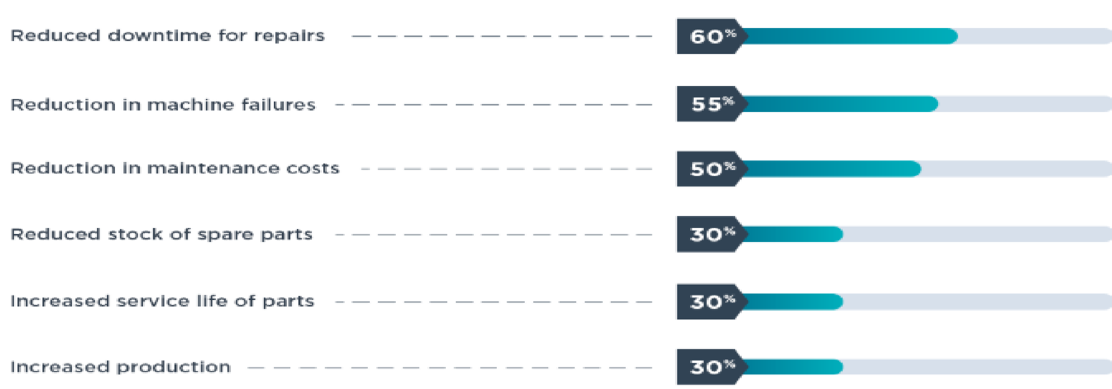

Figure 48: Machines monitoring benefits

4.3.2.3. Supply-demand balance

Fulfilling the consumer demand is essential for any supply chain department. The application of "internet of things" technology is not constrained to technical aspects; it can likewise provide insights to the manufacturer that increase its capability to forecast demands. The information caught through "internet of things" could allow a superior understanding of consumer behavior and needs. By analyzing why and how consumers are using the products, manufacturer is able to forecast future consumer demands. Manufacturer is consequently capable to adjust its products based on consumer needs. Doing so, manufacturer will increase his market share and profit[43].

4.3.3. Warehouse and delivery processes

The warehouse basic activities are described as follows: receive, store, retrieve the products, and finally prepare any delivery requested. Reducing the movement costs of products, increasing the space utilization, keeping track of all the products within the warehouse, and preparing deliveries requested in time are the necessary tasks for an efficient warehouse. These tasks are labor intensive and contribute to the major operating costs in a warehouse. "Internet of things" can automate lots of these tasks and thus, leads to higher warehouse operations efficiency.

4.3.3.1. Inventory management

The "internet of things" technology used in a warehouse increases inventory visibility, which has led companies to perfectly manage their inventory levels. The real time data provided by the IoT systems allow companies to take decisions based on existing, real, and exact information. Using IoT systems, information about the location and quantity of each product in the warehouse can be directly retrieved. This visibility allows firms to reduce the searching time, and to perfectly identify when they will run out of goods. With these capabilities, firms are therefore able to employ just in time(JIT) practices. JIT practices mean that the firms place order for stock replenishment just when they detect a low stock level. This JIT management, as stock level is decreased, allow the firms to have more spaces available in the warehouse and to increase investments in other areas[9].

4.3.3.2. Warehouse management

In a traditional warehouse, when orders are released, operators must search for the requested products, count them, and update manually the stock levels. Those activities are labor-intensive and therefore, companies must spend a big amount of money on labors. According to a study made in May 2018, a standard warehouse with around 100 workers could spend around 3,500,000 US dollars in labor expenses. This amount of money could represent around 65% of the total warehouse expenses. In todays' operations, every available space in the warehouse must be studied and utilized in a perfect way so that warehouse operators can retrieve, pack, and deliver as fast as possible. Companies can gain competitive advantage implementing "internet of things" system in their warehouse operations. "Internet of things" can enable companies to deliver fast and cost-efficiently through facilitating locating items. By implementing IoT technology in the warehouse, information about each finished product is continuously detected and automatically sent to the warehouse management system. This information contains the exact location where each product, according to its environmental requirement, must be placed. The system could alert the warehouse manager for corrective actions, if any product is not in the exact place. Once a delivery is requested, operators are automatically informed about the orders sequence, as well as the products requested by each order. Consequently, operators can efficiently prepare each order and make it ready for shipping according to the sequence given. As the delivery is being transmitted from the outbound gates, information about each transmitted product is detected and, inventory level is updated accordingly for precise inventory control. As a result, less operators are needed for these operations, and higher efficiency can be attained. Moreover, "internet of things" technology plays an important role in building smart infrastructures for the warehouses. Automated vehicles and autonomous material handling equipment can therefore be used. Consequently, manual intervention is reduced and could be eliminated. The automated vehicles and autonomous material handling robots can be used to move bulky items, to pick or place an item/pallet, and to transport an item/pallet from one place to another. Since all these material handling equipment, robots, and forklifts are connected to one network, collisions can be avoided and a better flow of materials in the warehouse is achieved. As a result, efficiency, productivity, and mobility are improved in the warehouse. In addition, by eliminating manual intervention from the majority of the operations, higher worker safety is achieved. In 2016, according to a study, 5 out of 100 workers were injured while working in the warehouse. This number could be decreased to 0 or 1 by implementing smart infrastructures for the warehouse and eliminating manual intervention. Hence, “internet of things” has not only succeeded in boosting productivity and lowering labor costs, but also has succeeded in lowering the chance of injuries. For example, according to a study made by Forbes, Amazon is managing over 500,000,000 different Stock Keeping Units and is operating more than 500 distribution centers or warehouses around the world. Amazon workers used to search for the requested products in these enormous warehouses. After the products have been found, warehouse workers must pick, transport, and pack these products for delivery. This process is labor intensive, time-consuming, and may be subjected to errors. So, Amazon, in 2012, has introduced automated warehouse robots in the warehouse operations to replace human labors. In 2017, according to the same study, 45,000 robots were operating in 20 different warehouses and have succeeded in reducing warehouse operating expenses by 20%, saving around 22,000,000 US dollars annually for each automated warehouse. If the automated warehouse robots were introduced in all Amazon warehouses, 5,000,000,000 US dollars could be saved annually[44][45].

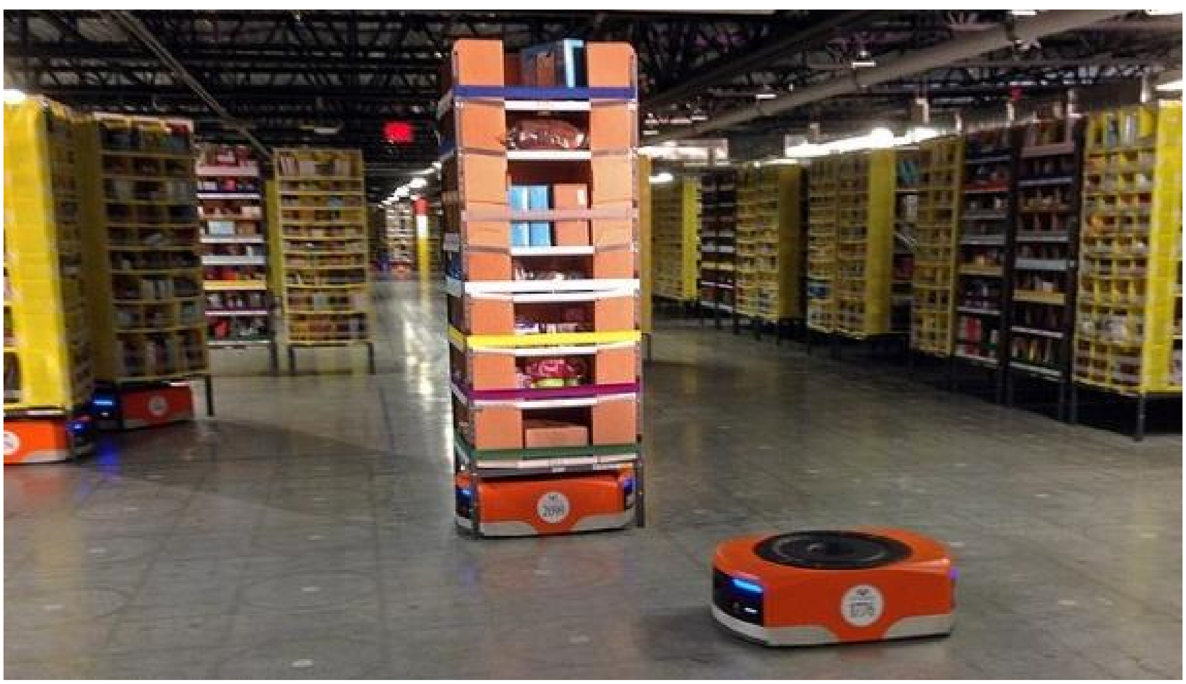

Figure 49: Automated warehouse robots inside Amazon warehouse

According to a study, the global e-commerce market is expected to increase by 20% to reach around 3.5 trillion US dollars in sales. China, the largest e-commerce market, will contribute for more than half (55%) of the online sales. Online retailers and logistics firms have been racing to find solutions to improve the warehouse efficiencies. Alibaba, a giant Chinese e-commerce company, is taking part in the worldwide race to accelerate deliveries. Since robotics has highly improved, many big companies, including Alibaba, were looking to introduce an automated workforce in their warehouses to increase efficiency. Alibaba company opened in 2017 a smart warehouse in China, Huiyan district. Over 100 automated guided vehicles(AGVs) were introduced in the smart warehouse. The automated guided vehicles, made by the Chinese Quicktron company, are responsible for moving goods inside the warehouse. With a size of 90 centimeters long, 70 centimeters wide, and 30 centimeters tall, each robot could rotate 360 degrees to easily access the shelves and can circulate with a speed up to 1.5 meters per second carrying a load up to 600 kilograms. The AGVs are equipped with sensors in order to sense each other and consequently avoid collision. Once a customer places an order on the Alibaba's online site, the robots are activated. Information, concerning the delivery, are then sent to the robots via Wi-Fi. The robots, empowered by "internet of things" technology, locate the shelves containing the ordered products and transport them to the warehouse operators. Operators pick, assemble, and prepare the ordered products for delivery. When the task is completed, the robots return to wait for another order. When fully charged, the robot is capable to work for 7-8 hours without a stop. During the process, if a robot runs out of battery, the robot can automatically move to the nearest charging source and recharges itself. A 5 minutes of charging permits the robot to work for additional 6-7 hours. The implementation of the automated guided vehicles has increased the warehouse efficiency three-fold. With the help of these robots, a warehouse operator can sort up to 3000 items during a 7-8 hours shift, taking around 2500 steps. While in the case of a traditional warehouse, an operator is only capable to sort up to 1500 items in a 7-8 hours shift, walking around 28000 steps. Neither Quicktron nor Alibaba have announced the exact price of the robot, but a similar robot designed for e-commerce could cost up to 35000 US dollars. Robots are not a cheap solution, but with the advantages they can bring to the warehouse, many big companies are spending or will spend money to introduce robots in their warehouses. To sum up, with the use of robots, warehouse efficiency is highly increased, operator safety and comfort are improved, and big amount of money and time are saved[46][47].

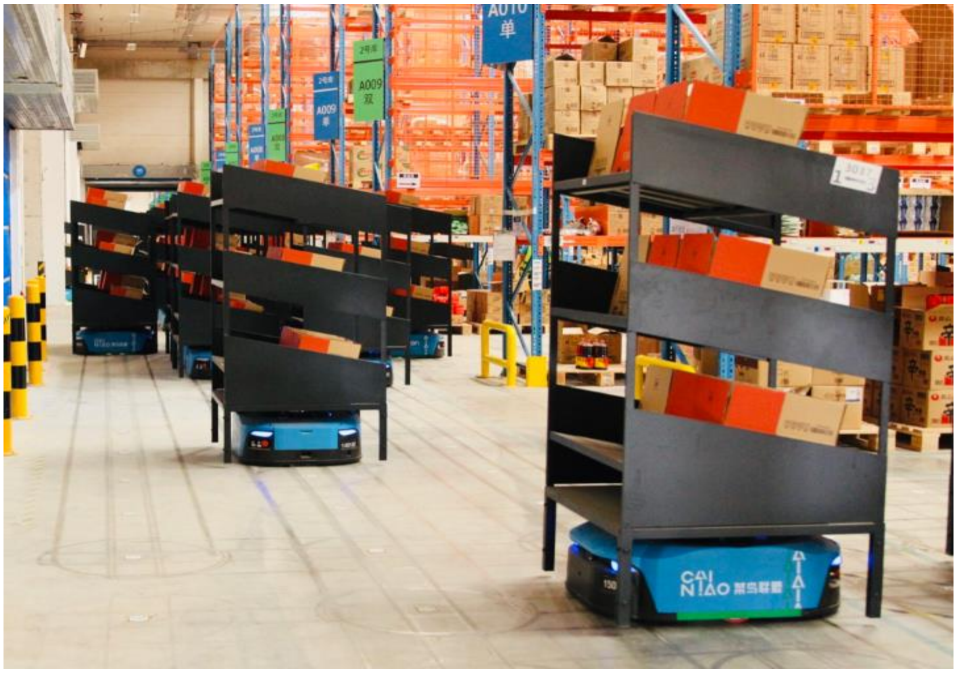

Figure 50: Quicktron robots moving shelves to the operators

4.3.3.3. Assets and space utilization

Beyond products storage, “internet of things” system can be utilized for optimal asset management and utilization. By implementing IoT technology in the warehouse, information about each forklift, robot, or vehicle is continuously detected and automatically sent to the warehouse management system. This information may contain speed, location, and the idle time of each vehicle. Consequently, the warehouse manager could simply detect the inefficiencies and search for better solutions. To achieve higher vehicle productivity, the warehouse manager could assign an additional task for vehicles with high idle time or could allocate a different path for a forklift. In addition, with the use of “internet of things” technology in the warehouse, each forklift is able to interconnect with other forklifts and workers, and consequently is able to be programmed in order to automatically slow when any forklift or worker is around. In addition, forklift will be able to scan the surroundings in order to prevent collision with any hidden objects. As a result, IoT plays an important role in improving workers’ health and safety and in increasing assets utilization and productivity.

The normal size of a warehouse has expanded to 16,000 square meters in comparison to 2003 normal size of 11,000 square meters. In any case, over 43% of companies are facing challenges to appropriately manage space in their warehouses. In addition, around 45% of warehouses and distribution centers handle different types of pallets and cases that are later arranged on racks or shelves. Products in such situation could easily be misplaced. Implementing “internet of things” technology helps managers to ideally use the space in the warehouse to accommodate the highest number of products. Warehouse managers, aware of the incoming and outgoing goods, can effortlessly compute the free space in the warehouse and consequently, select the best configuration for the warehouse[21][45].

4.3.4. Transportation

Whether by land, ocean or air, transportation and logistics are the vital elements for the companies to achieve profitable outcomes. In this evolving world, where real-time information is highly important, “internet of things” is playing a significant role in enhancing the transportation and logistics operations. Today, the improvement of “internet of things” and other technologies and innovations permits the different types of devices to be connected across a unique network. This is helping to detect and share the mission-critical information, allowing companies to achieve real-time visibility of transportation and logistics operations.

4.3.4.1. Visibility and fleet management

The “internet of things” increases the efficiency of communication among all the involved in the transportation cycle. Using “internet of things” technology, alongside a good connectivity, allows a company to detect real-time information about its fleet. This information may contain the location of any delivery truck or van in the fleet, route that a truck has traveled, truck’s condition and emission, freight condition, and driver’s health and performance.

Exact information of real traffic flowing through a specific street or highway at any timeframe can as well be gathered and related. By analyzing this data, precious information about traffic condition can be provided. As a result, plans to avoid traffic jam are easily realizable and achievable. Companies use this information to optimize the routes taken by their transport trucks. So, transportation is speeded up and customers are more thrilled. Therefore, it can be said that IoT technology, with no doubts, helps companies to increase their transportation efficiency.

Worldwide, logistics operations are responsible for the emission of around 2900 megatons of carbon each year. So, it is crucial that companies show a more responsible comportment and play an active role in controlling the situation. This is one more area where "internet of things" can have an impact. "Internet of things" systems and devices permit companies to monitor and even manage the emission of carbon. Firms could pinpoint the process that causes a high carbon emission and make the necessary procedures to make the operation more efficient. The information collected by "internet of things" sensors allow the firms to optimize the load and pick the most efficient transportation mode for a specific shipment[43][48].

Real-time visibility provided by the "internet of things" technology makes the transportation and logistics operations transparent. "Internet of things" devices inserted in the trucks help companies to monitor the load. If the truck is loaded more than its capacity, which could be dangerous to the products delivered, the company is alerted. And if the truck is loaded less than desired, which could represent a loss, the company is warned. Therefore, the company, taking actions according to the information sent, could ensure that goods are delivered legally and safely. In addition, since many products in the industry must be transported in a particular environment, tracking the condition of goods from the packaging process to the arrival at the store is important. For example, some goods may be sensitive to vibration; others, like medical and perishable food, must be transported in a cold environment. "Internet of things" devices and sensors are capable to detect real-time information, regarding the products condition, during the transportation. Therefore, IoT sensors could alert the fleet manager if any unacceptable variances in transport conditions has occurred, so they can be fixed instantly. IoT helps companies to reduce waste and guarantee the quality of the transported goods[43].

4.3.4.2. Vehicle and driver health

When a company is concerned about its fleet and drivers, is facing difficulties in the transportation processes, and spends a large amount of money for the operation cost which threatens the profitability, then "internet of things" technology is the solution. Sensors installed on trucks as well as driver's wearable devices will collect, transmit, and receive data. This data sharing, ensured by the IoT technology, allows the fleet manager to have a complete visibility. This visibility will improve and empower the fleet operations. Truck speed, driving pattern, fuel consumption, engine health, vehicle health, driver health, driver performance can be therefore easily monitored and managed by the fleet manager. If the driver is braking too hard, is accelerating too high endangering himself and the shipment, or is having a bad driving pattern, the fleet manager is alerted and appropriate actions are taken. Fuel consumption is higher with a bad driving pattern. So, appropriate actions improving the driver's driving pattern increase the fleet safety and efficiency. In addition, trucks breakdowns can cost the company a huge amount of money and time. Fleet manager, having the capability to monitor the engine and truck health, can predict, with the help of IoT technology, truck problems in the near future. Since, preventative maintenance costs less than reparation or replacement, the repair cost is reduced. To sum up, IoT helps companies to save money and time, to increase fleet and driver's safety, and to improve transportation efficiency[43].

5. Considerations

In today's operations, Low Power Wide area networks or cellular "internet of things" networks are suitable for most of the IoT applications. However, the number of connected IoT devices and the amount of data generated will extremely increase. Statista Research Department predicts that around 76 billion "internet of things" devices will be connected worldwide by 2025. According to the International Data Corporation (IDC), these devices or sensors are going to generate around 80 Zettabytes of data in that year. The actual networks will not be able to handle this increasing number of connected devices and amount of data generated. But new cellular networks, such as 5G, with its added benefits will obviously do the job. The major benefits of 5g are a higher transmission speed, lower latency, and higher number of connected "internet of things devices. Transmission speed can reach up to 15-20 Gigabytes per second. With the exploitation of this high transmission speed, lower number of processors are installed in IoT devices because computing could be done in the cloud. Lower number of processors installed means lower IoT devices cost. The decreasing cost of IoT devices will encourage many more companies to implement IoT technology in their facilities. Latency is the time required for data transmitted by the IoT device to reach the server, and for the server to process the data and send back response. In 5G networks, the latency is going to be ten times less compared to the latency of other networks. The low latency will allow the "internet of things" devices to communicate with each other and with the cloud servers in real time. This real time communication will boost the expansion of smart houses, smart manufacturing, smart warehouses, smart cities, smart cars, and etc. While in today's cellular networks, only a limited number of IoT devices (5000-6000) could be connected in a single cell, up to one million IoT devices could be handled by a single 5G cell. With all the benefits provided, 5G connectivity is going to be the key to the growth of the "internet of things".

In this thesis we have discussed how IoT technology is transforming, improving, and empowering the supply chain activities. In the forthcoming years, "internet of things" technology is going to change the way individuals live by offering high levels of services. Smart houses, smart cities, smart warehouses, and smart cars are just few examples where IoT technology will have a huge impact. The smart house we have seen in science-fiction movies is not a reality yet.

But, thanks to the advancements in IoT technology, big data analytics, and artificial intelligence, the smart house will certainly become a reality. In the near future, our houses will be gradually filled with more IoT devices. This trend will continue to grow until we live in smart houses where intelligent devices are capable to control our household tasks. For example, smart fridges can order groceries when we run out of milk or eggs. This will certainly change the way we used to live. In addition, our cities, with the help of "internet of things" technology, will be smart. In a smart city the security is increased, the infrastructure is improved, and the traffic congestion is mitigated. Traffic congestion and finding a free parking spot are the major problems facing any driver. With the implementation of smart technologies in a city, the driver could be informed about the traffic condition on a specific street or highway. The driver could be as well informed about the location of a free parking spot without the need to drive around. Acting accordingly, the driver can avoid traffic jam and save time and fuel. Face recognition, empowered by "internet of things" technology, is a way to make our streets and houses safe. The IoT technology is as well capable of determining the streets, bridges, and rails that need reconstruction, and also the level of their degradation. Smart streetlamps, which turn on only when a person or a car approaches, can save a big amount of money. Barcelona, using smart streetlamps, is saving around 40 million US dollars per year. Additionally, thanks to IoT sensors implemented, a car could easily receive information about its surroundings. Therefore, autonomous driving vehicles are on their way to become reality in the near future. To sum up, all the advantages provided by the "internet of things" technology will certainly change how people used to manage their life.

6. Conclusion

“Internet of things” technology as well as its impact on supply chain activities are discussed in this thesis. “Internet of things” consists of inserting sensors in regular or physical objects. The sensors sense the external environment and collect information accordingly. The collected data is sent, through a network, to computing servers to be processed and analyzed in order to deliver values and services to the user. Different types of sensors are presented as well as their benefits. The study shows that both active and passive RFID sensors cover a wide range of IoT applications, which is the reason why they are one of the preferred and frequently used sensors in IoT. In addition, different types of connectivity options are discussed and compared. The best connectivity option is the one which has vast range, is able to transmit lots of data, and consumes very little power. Unfortunately, this perfect connectivity type does not exist. Each available connectivity type is a tradeoff between range, power consumption, and size of data that can be transmitted. Since most of IoT applications do not require transmission of large amount of data, Low-Power Wide-Area Networks are the best solution. LPWANs transmit small amounts of information, which the reason why they can operate with low power consumption and high range. LPWANs characteristics are enormously useful for different “internet of things” applications. Moreover, the two different data processing options, cloud and fog computing, are analyzed. Regardless of the fact that cloud computing has various advantages, it is insufficient to meet the requirements of many “internet of things” applications. To solve the problem, some data processing resources are brought to the edge of the network. This concept is called fog computing and it is a much better solution for IoT. Finally, the benefits of IoT technology in inbound logistics, production, warehouse activities, and transportation are discussed and analyzed. The analysis shows that “internet of things” technology is having a huge impact on the supply chain activities. This impact of IoT, in the near future, will not be limited to the manufacturing industry, but it will also change the way we used to live.

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