Admont

D7.1

System specification and system related pilot line requirements

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Abstract:	This deliverable will present the market study regarding RFID sensor systems and the requirement specification for the RFID Sensor Chip.
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Executive Summary

This report makes clear that the Internet of things (IOT) will have a substantial impact on retail, asset management, supply chain management, (perishable) product monitoring, health management tracking, production optimisation and deployment as well as impacting consumer markets with smart home appliances and wearable devices. RFID will play a role in all of these specific activities, either as a passive unit or as active logging devices to track and record sensor information. All marketing reports indicate a substantial role for RFID in an IOT framework, and thereby RFID elements such as tags, readers and associated infrastructure will experience and a tremendous market growth in the next five years till 2020 and probably beyond.

In retail, the focus of RFID will be item level tracking and shelf management i.e. how can the items on the shop floor be effectively managed, and how can stores effectively utilise existing stock for fulfilling online purchases. Supply chain management will utilise RFID to continually monitor the objects during the production cycle and after it leaves the factory and arrives at its next station i.e. end customer. Customers can then obtain RFID tracking information during transport and data logging of the transport environment by RFID data loggers. This is most relevant for the area of perishable product monitoring, In health management, RFID will provide a substantial simplification of patient monitoring and tracking, and asset management within a hospital. This is also applicable to RFID enabled smart cabinets. RFID transponders will be implemented in a production environment, in particular for the focus area Industrie 4.0, which can simply be tracking, but may also extend to include production relevant information on tags for IOT enabled process toolings. Consumers will experience RFID extensions into packaging, wearable items and smart clothing, in particular in a smart home environment, which gains substantially from RFID enable devices being available for information transfer and data logging.

For the RFID chip devices of the future, a specific emphasis on the following is required in order to fulfil the IOT needs

- Both passive and (semi-)active functionality is required,
- Long read range to enable reads in large areas, e.g. shop floors or warehouses,
- Unique identification,
- Data logging capabilities,
- Extended memory capacity,
- Extension of functionality with additional sensors,
- Standardised bus interconnectivity to peripheral systems
- Integration on or in objects (e.g. packaging, clothing),

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Chapter 1 Introduction

The following report introduces the role of RFID in specific markets in the context of Internet of things (IOT), which will have a substantial impact on retail, asset management, supply chain management, (perishable) product monitoring, health management tracking, production optimisation and deployment as well as impacting consumer markets with smart home appliances and wearable devices.

RFID will play a role in all of these specific activities, either as a passive unit or as active devices to track and record or log sensor information. This necessitates a necessary work around on the current thinking of RFID transponder devices, but the focus of this report is to show which markets can be impacted by the extension of RFID usage and capability.

Many marketing reports will be briefly described which indicate a substantial role for RFID in an IOT framework, and thereby RFID elements such as tags, readers and associated infrastructure will experience and a tremendous market growth in the next years. However, the focus will be also at a technical level, in order to specify the requirements of the chips for these applications.

Chapter 2 Internet of Things (IoT)

The term “Internet of things” can be described according to the following widely cited definition:

“A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual ‘Things’ have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network.” (1)

This is a lot at once, so it is probably useful to view this in a historical perspective to get a fix on what this means. The Internet and whether this is between people or things is simply a method of transmitting information. Even as recently as 1970, the transmission of information was mainly done using paper. Automation of order processing and manufacturing environments using computers led to the first simplification of data collection and transmission. This factory or local level of automation expanded rapidly outside of this environment after widespread adoption of personal computer in homes and extended introduction of the internet. The transmission of information was now easier and more extensive. Despite the changes made in information transmission, the objects produced with greater efficiency as a result of automation have not changed substantially. The main difference between the new smart devices and those one commonly used in the past consists into embedded data processing and interconnection capabilities.This implies a large amount of data to be managed and requires new models for deploying and managing these IOT objects (2). This is by definition an extension of the current Internet in which began firstly as interconnection between computers, later shifting that to interconnects between mobile devices and especially smart phones and will probably find its final conclusive implementation in these smart objects (3).

To enable this IOT infrastructure, an architecture consisting of 4 specific layers is required to implement it across its hardware and software elements (4), (5)

- Sensing layer: unique identification of the object and ability to sense environment and neighboring smart objects at a local level. It has the capability can communicate with external network and /or receive and implement appropriate commands from network.
- Networking layer: this is a global level interconnection of smart objects and aggregation of data from different smart objects, assign roles to smart objects to deploy and manage specific implementations or commands.
- Service layer: middleware level, enabling data storage, search and enables interaction to the objects and planned service.
- Interface layer: in brief, plug & play capability. How does a smart object interject into an existing smart object space, and how does this space recognize and integrate this new smart object into its current space.

A specific similarity of these smart objects to computers and smartphones is that the objects also have a virtual representation in an Internet context such as having an IP address or a unique identifier. A specific difference compared to your standard computer or mobile phone is that the objects are ubiquitous, but may not be self-evident, and may connect directly to the cloud in order to exchange specific data information. These smart objects can be either multiple configuration items or simplified objects which have some specific identification but may also have a sensor function. With the sensors the objects can be aware of their context, can connect to nearby smart objects, can connect to the cloud or to specific internet services, and most importantly can interact with people. In some way the smart objects are a simple digital extension of an existing object, but achieve an additional value for our benefit. This is already becoming evident in practical everyday devices such as cars, fridges, washing machine, electricity meter etc. (6) (7) (8)

The smart object should address the following needs:

- Communication and cooperation : connectivity via wireless protocols such as Wi-Fi, RFID (NFC, UHF), Zigbee, Bluetooth, LTE etc. either with central servers or with neighboring smart objects
- Addressability: directed, contactless interfacing with the smart object (4)
- Identification: specification of a unique object, either directly via Wi-Fi or via a mediator, e.g. smart phone (4)
- Sensing: evaluation of a physical state, e.g. temperature, pressure etc.
- Embedded Data Processing: implementation of an application specific chip to summarize and evaluate data, which is to be transmitted.

RFID is an enabling technology for the Internet of things as it has the ability to uniquely identify a specific object. This already finds its way in a retail context of inventory tracking, where a contactless information transfer enables the automatic identification of objects in specific locations, such as in a warehouse, in a store, or during transport. The specific extension of RFID in the context of IoT is that the movement of goods or objects with unique identification is performed automatically. This can be utilized in a warehouse or store, allowing order fulfillment to identify and track items being prepared for delivery, and stock turnover automatically registers the need for item replacement (6). Therefore, RFID fulfills one of the primary requisites of the IoT construct by identification of a single object, i.e. thing. RFID alone cannot enable IoT to sense an environment, but with the unique identifier associated with the RFID chip the object can be identified and the relevant information can be retrieved. (4) (8) (9)

Chapter 3 RFID in brief

This is a brief overview of RFID, in order to inform a non-expert on general concepts and terms. More extensive information can be found for instance in the references (6) (9) .

Historically, RFID utilized for access, e.g. ski tickets. operated at limited distances (< 10 cm) utilising the high frequency (HF) 13.56 MHz frequency range, allowing contactless communication between RFID reader and RFID transponder tag via inductive energy coupling. The RF field not only is used for the data transfer but also for the contactless energy transfer to the tag coil. As for all RFID systems, a RFID reader connected to a computer sends commands and receives the response from the RFID tags. Common RFID chips in the early adoption were for example the Philips / NXP MiFare family. That said, semi-active and active HF RFID Tags also used a battery, which allowed continued operation of the RFID chip in absence of a high frequency 13.56 MHz field. (passive tags get their energy from the RF field, semi-active and active tags also have a battery, but semi-active do not power the RF engine, whereas active tags power the RF engine from the battery)

The HF 13.56 MHz frequency range is not the only frequency range utilized for RFID applications. The following frequency ranges have been utilized by most of the principal RFID chips and transponder tags over a number of decades:

- Low frequency, LF : 100–135 kHz
- High frequency, HF : 13,56 MHz
- Ultra-High frequency, UHF : 868 MHz (Europe) / 915 MHz (USA)
- Microwave : 2,45 GHz und 5,8 GHz

The common characteristics of the frequency ranges and the common applications are shown in Table 1.

For the IOT RFID application space, only a subset of these frequency bands are specifically relevant, these being the long range UHF frequency range and short range HF frequency band, whereby only a subset of specific ICs and tags in this frequency range are currently IOT relevant, namely NFC chips and tags (NFC : near field communication)

In the frequency ranges 868 MHz (for Europe) or 915 MHz (for the USA), the energy transfer to the transponder antenna takes place via electromagnetic coupling. The electromagnetic wave from the antenna generates an alternating voltage in the antenna structures, which is then rectified by the UHF chip, provides power to the chip itself. The antenna construction is typically dipole-like, although other types of antenna constructions are available. Typical read ranges for these UHF transponders are much longer than in case of HF RFID transponder and lie generally between 3 and 6 meters. Under certain environmental conditions also larger read ranges of up to around 14 m can be achieved (6) (9).

	HF RFID	NFC	UHF RFID
Frequency	13.56 MHz	13.56 MHz	902 – 928 MHz N. America 860 – 868 MHz Europe
Read Range	10 – 20 cm	< 10 cm	< 3m EU 0.4W 3-6 m EU 2W 5-7 M USA 4W
Read Rate	50 tags / sec	Std. 106 kbit/s Max. 848 kbit/s	50 kbit/s (alt?
Memory Size	64 – 256 bits read/write	64-888 bits read/write	64 – 2048 bits read/write
Power Source	Inductive / Magnetic Field	Inductive / Magnetic Field	Capacitive / Electric Field
Advantage	Low Cost Standard Frequency	Low Cost Standard Frequency	High Speed Longer read range
Standard	ISO/IEC 14443	ISO/IEC 18092, ISO/IEC 21481, NFC Forum	ISO/IEC 18000-6C
Tag ICs suppliers	NXP, Infineon, …	NXP, …	NXP, Impinj, RFMicron, …
Common ICs	Mifare	NTAG	UCODE Monza5, Monza6

Table 1: Comparison of HF RFID, NFC and UHF RFID (7) (10)

A specific concern for IOT applications is smart object uniqueness, i.e. the ability to be singularly identified. Although this may seem obvious now, this was certainly not self-evident until the start of the last decade, and was made possible through the work of the Auto-ID center at the MIT. This has since been taken up by the EPC Global consortium (7).

The core element of unique identification is the Electronic Product Code (EPC). This has its origins in the common barcode. Besides the vendor and product number typical of barcodes, the EPC contains an additional serial number which is used to uniquely identify the article. This EPC can be stored on the RFID transponders and allows the unique identification of an individual transponder and the item which is associated with this transponder (6).

The standard EPC transponder coding has the EPC code may have a filter value, if this is necessary, so that the EPC transponder can be effectively and efficiently read.

Since only the EPC is located on the RFID transponder, an Object Naming Service (ONS) was conceived, which would associate the EPC to the physical object. The implementation of the ONS today is a cloud service, which takes the EPC and identifies the associated information to the product in the cloud.

The EPC is broken down into 4 elements which represents a meta coding scheme: Header, EPC Manager, Object Class and Serial Number. The header defines the EPC format. EPC manager identifies the company. The Object identifies the product type or class from the company. The serial number is then used for unique identification individual objects of this object class.

This EPC meta coding scheme is managed by the EPC consortium and takes in the historical requirements of different branches which add derived from the original barcode naming scheme. As a result of this the EPC supports a number of schemes, usually GID (Global Identifier), SGTIN (Serialized Global Trade Item Number), SSCC (Serial Shipping Container), GLN (Global Location Number), GRAI (Global Returnable Asset Identifier), DOD (Department of Defense) and GIAI (Global Individual Asset Identifier). In each case there is either a 64 bit scheme or a 96 bit meta coding scheme, but for GID there is only a 96 bit meta coding scheme.

Within the specific meta coding scheme for the EPC there are number of ways of representing the EPC code which facilitates the storing of the EPC in RFID memory or its utilization in a database where specific software systems can be used to search, find, copy and associate the EPC with a manufacturer relevant information such as object, production time, factory etc. This possible representations are listed here below, which are called generally levels [5]:

- **Binary** : The EPC is stored in physical transponder format.
- **Transponder encoding URI**: The EPC meta coding includes all information that are located in the binary representation in text form.
- **Only Identity URI**: Used by parent applications that do not need all the information in the physical transponder.
- **Legacy code number:** Encapsulates an identifier in an EPC identifier in GS1 Legacy format (Global Standards 1).

The translation between binary and transponder encoding URI is possible in a straightforward way and as defined by Tag Data Translation standard of the GS1 EPCglobal consortium. However, there is no possibility to translate between the different meta coding schemes, i.e. GID cannot be translated to GSTIN

An example of the different representations of the same EPC code for the SGTIN-number 10075720000814 is shown in Table 2. A typical data sheet description of a UHF chip will contain thereby the following relevant information on whether it is EPC conform e.g. This RFID chip is EPC Class-1 Generation-2 (Gen2) IC compliant with ISO/IEC 18000-6:2010 Type C. Each chip is manufactured with a 64-bit Unique Identifier to ensure full traceability.

Level	Value
Binary	001100000111010000000100100111110010000001100001101111 000100000000000000000000000000000000000000
Only Identity URI	urn:epc:id:sgtin:0075720.100081.0
Transponder encoding URI	urn:epc:tag:sgtin-96:3.0075720.100081.0

Table 2: Different representations of the SGTIN number 10075720000814 (11)

The second most important specification for the usage of RFID in a general context is the anti-collision specification. This is important because the RF field is a homogeneous field emanating from the sender / receiver and as a result can communicate with all tags in the field at the same time. This normally means that all tags in the RF field respond to the ASK command and return their EPC code or UID. However, only one of the specific objects may be of interest and this must be **isolated** from the other objects in the field. The way this is done is called anti-collision (9).

In the *broadcast* mode of the reader, all transponders in the field receive the information simultaneously. Then all transponders transfer their information to the reader, in a *multi-access* communication mode. In this mode, the communication channel capacity is limited, as defined by the bit transfer rate and the RF field availability. In multi access mode, the capacity needs to be divided to each transponder in the field without mutual interference, in jargon, without collision.

In addition, RFID is characterized by usage in a mostly periodic fashion where the transponder may be in the field for a short time and authentication, read and write has to take place in a few milliseconds. After that there may be no transponders in the field for some time. However it can also occur that there are several transponders in the field at once. The multi-access procedure must detect the correct transponder in a short time and perform the action without alteration of the other transponders in the field. A technical procedure (access protocol) that facilitates the handling of multi-access without any interference is called an anticollision system or protocol.

This is a common problem in radio technology. Four different procedures try to overcome this. These are space division multiple access (SDMA), frequency domain multiple access (FDMA), time domain multiple access (TDMA) and code division multiple access (CDMA).

SDMA reuses a specific frequency range by limiting the size, i.e. space of the interrogation zone. In this way the range is limited but this is compensated by using a large number of limited range readers. Interference is avoided as a result of this implementation. This concept is used to track for example marathon runners. Mats with readers along the route read the runner transponder and thereby are able to collect a considerably larger moment of information using a very specific technique (9).

FDMA is the division of the frequency band allocated for RFID frequency into several channels. All frequencies are available in the interrogation zone, and the transponders respond on a specific frequency, thereby preventing interference by using different on different communication channels. The disadvantage is the high cost of the antenna system due to the number of frequency ranges which have to be made available.

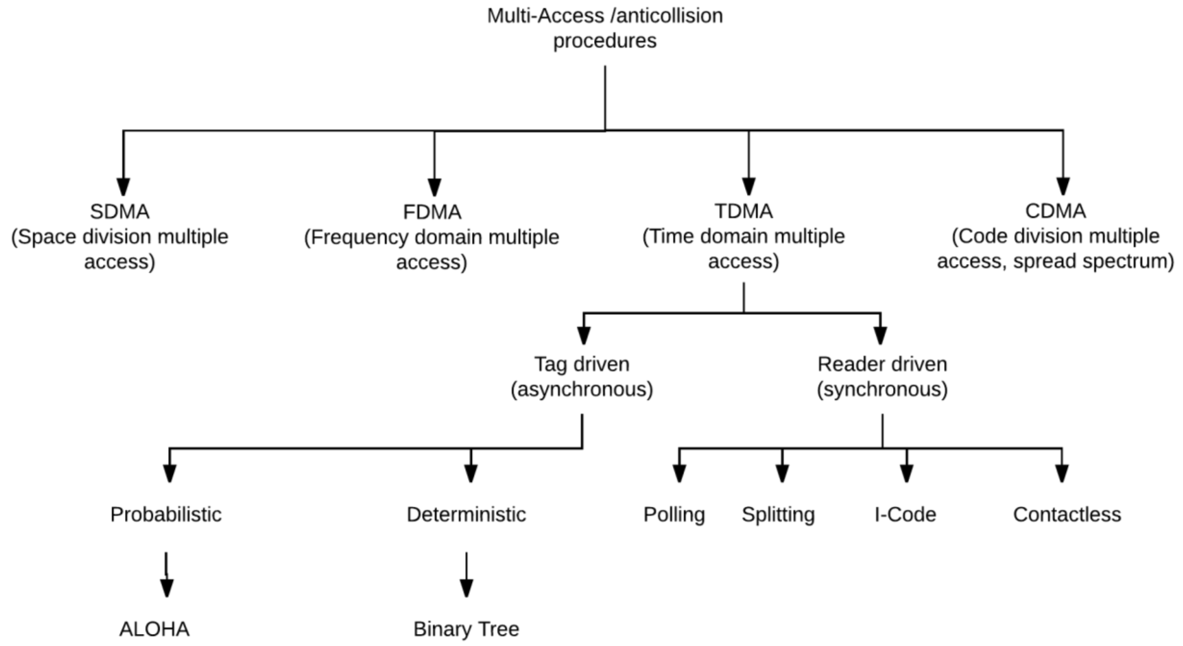

Figure 1: Anti-collision procedures

TDMA divides the entire channel capacity between the participants chronologically. In RFID, TDMA is by far the most widespread method of anti-collision procedures. In TDMA the tags in the reader’s field transmit their data at different moments in time. However, one must distinguish between transponder driven and interrogator driven procedures (probabilistic or deterministic procedures). In both cases however, the basic requirement is for each transponder to have a unique identifier to enable each tag to be identified.

Most applications use procedures that are controlled by the reader as the master (interrogator-driven). All tags are controlled and checked by the reader simultaneously. A specific transponder is singulated, authentification, read & write takes place, and then the data transfer is terminate and the reader moves onto the next transponder.

A transponder driven, probabilistic procedure is the ALOHA procedure, since the reader does not control the data transfer. In ALOHA, the reader broadcasts to all tags in the vicinity. In multiple tag environments, which are using passive tags (tag is on in RF field) the tags transfer their packets in every frame, so that the collision is likely. The likelihood dramatically increases, when there are a lot of tags and the ALOHA becomes inflexible.

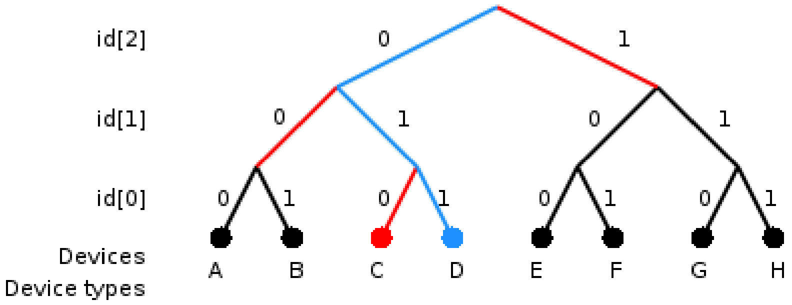

Figure 2: Tree search procedure in deterministic TDMA reader driven tag singulation (12)

This transponder driven ALOHA procedure can be optimized by an interrogator procedure called slotted ALOHA (S-ALOHA) procedure. In this procedure, the transponders transmit their data in specified points in time, thereby controlled by the reader. The occurrence of collisions is reduced in half, as the data packets can only be made available at the specified time interval, and not in a random manner.

For the deterministic protocols, which come under the classification of tree-based protocols, each tag is a node in a binary tree (see Figure 2). A sequence of commands and responses between reader and several transponders is performed with the objective selecting any desired transponder from a large group. This will only work, if each transponder has a unique identifier.

The binary search tree begins with the highest possible identifier in binary code, and then searches for collisions in the returned binary codes, which occurs when more than 1 transponders returns its unique identifier. A bit wise search of the returned transponder serial numbers enables the identification of collisions. A common procedure is the Manchester code which basically identifies 0 and 1 bits in the decoded data stream at the reader by the positive or negative transitions associated with 0 and 1. A collision occurs when the transition is not found within the length of the bit.

By using the collision positions along the sequence of bits for the returned data stream, the number of tags in the interrogation zone can be approximated, and possible tag unique identifiers are calculated based on the correct parts of the existing data stream. Sequences of possible identifiers adjusted the collision information are sent, and this reduces the tags responding to a subset of tags, which also have collision information in the data stream. By repeating this procedure and noting the position of the collision on the data stream, the tag code can be identified. Using a select command, only the identified transponder responds to the read and / or write commands and is then is sent to silent mode after the data transfer. This procedure continues to the other tags until completed. (9)

There are simplifications of this procedure, e.g. searching only for tags which correspond to a specific set of start bits, but the general procedure remains the same. The reader asking sequentially all tags with a serial number that starts with either a 1 or 0 in the EPC binary form to respond. If more than one tag responds, the reader might ask for all tags with a serial number that starts with 01 to respond, and then 010 etc. This simplifies the search procedure, but still utilizes the general concept illustrated above.

Due to the prerequisite of a specific tag unique identifier e.g. EPC in the context of Internet of things, the anti-collision procedure as outlined above enables the reader to

- Search and Find the unique identifiers or EPC codes of all tags in the reader RF field.
- Select the RFID tag with a specific unique identifier or EPC in the RF field
- Transfer information only from and to this selected RFID tag
- Send the tag to silent mode so that data transfer can take place to other tags in the RF field.

This is important in the specific context of Internet of things: the unique identifier is required to distinguish similar tags within the reader RF field. Many applications can then use this identification or "singulation" procedure to enable the recipient to strictly recognize the different identities of the existing tags in sequential way. The concept is provided in the standard RFID elements and is also included in EPC Gen 2 Class 1 standards, and is now finding widespread use in the future applications. (13)

Chapter 4 Market assessment

Many different interpretations exist about the Internet of things, which today would be synonymous with the wireless connectivity afforded by smartphones and in the future by smart-glasses and smart-watches. According to Gartner Research, in 2009 there were 0.9 billion sensors and 1.6 billion personal devices, which have unique identification, but by 2020, this number will grow to become 30 billion things. Gartner projects that the total economic value-add for the Internet of things will be $1.46 trillion euro by 2020. Research firm, IDC, predicts 212 billion internet of things by the end of 2020, including 30.1 billion installed connected autonomous things concurrent to Intel predictions for 31 billion connected devices. (14) (15) (16)

These set of networked devices and sensor elements will result in an ever increasing flow of data which would have to be collected, stored, analysed and acted upon. This is an important driver for the cloud computing, where the information is sent from somewhere to a cloud storage area, which allows an application interaction to analyse this data. The added value which results from these predictions is not only for physical devices, but also tools, systems and facilities which allow utilization of this information.

The number of these previsions can be slightly different if considering active devices (e.g., smart phones or watches) or passive devices (e.g., RFID tag), which passively waits until there is a data request by an external query (from reader, smartphone etc.). Passive tags can have a much more widespread implementation in an Internet of Things space, in a way similar to barcodes, without ever really registering their presence and importance.

As shown in Figure 3, many factors will enable this economic value of Internet of things to be reached. There will be revenue generated from the sale of “things”, but there will also be an essential economic impact from the software, infrastructure and security features which come with data collection, protection, analysis and storage. In the next years, business processes of logistics, manufacturing, information technology, research and development and business models implemented in sales, marketing and corporate strategy will undergo an enormous change based on a fundamental impact caused by this data assimilation and integration, which is only possible via the Internet of things.

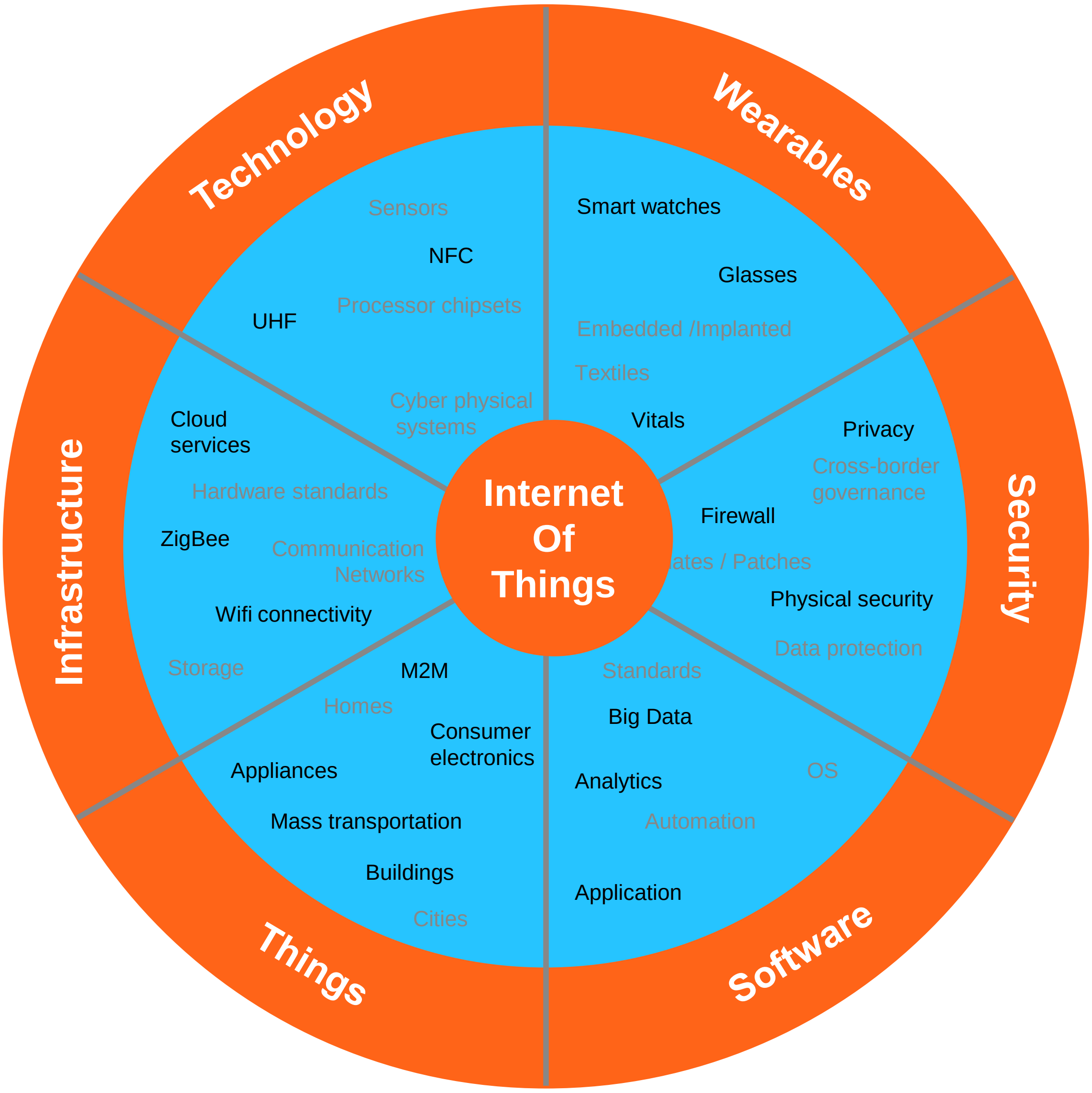

Figure 3: RFID / NFC as an essential technology base for the Internet of Things Ecosystem (17)

4.1 Importance RFID to Internet of things (IOT)

The implementation of an IOT space requires essential parts from the ecosystem, which will include RFID and NFC Tags. RFID has always been associated with the tagging and identification of products. This is a generic baseline structure for a range of systems using HF and UHF RFID Tags for public access, logistics, inventory control. Recently introduced, NFC RFID tags use a specific protocol employed in mobile devices (NFC enabled!) such as smartphones, which allows communication to another NFC enabled device i.e. NFC Tag. Currently, there is little vertical integration, and the value chain can be roughly divided into RFID tag manufacturers, readers, middleware providers and system integrators.

Both RFID and NFC Tags employ specific device communication protocols in HF frequency band – 13.56MHZ – most importantly IEC-ISO 14443 & IEC-ISO 15693, and in the UHF frequency band - 860-920 MHz – with the communication protocol standard IEC-ISO 18000. This allows usage of HF and UHF RFID silicon chips from a number of chip suppliers (e.g. NXP, Infineon, STMicroeletronics, EM Microelectronic, IMPINJ etc.) whose functionality conforms to these standards, and allows usage in generic reader systems designed for these standards. Theoretically, chips from different manufacturers can be employed in the same RFID tag and exchanged as required. Practically, as in all industries, technological advantages in read range, sensitivity and more practical issues such as memory size allows for chip suppliers to specify chip types for different market segments.

Unique to each RFID and NFC tag is a so called Electronic Product Code (EPC). The EPC is an identifier of items (e.g. cases, pallets, locations, etc.), which replaces older GS1 System identification numbers, such as UID, VIN, and others. This EPC is the key item of the RFID or NFC tag which will enable Internet of Things. Its purpose is to uniquely identify every single instance of an object which has a RFID and NFC tag attached to it i.e. every jar of jam, every bottle of water, every product sold or produced with an RFID tag will have its own unique identity (17). This will obviously have a major impact on logistics, merchandising, and manufacturing processes and how objects are tracked, categorized and sold.

The importance of this fundamental change is understood by SMARTRAC. As the largest RFID tag producer in the world, SMARTRAC has announced in 2014 a plan to seed a new platform by adding a secure link, tag identification credentials and supplementary data to the more than 1.5bn RFID and NFC tags it produces each year (18) (19). Businesses and consumers will then be able to use these data and the Smart Cosmos platform to associate tagged products with cloud-based applications. This is the first stage of the data assimilation process for the Internet of things, and the HF, NFC or UHF tag plays a central role in this implementation.

4.2 RFID in Retail industry

The retail industry is one of the largest users of RFID right now. This is set to increase dramatically in the next years from predictions from relevant sources. This adoption increases not simply as a barcode replacement, but due to the fact that RFID enables data collection to cloud applications, which can present actions based on cloud data analysis.

On the passive side IDTECH estimates that in 2014, the market for RFID tags was €9.18 billion, up from €8.6 billion in 2013. In retail, there will be a demand for 4.6 billion RFID labels in 2016 which is still only 15% of the total apparel market. Ticketing and access reaches 800 million tags in 2016, and tagging of animals 425 million pieces. Approximately 8.9 billion tags will be sold in 2015 and 10.4 billion in 2016, with most of the growth coming from passive UHF RFID (RAIN RFID) labels. Growth to 2026 is expected to reach €18 billion, which would be a market increase of 100 % over 10 years. (20)

In 2015, 80% of the RFID systems deployed in China are based on HF RFID (operating at 13.56MHz), but RAIN RFID implementation is gaining ground, with UHF chip design and manufacture listed as one of the priorities of China's IoT development with respect to funding. (21)

By 2020, the market volume of 50 billion RFID tags in the retail sector is now being estimated. Much of the current growth will come in particular for UHF RFID for use in storage and shelf management. In 2020 around 25 billion RFID tags will be used in the clothing and footwear retail be and a similar number in other products with high visibility. Now China has also rapidly become a large exporter of RFID, going from having a global market supply share in UHF RFID inlays of less than 10% in 2012 to 30% in 2015, mainly used to tag apparel by clothing retailers around the world. [12]

Branch	Units [Millions]	Types
Drugs and healthcare	398,00	
Retail apparel and CPG Pallet/case	9.295,00	UHF
Consumer goods	170,00	
Tires	0,10	
Postal	83,00	
Books	1.420,00	HF
Manufacturing parts, tools	1.963,00	UHF
Archiving (documents/samples)	49,70	
Military	658,00	
Smart cards/payment key fobs	9.400,00	HF
Smart tickets	3.515,00	HF
Air baggage	561,00	
Conveyances/Rollcages/ULD/Totes	760,00	
Animals (Livestock and Pets)	1.861,00	LF
Vehicles	260,00	
People (excludes other sectors)	219,00	
Car clickers	939,00	LF + active RFID
Passport page/secure documents	560,00	
Other tag applications	1.788,00	

Table 3: Cumulative tags sold per branch 1940-2015 (22)

Application	2013	2014	2015	CAGR
Retail : apparel, shoes	2.250,00	3.000,00	3.750,00	25%
Retail items, other	25,00	50,00	90,00	80%
Logistics, roll cages, conveniences	125,00	125,00	130,00	4%
Asset management inventory documents	450,00	475,00	510,00	7%
Medical/healthcare	18,00	23,00	38,00	65%
Air baggage and cargo	72,00	74,00	74,00	0%
Access Control/ticketing	1,50	2,00	3,00	50%
Embedded	0,10	2,00	5,00	150%
People	22,00	24,00	30,00	25%
Other	65,00	70,00	75,00	7%
Total	**3.079,00**	**3.845,00**	**4.705,00**	

Table 4: UHF Tag sales in 2013 – 2015 (22)

Examples of this implementation include announcements from the Inditex Group announced in 2014 that it will implement RFID-based Inventory Intelligence from Tyco across its entire Zara chain in 22 countries, in order to provide accurate visibility into all merchandise styles, colors and sizes (23). Gerry Weber has announced in 2016 similar implementation on its 30 million pieces of apparel where RFID inventory tracking will be used to facilitate storage and shelf management, including receiving, replenishment and point of sale support (24)

Smartrac is currently developing solutions based on its SMART COSMOS platform to facilitate inventory shelf management in store in corporation with INTEL for Levis. Current demo status in a few stores is planned to be extended to regional store locations as the initial indicators have yielded positive effects in terms of sales and store management. Obviously the basic item level tracking unit is an RFID tag, in this case a UHF (RAIN) RFID tag. [Smart Cosmos / Levis]. Levis has been an early adopter of this technology, due to the basic similarity of jeans in a store. Waist, length and styles are the parameters for a Levis jean in a store, which makes locating a specific item requested by a customer quite difficult, if this moves from the original position on a busy day. The objective is shelf management: locate out of place items and replenish out of stock items.

A similar solution is provided by Tyco Retail Solutions inventory visibility which also uses radio frequency identification (RFID) technology, also based on UHF RAIN RFID tag technology. These solutions provide a methodology to track inventory and maintain an accurate and efficient shelf management within a store environment (25).

However the inventory visibility as briefly shown above does more than just simply track if the items are available on the shelf and in the storeroom. It also creates visibility outside of the store to a central cloud server, which allows a correlation to incoming orders. A specific example is the possibility to order clothing items from Gap by the Lucy hotel app, as this may have been forgotten to pack prior to travelling. The additional benefit achieved by this application is that the hotel personnel will pick up this item from Gap for the hotel guest, places in their room and charge the cost to their hotel bill. This is only possible if Gap has item level visibility of items in individual stores to enable a precise locating of the ordered object in a store near to the Lucy Hotel. This item level visibility of the items in the Gap store is made only possible via RFID in particular UHF RAIN RFID, and the cloud connectivity of the current store inventory (26).

In store, using RFID technology, it is possible for customers to get fast and customized recommendations. GSTAR has implemented a solution in its stores, whereby a TV automatically shows additional information about the piece of clothing a person is carrying, and also makes suggestions on which items in the store would complement this piece of clothing. The UHF RFID tag enables the identification of the object by a reader near to the TV and this is translated to part information which leads to the presentation on the screen. Adobe and Razorfish demonstrated a similar application where a RFID tag in a shoe is read at a specific RFID reader in the store, and allows the customer to pull up more information about the production on the mobile device (smartphone or tablet). In the case here, NFC RFID tag technology is used since this enables the direct communication of a web page (26).

The item level inventory management at the shelf and in the storage area which is enabled by RFID opens the possibility to enabled two specific constructs which are still in an early stage: click and collect & ship from store. The former allows you to order online and the item level inventory management allows stores close to your location to be identified, so that you can pick the item up, or transport cost is saved as the ordered item can be shipped from the store rather than from central storage area (save cost and get the item faster) (27)

So overall RFID will play an important role in the retail industry, with UHF RFID tagged items have been the major growth potential in the next years for the reasons illustrated above. However, the RFID tag is not only a simple replacement for the barcode. It allows a more extensive and complex inventory management, which facilitates an extension to the online virtual world.

4.3 Asset management

Asset management using RFID solutions allow integration of asset related information, such as object type (computer, table, monitor etc.) with identification of the location of the assets. Asset management RFID based on UHF RFID tags will increase by 7% year on year till 2020, with increased integration of these solutions in enterprise asset management solutions and middleware (22) .

Solutions based on RFID item labelling allows identification of current location of the asset and how goods may be moved within a specified area. The RFID tag, in this case UHF RFID tag is captured by overhead RFID readers and this is then collected and analyzed by a middleware solution, to identify location, and yield this information to an application environment, such as an asset management database or asset management system software, such as IBM Maximo, Oracle, HP Asset Manager and others. The RFID middleware solutions provide an input into the enterprise asset management systems. RFID offers the advantage over standard barcode asset tracking is firstly faster than the usual barcode methods and there is a substantial reduction in the discrepancy between the expected and actual asset inventory. Indeed Gartner estimates that most organisations without RFID solutions have be at least a 30 % discrepancy (28), (29)

Therefore the key input for RFID in an asset management solution is

1. Collection of physical inventory using automated tools
2. Linking with additional information about the assets e.g. licensing information, purchase information, lease rental etc.
3. Continual actualization of the information, e.g. current location, status, software updates etc.

Obviously RFID cannot manage the latter 2 items in this list without an associated software. But without the UHF RFID tag associated with the object, there is a substantial discrepancy between the asset listings in the physical world and in the virtual world.

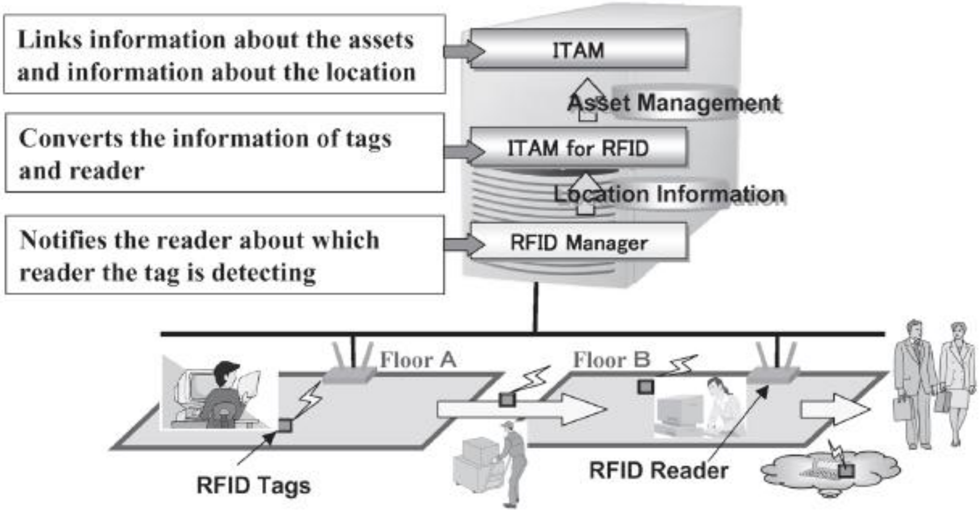

Figure 4: Outline of RFID asset tracking system using overhead readers, indicating movement tracking, conversion to location information and integration to the enterprise asset management software (28)

4.4 Healthcare Asset Management Market

The healthcare asset management market is expected to reach USD 29000 Million by 2020 from USD 7000 Million in 2015, growing at a CAGR of 34.6% (30).During the forecast period RFID in healthcare asset management can be utilized in ways such as tracking assets, managing inventory, monitoring patients, preventing objects from being left behind during surgery, ensuring patient safety and optimizing supply chain management. RFID healthcare market can be divided into unique segments such as tags, readers, smart cabinets and middleware. An example is Denmark's New University Hospital (DNU), which is expected to be the largest facility of its kind in Europe, with 100000 inpatients and 900000 outpatients annually. It will utilize RFID to track patients and assets within the building. UHF passive tags will be attached to patients, and a total of 350000 tagged assets will be monitored by 2500 fixed readers (Zebra FX7500) and 3 Zebra An480 RFID antennas. The enterprise asset management software based on the RFID tagged items and reader systems will be used to optimize the workflows within the hospital, improve efficiency, but also perform basic safety functions such as ensuring patients do not enter unauthorized zones (31)

RFID smart cabinets market is USD 784.6 million by 2020, growing year on year 11.5 % till 2020, and these allow real-time tracking of hospital inventory, in particular in OR procedures rooms (32) These use the RFID technology for real time tracking of FDA approved medical devices such as stents, implants and other medical devices. Due to the high level of safety required by such a hospital device in compliance with regulatory standards, the tagged item is usually swiped across a reader interface prior to leaving or to entering the cabinet. RFID item level inventory tracking is monitored in the smart cabinet using HF RFID tags due to the relative proximity of the object and the RFID reader in the smart cabinet. This is also probably a historical topic, since the usage of the tag (HF or UHF) requires U.S. Food and Drug Administration (FDA) approval, since the system can be categorized as medical devices, e.g. due to the use of the technology with blood bags destined for human transfusion or with sensitive drugs with short lifetimes outside of the colder storage area (33).

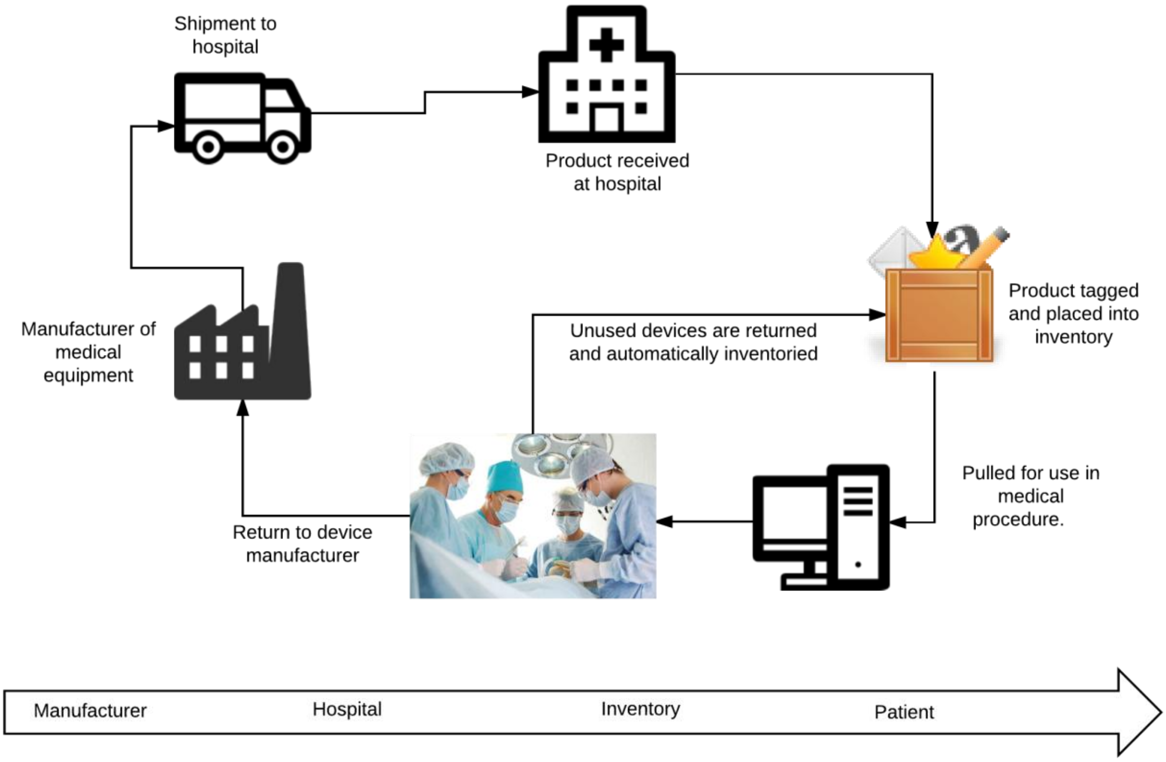

Figure 5: Smart Cabinet inventory management with RFID [Wavemark].

4.5 Supply chain management

The supply chain product visibility is substantially improved mostly by UHF RFID solutions which allow tracking of the item in the logistic network. The entire product lifecycle from conception, manufacturing, distribution, and delivery to end customer can be tracked by an RFID technology. This obviously cannot be done by the RFID tag alone, but requires the integration of the EPC code with the associated product information to enable an overview of the life cycle. In the context of a logistic network, RFID assists in maintaining product visibility when the item leaves the factory and comes to the end customer. This also includes how the product is managed in the warehouse environment with item level tracking enabled by RFID. The connected supply chain network or logistics network which is enabled by Internet of things, and will include RFID solutions, is expected to grow from USD 5.05 Billion to USD 20.46 Billion by 2020, representing a CAGR of 32.3 % (34).

One of the most important aspects of RFID usage is the substantial improvements in efficiency and effectiveness of the supply chain management. Total operation time can be saved by 81% with the integration of RFID in the supply chain and the operation time can be improved to 89%. Using UHF RFID tags attached to cartons and pallets, the read rate in the warehouse can be approximately improved by 99.5%, enabling item tracking and retrieval within the storage area (35). This is a practical way by introducing UHF antennas on to a forklift and also into the check in and check out gates of a warehouse. In this way the locations of items in the warehouse, items transported, items which have left the warehouse and items which have been brought into the warehouse can be identified and tracked. This basic solution is extended to solutions with the overhead readers which enabled position identification and robotic readers which move between shelves reading and verifying the saved positions of items in the shelves.

Figure 6: Forklift with UHF antenna and associated interrogation of the readers in operation (36)

Obviously the usage of a UHF RFID tags for the item level tracking of product, container or pallet is already present in existing logistic networks and can be extended by the introduction of these warehouse RFID solutions to allow tracking by the enterprise supply chain management software. In this way, the specification even down to item level is possible so that the origin of a specific product can be followed right back to the manufacturing plant and manufacturing time frame. In this case the growth is achieved by extending existing solutions to a broader framework and enabling middleware and enterprise application software solutions to utilise the EPC information to facilitate an IOT reference strategy. In a sense this is nothing new from a technological perspective, i.e. UHF RFID antennas exist and the enterprise software solutions exist, but now the breadth and the reach of these solutions will be extended substantially in the next years, contributing to the expected RFID growth (36) (37).

In parallel, there has been extension of the capacity of RFID systems to include additional sensor functionalities, to measure simple physical parameters such as temperature. By coupling a RFID unit with a sensor, either integrated or as two separate ICs, allows firstly identification of the sensor unit, secondly, it allows data transfer of the specific physical parameter measurement, e.g. the temperature, and thirdly, can also be combined with location information, if the RFID Sensor unit is attached at a known position contained in a database application. The usage of a RFID and Sensor requires additional capabilities such as a power source (battery) and a microcontroller (CPU + Memory) in order to enable operations on the sensor unit and transfer of data between the RFID chip and the Sensor chip.

The other aspect is the different modes of operation. A passive RFID sensor system measures and transfers sensor information when in the RF field, i.e. when interrogated. Between the first tag interrogation and the next tag interrogation, the RF field is off, and the tag does not measure any physical parameter. Therefore the information obtained is a snapshot at that moment in time when the reader activates the tag with this RF field. For fixed location units this is certainly a good solution, if the measurement is only required at certain times or after certain events. The requirement is a function of the application in question, and this will determine how often the tag is activated in order to take a measurement and transfer this information back to the reader via the RFID chip.

For concepts such as product lifecycle management, an additional logging of measurement data over a period of time is essential. This must then be done in times when the RFID and Sensor tag is not in the vicinity of the RFID field, so a battery is essential for the operation of the Tag sensor in the absence of an RF field. This is a very specific requirement, and these so called active RFID tags distinguish themselves in this requirement when compared to the passive RFID tags. There is also a requirement for extra on chip memory in order to save the measurement data prior to the transfer, as periodic measurements take place with the battery power supply (38).

A specific measurement using RFID & Sensor chip is made in a relatively small area, both for passive RFID solutions and for active ones. The advantage of both however is the low cost in combination with the capability to uniquely identify the specific RFID unit via the EPC code. For passive solutions with a RFID reader in the vicinity, several low cost RFID & Sensor tag units can be placed in a specified area near this reader to determine a good average of the physical parameter. For active solutions, individual active RFID & Sensor tags can be attached to similar product items, which results in an array of measurements for each item which have been dispersed in the supply chain logistics network to different customers. In this case, the logging feature monitors the data from the tag during transport, and communicates this data to reader via RFID at the end customer.

With increased globalization, there is a need to reduce (a) food spoilage and (b) ensure vaccines, drugs and clinical trials products are maintained at specific temperatures during transport. Therefore the market that for cold chain (cooled supply chain logistics) has had a steady growth and this will continue for the foreseeable future. RFID combined with temperature sensing can assist in extending the life of perishable goods and lead to improved food and drugs safety, and a longer vaccines and drug lifetime (39). It is estimated, that the cold chain market (refrigerated storage, chilled or frozen food, or fruits, bakery, dairy & frozen products) will increase form USD 97 Million in 2013 to USD 233 Million by 2019. Uniquely, this growth is achieved in Asia Pacific region, where India, China and Latin America are the most interesting regions, due perhaps to the higher average temperatures all year round.

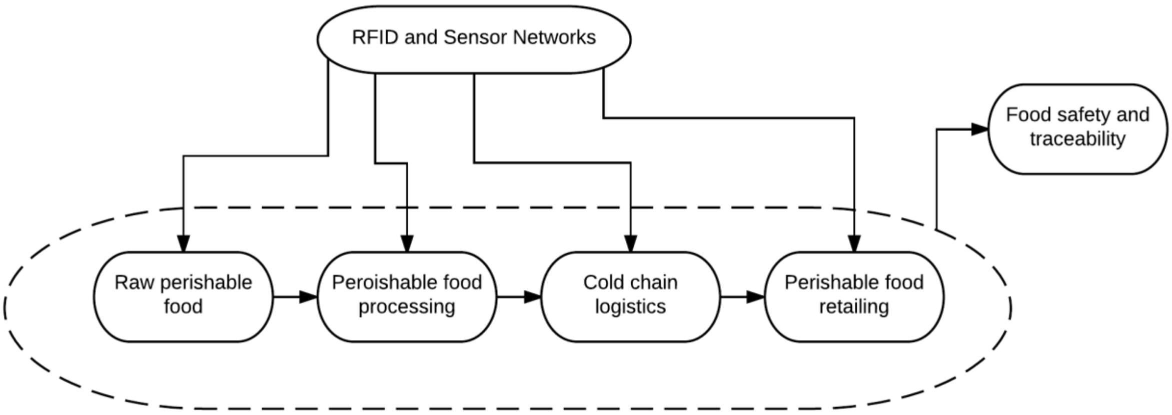

Figure 7: Cold Chain supply chain management with RFID (39)

RFID temperature loggers based on EPC Global UHF RFID standards are an important part of a cold logistic chain for supply chain management. The most common type of RFID IC which is operational in the UHF RFID tag is a CMOS integrated temperature sensor, which returns a specific value to the memory based on the temperature of the chip at that point in time. Since the temperature is measured by the chip, how the chip is integrated into an antenna structure is an important aspect for a correct measurement of the temperature at that time. A modification of the technology for antenna integration makes sense, since it will require different approaches for heat conduction from the object to the chip. In this case the specific product requirements must be taken into account. For the specific functionality, one can define specific ranges for the UHF RFID sensor chip which define the technology for the assembly and integration of the chip in a product. Three separate ranges decisively determine the configuration of the final product, and thereby the production technologies of the chip

Type A	Less than 1 second	Efficient heat transfer for chip direct contact between chip and heat conductor
Type B	> 12 hours	Thermal equilibrium No special requirements
Type C	1 minute - 30 Minutes	Both apply.

Table 5: Different types of transponder configurations for thermal RFID applications

The above requirements for efficient thermal heat transfer to the RFID sensor chip have an impact on the actual connection technology for the product. For Type A requirements, a fast and efficient heat transfer is necessary-to give a good heat transfer between the chip and the heat source. In this case, a physical connection between the heat conductor and the chip back side is indispensable. For Type B, the large time interval between measurements facilitated reduces the demands on the chip mounting process. In this case, the thermal equilibrium between the chip, the measurement point and the source of heat is guaranteed if the transponder is located in reasonable proximity to the heat source. For the C-type product, which lies between type A and type B, an efficient thermal coupling to the RFID sensor chip is required, depending on which product specifications arise. Nevertheless products approaches could be used by the other two variants of type C. The antenna must therefore be tested with respect to the product specification, and the interconnection and lamination technologies defined with respect to the product and general requirements in the table. Determining and minimizing the interaction between antenna and circuit due to the electric contact on the chip rear side must be examined by simulation and represents a major challenge.

Commercial solutions for chips with a temperature measurement capability exist from a number of chip manufacturing houses such as EM, AMS, etc. The implementation of these solutions can be utilized depending on the requirements of the product (active vs. passive, HF vs UHF).

Similar considerations can be brought into focus when considering humidity sensors. This specific difference in this case is that a CMOS integrated humidity sensor is unlikely, so this solutions focus on integration of antenna structures which enable a correlation to the actual measurement. In this case, changes in the electrical properties of the antenna structure due to the presence of moisture can be determined by specific electrical features in the chip. These can be converted to a digital value, which is in read out by an appropriate reader system. An essential point in this construct is the necessity for an appropriate antenna design. It is of critical importance in order to enable an optimized antenna structure which will facilitate the measurement of moisture by the chip due to the change electrical properties of the antenna. Structures on the antenna which facilitate greater sensitivity towards the moisture are in this case as important and the UHF or HF antenna design in itself.

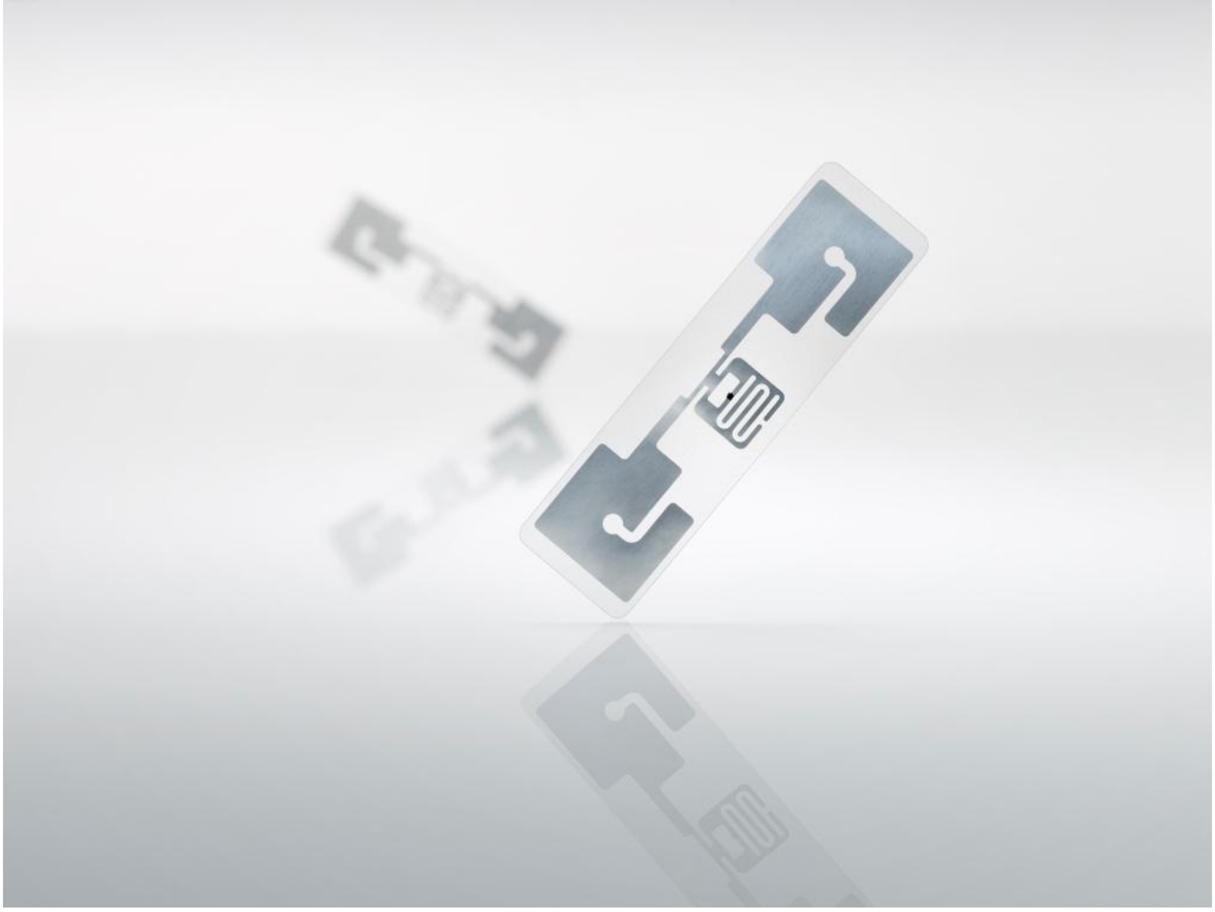

Figure 8: Smartrac Sensor Dogbone

In this respect, Smartrac has already introduced a moisture sensing passive UHF RFID tag known as sensor dogbone, which has specific additional antenna structures to enable this moisture measurement. As is expected, this tag conforms to EPC Generation 2 class 1 standards to enable an effective measurement of the moisture values by standard reader systems. In the case here, the Sensor Dogbone is manufactures with a Magnus S Sensor chip supplied by Smartrac partner RFMicron.

The alternative to a solution which utilizes specific antenna designs to allow a measurement is to utilize specific sensor structures in combination with a RFID chip. This requires an extension of the RFID chip capability to allow a connection via bus to a unit containing sensor functionality, which operates on the same bus. Common bus protocols which allow communication at low power are I2C and SPI, whereby I2C solutions are commonly found in NXP solutions for historical reasons, and SPI in many other chip manufacturer products.

I2C bus is a two wire solution using a pull up resistor connected to Vcc or Vdd, with bidirectional lines, Serial Clock Line SCL and Serial Data Lines SDA for data transfer at 100kbps (bits per second) [Interfacebus]. Data and clock signals are sent from the master, which is valid when the clock line is high. All devices relate their output levels to the voltage produced by the pull up resistors.

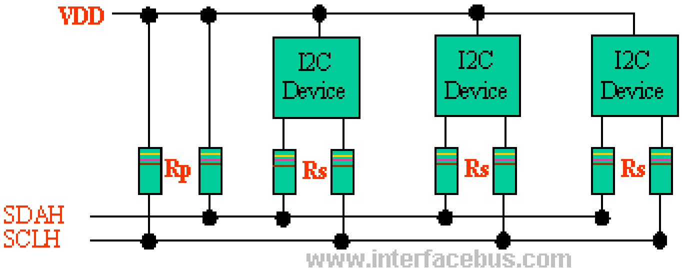

Figure 9: SPI data and clock lines connected to a number of devices. Rp is the pull up resistance

SPI, Serial peripheral interace, has a quite straightforward implementation to enable communication between two chips :

- A clock signal named SCLK sent from master to slaves.
- Slave Select Signal SSn,
- Data line Master to Slave MOSI (Master Out, Slave in)
- Data line Slave to Master MISO (Master In, Slave out)

Figure 10: SPI bus implementation [wiki]

Both of these serial buses are found in a number of commercial RFID chip solutions in order to allow the integration of an RFID chip with some other unit which operates on the same bus. Examples include NXPs NFC I2C solution which can operate in passive mode, drawing energy from the reader or smartphone (13.56 MHz RF field) , when the RFID tag with Sensor unit is in the RF field [NXP]. Similar solutions exist from ST Microelectronics, Texas Instruments, AMS, etc. [NFC World]. The solutions in these cases are on the HF range, and primarily operate in a passive mode, whereby active RFID solutions necessary for logging of data over a period of time are possible in some cased, which requires energy from a power source e.g. battery.

In the case of UHF RFID tags with additional sensor functionality, the solutions exist only in active mode, i.e. with battery, as the current drawn from a UHF RFID chip is far too low to drive a peripheral system via I2C or SPI bus. Therefore the tags which include an UHF RFID chip connected to a peripheral sensor system via I2C or SPI bus require an additional power source e.g. battery. For the HF RFID solutions, the current leaving the inductively coupled chip is much greater and can be utilized to drive a peripheral via an appropriate us independent of a power source e.g. battery. The HF RFID tag with sensor must of course be in the RFID field to obtain this driving current.

As examples of specific applications, a UHF RFID data logger for monitoring in the cold chain has been presented by [Trebar2013]. Track-It RFID Data Loggers are battery powered stand alone compact devices that record from 22.5 hours to 337.5 days of temperature or temperature and humidity data [Track it]. Agilox has a semi passive UHF RFID data logger for tracking of temperatures, and read out of the data takes place in the UHF RF field [Agilox]. Many other similar examples can be found.

An aside related to the use of RFID on IOT the but not directly relate to the content of this report is the extensive development currently taking place on the printed sensors. Combination of a printed sensor with an RFID chip would enable a contactless determination of the physical value measured by the sensor. There are sensors which act as biosensors, capacitive sensors, piezoresistive sensors, temperature sensors, humidity sensors and gas sensors. These sensors are printed on the surface of the foil, and the particular material properties of the sensor material enable its functionality as a humidity sensor, gas sensor, temperature sensor etc. Interconnection of an appropriate RFID chip to the printed sensor would enable this external communication with a RFID reader. Development work is required to design and manufacture appropriate RFID chips, which can operate on the voltage and current levels of the printed sensors, as the standard serial bus protocols may not be effective in these cases.

In some cases, the sensor simply modulates the impedance of the antenna as a result of the measurement. This can be for example changed resistance if the temperature goes over some threshold or if the moisture level has reached a certain level in an enclosed enviroment. Although these types of sensors do not directly measure a physical value, they indicate an event, thereby acting as a passive warn signal (40). Printed Gas sensors that can detect pollutants such as Carbon Monoxide, Nitrogen Dioxide, Ozone etc (41). Since this is nascent field, different types of solutions can be considered to yield equivalent results for the measurement of identical physical parameters.

4.6 Smart Factory (Industry 4.0)

In Germany, in particular, Industry 4.0 is a facilitator for the smart factories of the future. So called cyber-physical systems are present in the factory which continually overview the ongoing processes. This information is transferred to a digital infrastructure, either on site or in the cloud, and applications utilizing this information make specific decisions, or enables decisions from humans. One specific, less evident aspect of the smart factory, is the so called internet of services, where the end customer can review the status of a manufacturing process, and even introduce customer specific changes into the value chain (42).

On the granular level, the basic implementation of industry 4.0, Smart factory, or industrial internet of things is

- firstly, a real time monitoring of industrial tool sensor and actuators data, which is transferred to virtual space, i.e. local and cloud computing resources,
- secondly, application based decentralized actions based on the information from these tools to enable interoperability between tools and
- thirdly, services to collate, analyse and apply changes to existing modular processes.

The value created from this is (a) increased efficiency (equipment maintenance schedule, long term usage, process regime optimization) (b) product flexibility (user input) and (c) effective business model implementation.

RFID solutions have a reasonably important role to play at the baseline level of the smart factory, by making substation contribution to the sensor functionality of toolings and equipment present in a production line. Obviously, the tracking functionality coherent with RFID core capability is a self evident property.

Real world process optimization uses active RFID tags for labelling tools, logistical units and production units. This enables the ability to track the units within the factory floor space. The tracking is not alone relevant, but the analysis of the specific tool usage in the factory can also be called up, saved in a database and analysed by application software. On a basic level, tools can be found more quickly, when they are tracked in the resident IT system. In addition, calibration procedures, which are prerequisites in a precision engineering environment, can be coordinated better and a calibration can even take place after a specific number of use intervals, something not possible right now. This coordination takes place for all toolings within a factory unit, replacing local department determined calibration planning. In addition, localization of tooling to specific zones, enabled by RFID tracking, prevents misuse or damage to the tooling, or even to the manufactured hardware, which later may have consequences for hardware failure in field (43)

In a production process, RFID tags have an important logistical role to play in the context of a future smart factory. UHF RFID tags are again the more important tag to support this environment. It is also not any more sufficient to have simply EPC code tracking, rather an extension of the available memory on the chip is necessary in order to save real time process information to the manufactured object. In this way, the UHF RFID tags can not only function as a tracking element, but they can also carry specific information such as the production requirements of the part at the specific tool in the next process step. This is important link for internet of service, since custom specific information can be transferred to the UHF RFID tag, allow the assembly or processing plan to run according to expectation, while having reasonable flexibility to change production routing in accordance with tool availability. This enables a move to more personalized products, which normally causes additional costs, but RFID tagging could allow enough flexibility to permit custom solutions without tooling up separate production lines. More aggressive concepts would even transfer information concerning the production of the part to the tooling itself, and perform the specific stored operation on the tagged item in accordance with the assembly plan as it moves through the production line. This decentralized implementation of the production process obviously requires a substantial rethink on IT implementation of the production process to enable this functionality (44)

In terms of maintenance of the quality levels for the incoming material, and outgoing material in the supply chain and manufactured parts in the factory, RFID with a sensor elements which can maintain and monitor temperature, vibration, shock, humidity and even distance are important future elements to prevent quality issues in parts manufactured in the line. In a sense, it is an extension of QA procedures on incoming material to the supply chain which delivered the material to the factory, maintenance and extension of QA methods on the factory floor, and follow on activities to ensure that the part gets in good shape to the next stage. This requires an extension of the current RFID solutions to become active RFID elements to monitor the environment via sensor, but also participate in the production process. Clearly, power supply to the RFID tag, as a battery, or by some kind of energy acquisitions is an important component of these future RFID tags which requires more R&D effort.

Predictions on the growth of this nascent but emerging field is difficult define precisely, and quite often mixed into the predictions of growth in smart factory, which obviously includes the extension of the existing IT infrastructure. Agreements exist on one thing however: significant growth is expected and this will materialize in the mid-term (2 - 5 years) rather than the long term (> 5 years).

4.7 Wearables

Wearables is a trending item as I write this article, in particular when one looks at smart watches and that trend to develop smart glasses (Apple Watch, Fitbit, Google Glass, etc.). Each is classified as a Wearable Technology but each is clearly far more complex than a RFID tag. The connection technologies can be WiFi, or some more complex interconnection scheme, where information collected by or sent to the device goes over commonly available channels. In addition, for watch applications some geopositioning capability is a must for the general usefulness. In most of these cases, this solution is seen as an extension of the smartphone, taking up some specific functionality which is difficult to implement in a specific situation (45). For example in the fitness studio running on a treadmill is not exactly optimal with your smartphone in your hand, nevermind on a stretch of forest road. Nike has put a sensor if into their shoes which allows wireless communication with the music player or smartphone and allows stats like distance run, calories burned, etc. to be communicated to the app on your smartphone (46). Other more common but less evident examples include blood pressure watches or blood sugar monitoring technology which can connect via WiFi to allow online access and emergency alerts.

Another area of interest in wearable technologies is smart clothing. Active and interactive clothing has been available as demonstrators since mid 2000, and typically require wired battery packs and controllers, but advances in material science made integration more likely. After all, a wearable technology requires in most cases a flexible pieces of electronics, whereby most electronic in your PC, tablet and smartphone is certainly rigid. There is a lot of basic engineering required in translating what is now a piece of microelectronics on a PCB to a piece of electronics on a flexible substrate. However due to their small size RFID tags can be integrated relatively simply into a wearable technology, either as a passive tag solution, or with sensor elements or even as active tag solution performing some specific data logging function. This is probably most relevant for specific medical or health / fitness electronics, where specific body signals (temperature, pulse rate, skin moisture) are monitored. However, the down side (or upside, depending on your position in the company) can be that wearable RFID tags will allow the internet to be aware where we are, when a RF grid similar to the cellular grid has been set up. By this awareness, advertising can be triggered as we move about, and information may also be obtained on what we purchase in a store. Having active processors talking to the cloud in some way from a wearable technology, would require cellular technologies such as 3G or 4G.

Smart clothing will probably being with very practical way. There is a trend to integrate for smart home general IOT devices in basic appliances such as fridge, washing machines, dishwasher, dryer etc. which will have a WiFi or cellular connection to enable connection to the cloud. For example, future refrigerators may be semi-transparent, the opaque smart display will list the items in the fridge and also the expiry date. Similarly, the smart washing machine which has an integrated RFID reader, will know how to wash your clothes base on instructions written to the RFID tag (47).

This only possible if the RFID functionality is somehow embedded in the clothing. Idtechex predicts a growth market for pure e-textiles in the next years, which is worth approx. $100m in 2015. Clearly, what is important is the RFID capability, but also how can antenna structures or even conductive structures be integrated into the clothing, thereby enabling connectivity of some sort. This is not only of RFID relevant, but for all other types of communication interfaces, since the threads alone cannot give conductive elements for antenna structures production. The fabrics can be divided into 3 specific types:

- Passive smart textiles: sensor sensing environment based on sensors
- Active smart textiles: sensing and actuation
- Very smart textiles: sensing, actuation and adaption

The sensing elements in fabrics, upon which a lot of research has been done, are for example, ECG, EMG, EEG, and obviously temperature, pressure, and form changes sensing. Even biomedical relevant elements such as oxygen, moisture, salt etc. can be determined by these fabric sensors. However, power supply from fabrics is also an intensive area of research, since the large area available is applicable for the generation of power in some way. This can be done by piezoelectric or photovoltaic elements, but zinc oxide conductors can also be integrated in the clothing to enable energy harvesting. General print technologies such as inkjet or screen can also print the conductive materials onto the fabrics in some way, and also generate specific areas for the conductive structure in the fabric (48).

Ohmatex has already developed a range of products which makes smart textile functions easier, such as conductive textile cable and conductive elastic. Sensors utilize primarily the electrical functions of conductive threads in the fabric to determine specific body functions. Right now, the interconnect technology is Bluetooth. Theoretically, integration of RFID solutions can also implement similar connectivity (49). AIQ smart clothing merges electronics with clothing, utilizing stainless steel fibers to manufacture conductive clothing items, such as shirts which allow biomonitoring via Bluetooth connectivity to a nearby smartphone (50). Wearable Life Science has recently introduced its Antelope smart fitness clothing line. On RFID solutions, Identy Tag can deliver a UHF RFID textile tag, which is set down on a nylon material base, and can be stitched into fabric materials in order to embed the UHF RFID tag within the clothing (51) Textrace has a woven brand label, which is sewn onto the garment, bag or accessory early on and stays with it throughout its life cycle. With UHF RFID built in, the label provides added value from garment manufacturing through logistics to sales and after-sales management (52). Obviously integration with IOT enabled systems such as smart washing machines is possible with these systems. Fraunhofer IZM has integrated electronics in textile and stretchable substrates, developing new interconnection technologies along the way to enable these solutions. This has been used in an intelligent bus seat with a RFID solution (53).

Chapter 5 RFID Sensor Chip Specification

Frequency	860 to 960 MHz
Type	Passive, Active or Semi-active
Operating Distance	> 1 meter, < 10 meters
Sensitivity	>10dBm
Encoding	>500 bit/s
Compliance	EPC Class-1 Gen-2 certified
	ISO 18000-6C compliant
Memory	64-128 bit EPC
	48-64 bit Unique Identifier (TID / UID) (non changeable, factory locked)
	32 - 8416 bits additional user memory
Chip Size	0.5 mm x 0.5 mm to 2.0 mm x 2.0 mm
Pins	Minimum 4 pins, maximum 16 pins
Temperature Range	-40°C to +125°C
Power	Energy harvesting from reader field
	Battery : Minimum 1.2 V; Maximum 3.6 V
Antenna Voltage Range	0.5 V – 3.7 V
Battery Voltage Range	1.2 V – 3.6 V
Maximum Input Current	100 mA
ESD Rating	2 kV HBM
On Chip Sensor	Temperature sensor
Bus	Serial peripheral interface bus : I2C or SPI
Maximum Output Current	200 µA
Periphery voltage (Std.)	3.3 V
Periphery voltage (Max)	5 V
Clock	Internal clock to permit timestamp for data logging
Switch	Command driven On/Off capability to periphery devices (write wakeup mode)

Chapter 6 Summary and conclusion

The foregoing reporting has made clear that the Internet of things (IOT) will have a substantial impact on retail, asset management, supply chain management, (perishable) product monitoring, health management tracking, production optimisation and deployment as well as impacting consumer markets with smart home appliances and wearable devices. RFID will play a role in all of these specific activities, either as a passive unit or as active logging devices to track and record sensor information. All marketing reports indicate a substantial role for RFID in an IOT framework, and thereby RFID elements such as tags, readers and associated infrastructure will experience and a tremendous market growth in the next five years till 2020 and probably beyond. If

In retail, the focus of RFID will be item level tracking and shelf management i.e. how can the items on the shop floor be effectively managed, and how can stores effectively utilise existing stock for fulfilling online purchases. Asset management activities utilises RFID to track foremost warehouse stock levels, but company assets can also be tracked, which includes information such as licencing, calibration cycles, leasing status etc. The focus of supply chain management is a continual monitoring of the object during the production cycle and after it leaves the factory and arrives at its next station i.e. end customer. The customer will also be able to extend their quality assurance activities to incoming items, by obtaining tracking information during transport and data logging of the transport environment by RFID data loggers. This is most relevant for the area of perishable product monitoring, which can be extended beyond the pharmaceuticals, to more common items such as electronics etc. In health management, RFID will provide a substantial simplification of patient monitoring and tracking, and asset management within a hospital. This will have relevance for sensitive times stored within smart cabinets. Similar tracking and logging of data will be employed using RFID transponders in a production environment, in particular for the focus area Industrie 4.0, which can simply be tracking, but may also extend to include production relevant information on tags for IOT enabled process toolings. Consumers will enjoy the fruits of this RFID extension into packaging, wearable items and smart clothing, in particular in a smart home environment, which gains substantially from RFID enable devices being available for information transfer and data logging.

For the RFID chip devices of the future, a specific emphasis on the following is required in order to fulfil the IOT needs

- Both passive and (semi-)active functionality is required,
- Long read range to enable reads in large areas, e.g. shop floors or warehouses,
- Unique identification,
- Data logging capabilities,
- Extended memory capacity,
- Extension of functionality with additional sensors,
- Standardized bus interconnectivity to peripheral systems
- Integration on or in objects (e.g. packaging, clothing),

These requirements comply to the current demands on RFID transponder units for a future enabling of IOT environments in retail, supply chain management, Industry 4.0 etc. The different requirements cannot be met by a single device, but rather require a specific set of RFID chips, which enable specific segments. This would need some development effort to provide the envisaged solutions.

Chapter 7 List of Abbreviations

Abbreviation	**Explanation**
ALOHA	Additive Links On-line Hawaii Area
CDMA	Code division multiple access
DOD	Department of Defense
EPC	Electronic Product Code
FDMA	Frequency domain multiple access
GIAI	Global Individual Asset Identifier
GID	Global Identifier
GLN	Global Location Number
GRAI	Global Returnable Asset Identifier
HF	High Frequency
IEC	International Electrotechnical Commission
IOT	Internet of Things
ISO	International Standards Organisation
NFC	Near field communication
RFID	Radio Frequency Identification
SDMA	Space division multiple access
SGTIN	Serialized Global Trade Item Number
SSCC	Serial Shipping Container
TDMA	Time domain multiple access
UHF	Ultra High Frequency
URI	Uniform Resource Identifier

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