TYPOLOGY OF RFID SYSTEMS

Bartłomiej GŁADYSZ

Summary: Radio Frequency Identification (RFID) is still evolving technology. It is technology with many possible applications. There are also many different possible frequencies, different physical forms of RFID tags, different possible use cases for RFID readers. There are also many standards related to RFID. In this paper state of RFID standards is presented. Typology of RFID systems according to six different criteria was proposed. This overview can serve for engineers, managers and decision makers, when doing first insights into technology.

Keywords: RFID, radio frequency identification, typology

1. Introduction

RFID (radio frequency identification) technology is present every time when radio frequencies are used to identify and locate a tagged object. So RFID technology is each technology based on radio frequencies (RF) which is enabling the process of identification and / or localization. The history of RFID evolution was described by [1]. First systems were single bit and allowed only to detect the presence, what is enough for electronic article surveillance. The development of RFID needed developments in other areas such as miniaturization of circuitry etc.

RFID systems are composed of:

- hardware: tags and readers in various forms,
- software: computer applications managing hardware and being an edge between it and end-user information systems.

Tags are used to identify object, so they are data carriers. In a tag memory unique identifier of an object is stored. Tags are attached to the objects. Readers are used to read data from tags. Usually readers are also able to write tags and encode their unique identifiers. Tags and readers are accessible in different forms depending on the use case. There are accessible solid tags as well as inlays, labels, fobs and others. The physical form is dedicated to use case and specific application. Readers are accessible in a form of mobile readers (PDAs) as well as fixed readers integrated in portals, gates, barriers, kiosks, printers etc. depending on designed process and reading point. [1] pointed that RFID spans various engineering areas (systems engineering, software development, circuit theory, antenna theory, radio propagation, microwave techniques, receiver design, integrated circuit design, encryption, materials technology, mechanical design, and network engineering, among others). There are many papers on RFID basics e.g. [2,3]. Brief history of RFID was presented by Jung and Lee [4] and can be summarized to following points:

- 1886 – work of Frederick Hertz on using radio frequencies to reflect waves from objects,
- 1930–1940 – development of IFF (Identify Friend or Foe) system,
- wartime (World War II) – applications and works of American, British, Soviet and

German armies,
- 1973 – first patents on using RFID technology; Jung and Lee [4] claim it to be C. Watson's RFID-operated door-lock, but some claims M. Cardullo's RFID tag [5],
- 1980–1990 – Americans and Europeans started to manufacture RFID tags,
- 2003 – establishing EPCglobal,
- 2005 – Wal-Mart's RFID pilot.

Most popular use cases for RFID applications were categorized, analyzed and described as RFID Reference Model [6]:

- mainly object tagging:

A. logistical tracking & tracing,
B. production, monitoring and maintenance,
C. product safety, quality and information – e.g. temperature sensors,

- tagging with reference or potential reference to individuals:

D. access control and tracking & tracing of individuals – e.g. transportation tickets, entry cards,
E. loyalty, membership and payment,
F. eHealth care – e.g. real time locating of assets like infusion pumps,
G. sport, leisure and household – e.g. car rentals, books.

The reference model also contains such information as frequencies used in different application fields and remarks are related to design challenges. For examples of specific RFID applications one may refer to the model [6], RFID Journal website [7] and RFID Knowledge Database [8], where one can find almost 5,000 use cases.

There are many popular applications in everyday life like transportation tickets, credit/debit cards, access control etc. For more information on RFID trends one may refer to detailed reports [11]. Poland-wide analysis of RFID applications was presented in [10,11]. Apart from many B2C applications, it is worth to mention following popular areas among applications of RFID in industrial environments:

- work-in-process tracking and shop-floor logistics e.g. [12,13] tracking status of order and its stage,
- warehousing e.g. [14] – locating in warehouse, registering inbound and outbound operations,
- assets management e.g. [15] – inventory, locating valuable assets,
- retailer operations e.g. [16].

Readers are mounted in doors, docks, intermediate storage and generally between areas that are logically separated according to manufacturing or logistics process. RFID systems differs also in type of tagged objects. Items could be tagged directly, but also bulk units. Object can be tagged directly or its package or transportation item could be tagged and linked with carried object.

RFID allows for identification and for some solutions also for 2D and 3D location [17]. This is a technology impacting many areas of organization's activities and it is not just a tool to accelerate processes, but also a technology allowing new ways of processes' execution.

2. Typology of RFID systems

In this chapter, a typology for RFID systems is described. There are many different possible standards and use cases, so the proposed typology is a map and global view on a wide range of possible RFID applications. It is useful for adopters, who are seeking for compendium on RFID. Different systems' type according to reading rules and used frequencies are shown in tab. 1 and tab. 2.

Tab. 1. Types of RFID systems according to reading rules

<table>
<tr><th>System' types</th><th colspan="2">Description</th><th>Frequencies and standards</th><th>Typical applications</th><th>Reading range</th></tr>
<tr><td>active</td><td colspan="2">tags transmit independently on reader, with own battery</td><td>433 MHz
2.45 GHz
5.8 GHz
see tab. 2 for standards</td><td>– RTLS
– long distances
– sensors</td><td>up to 1000 m</td></tr>
<tr><td>passive</td><td rowspan="2">tags transmit signal when interrogated by reader</td><td>without battery</td><td rowspan="2">LF
HF
UHF
see tab. 2 for standards</td><td>– logistics
– access control
– registering working time</td><td>1 cm – 10 m</td></tr>
<tr><td>battery assisted passive (BAP)</td><td>with own battery to power e.g. sensors</td><td>– logistics
– long distances</td><td>over a 30 meters</td></tr>
</table>

Source: own based on [17,18]

ISO developed a family of standard (ISO18000) related to radio identification. The family covers all most popular frequencies used all over the world. The family is called "Radio frequency identification for item management" within "Information technology standards and its specific parts are:

- ISO/IEC 18000-1:2008: Reference architecture and definition of parameters to be standardized,
- ISO/IEC 18000-2:2009: Parameters for air interface communications below 135 kHz,
- ISO/IEC 18000-3:2010: Parameters for air interface communications at 13.56 MHz,
- ISO/IEC 18000-4:2015: Parameters for air interface communications at 2.45 GHz,
- ISO/IEC 18000-6:2013: Parameters for air interface communications at 860 MHz to 960 MHz General,
- ISO/IEC 18000-61:2013: Parameters for air interface communications at 860 MHz to 960 MHz Type A,
- ISO/IEC 18000-62:2012: Parameters for air interface communications at 860 MHz to 960 MHz Type B,
- ISO/IEC 18000-63:2015: Parameters for air interface communications at 860 MHz to 960 MHz Type C,
- ISO/IEC 18000-64:2012: Parameters for air interface communications at 860 MHz to 960 MHz Type D,
- ISO/IEC 18000-7:2014: Parameters for active air interface communications at 433 MHz.

ISO 18000 family have analogue standards within ISO/IEC TR 18047 family, which is related to the test methods for air interface communications. Additionally family of ISO/IEC 18046 standards is dedicated to test methods for system, interrogator and tag performance, while ISO/IEC 24791 family is dedicated to software system infrastructure (architecture, data management, device interface).

Tab. 2. Types of RFID systems according to radio frequencies

Systems' types	**Description**	**Frequencies and standards**	**Typical applications**	**Reading range**
Low Frequency – LF	passive, BAP, LF does not allow to read/write of many tags at the same times	125-134 kHz – ISO 11784 – ISO 11785 – ISO 14223 – ISO/IEC 18000-2 – ISO/IEC TR 18047-2 – Unique	– access control – tickets – working time registration – animals' identification	up to 50 cm
High Frequency – HF	passive, BAP, read/write of many tags simultaneously	13.56 MHz – ISO/IEC 14443 – ISO/IEC 15693 – ISO/IEC 18000-3 – ISO/IEC TR 18047-3 – NFC Forum – Mifare (Ultralight/ – Ultralight C, Classic 1K/4K, Plus, DESFire) – I-Code (ILT, SLIX)	– access control – tickets – registering working time – libraries – automatics	up to 60 cm
Ultra High Frequency – UHF	active, possible communication of tags (meshing)	433 MHz – DASH7 – ISO/IEC 18000-7	– RTLS – sensors – military	up to 1 km outdoor
	passive, BAP, longest read range of all passive frequencies, reading many tags simultaneously	860-960 MHz – ISO/IEC 18000-6 – ISO/IEC TR 18047-6 – EPC Gen2v2	– supply chain – warehousing – work in process – inventory – passive RTLS (pRTLS) – accuracy up to 1 m	up to 15 m, (BAP over 30 m)
	active, possibility of Wi-Fi (ISO 802.11) compatibility	2.45 GHz – ISO/IEC 18000-4 – ISO/IEC TR 18047-4 – ISO/IEC 24730-2 – ISO/IEC 24769-2 – ISO/IEC 24770-2	– RTLS – assets & personnel tracking & identification in hospitals and mines – sensors	up to 200 m

Tab. 2. Types of RFID systems according to radio frequencies

Systems' types	**Description**	**Frequencies and standards**	**Typical applications**	**Reading range**
Ultra Wide Band – UWB	active, multi bands	multiple bands of frequencies simultaneously (3.1-10.6 GHz) – ISO/IEC 24730-6 – ISO/IEC 24769-6 – ISO/IEC 24770-6 – IEEE 802.15.4	– RTLS accuracy up to 15 cm – sensors	up to 300 m
Super High Frequen-cy – SHF	active, smaller and more effective than 433 MHz and 2.45 GHz, longer battery lifecycle	5.8 GHz – ISO/IEC 18000-5 – ISO/IEC TR 18047-5	– RTLS – sensors	up to 200 m

Source: own based on [17,18]

Discussed standards are popular ones, but the list is non-exhaustive. For full list of RFID-related standards one may refer to ISO website. There could be found also standards related to RFID use for animal tagging, gas cylinders tagging, definitions and vocabulary, applications requirements, recycling, logistics applications, packaging, data protocol, freight containers, identification cards, license plates, tag data security among others. According to GS1, regulations for RFID use in the EPC Gen2 band (860-960 MHz) are already adopted in 78 countries representing 96.5% of the world's gross domestic product, and 3 more countries are working on regulations, what enables interoperability of systems [19]. UHF/EPC is the most popular technology for logistics purposes in areas of manufacturing, distribution, warehousing etc.. It is passive, so tags are cheaper if comparing to active tags, and it also enables longer reading distances, than other passive technologies (HF and LF). ISO has also developed a family of standards related to real time locating systems (ISO/IEC 24730, ISO/IEC 24769, ISO/IEC 24770) operating at 2.45 GHz (Part 2, Part 5) and Ultra Wide Band (Part 6).

Tags were categorized by Auto ID Center of Massachusetts Institute of Technology according to their features and originally 5 categories were listed [20]. EPCglobal is the organization that develops, maintains and manages standards for UHF passive tags and it is a successor of Auto ID Center. EPC stands for Electronic Product Code. Auto ID Labs is the organization managing research related to EPC/UHF technology. Initial list of classes evolved with technology development (see tab. 3), but truly the class system was never really adopted when EPC standards were created. EPC-type tags widely used for logistics purposes have no classes, even sometimes they are referred as Class1 Gen2 tags. UHF EPC tags that are battery assisted and would be referred as Class3 according to original classification are now referred to Gen2 BAP (battery assisted passive), because they communicate in the same way as passive UHF EPC-compliant tags. Battery is only used to power sensors [21].

If discussing RFID applications in logistics (manufacturing, warehousing, distribution etc.), it is important to mention that there is close link between EPCglobal standards and GS1 standards for logistics identifiers [22] such as Global Trade Identification Number

(GTIN), which is Serialized GTIN (SGTIN) for ECP/UHF tags, Global Returnable Asset Identifier (GRAI) and others, are related and coding schemes of GS1 identifiers can be found in EPC Tag Data Standard. [23]

RFID systems could be also classified according to use cases and areas of their applications. However, it is really hard to establish full, extensive and clear lists of possible use cases areas of applications. Some possible use cases were listed and described in tab. 4. Categories were based on different possible application of RFID readers.

Tab. 3. Types of RFID systems according to tags' features

Systems' types	**Functionalities**
Class0	RO (read only) tags
Class1	Gen1 – WORM (write once ready many) tags Gen2 – WMRM (write many read many) tags with memory min. 256 bits (typically 96 bits for EPC identifier), comparing to Gen1: smaller circuits, faster reads, vendor neutral design
Class2	Extended Class1 tags: extended user memory, authenticated access control, specification not yet finished
Class3	Semi-passive (battery assisted passive), communicating passively, but with supplemental power source enabling longer reading distances and integration with sensors (e.g. temperature, humidity etc.)
Class4	Active tags not interfering with lower classes tags, peer to peer communication
Class5	Reader functionality, communicating with other class5 tags and reading lower classes tags

Source: own based on [20]

Tab. 4. Types of RFID systems according to use cases

Systems' types	**Description**
Mobile reader	Pure identification with mobile readers (PDAs)
Chokepoint detection	Presence detection / pure identification; mostly passive, frequencies dependent on environment and expected reading distances
Door discrimination	Portals, usually supporting algorithm and technologies needed to recognize movement direction
Conveyor belts	Chokepoints integrated with conveyors
Intelligent shelves	Detection with regard to particular shelf e.g. within warehouse
Staging areas	Detection of presence within defined area on floor
Real time locating systems	RTLS, active (mostly Wi-Fi or UWB-based) or passive (pRTLS), approximation of position coordinates (usually 2D)
Desktop	Pure identification e.g. for encoding purposes
Printers and applicators	Encoding RFID labels and printing additional data on it Possibly integrated in manufacturing lines and conveyor belts
Dispensers and kiosks	Encoding tags and automated release of tags e.g. when tag is inserted into kiosk files are printed for the user or self-check kiosks in libraries; readers integrated into kiosks, integrated with printers etc.

Source: own

Similarly, systems can be described according to types of RFID tags applied. Different tags' types are listed in, but not limited, tab. 5.

Tab. 5. Types of RFID systems according to applied tags' forms

Systems' types	Description
Cards	Used for access control, ticketing, banking etc.
Display tags	Devices with integrated RFID tags, could be used e.g. as electronic kanbans
Hard tags	Tags in industrial forms, dedicated for industrial and harsh environment
Inlays	The simplest form, transparent sticker with chip and antenna
Keyfobs	Similar application as for cards
Labels	Printable labels with RFID inlays
High memory tags	Tags used when no reliable access to database can be ensured
High temperature tags	Designed to withstand high temperature e.g. ceramic tags or laundry tags, some of them withstands even 350°C
On-metal tags	Designed to be attached to metal base
Seals	Seals with RFID could be automatically identified and checked
Sensor tags	Integrated with sensors of temperature, humidity etc.
Wristbands	Used for access control, patient identification etc.

Source: own

Huebner et al. [25] analyzed RFID systems from cyber-physical perspective and proposed classification of RFID systems (see tab. 6).

Tab. 6. Types of RFID systems according to cyber-physical perspective

Systems' types	Description
Autonomous architecture	No network of readers Typical for applications like access control Readers with enough computational resources to be operated independently
Centralized architecture	Network of readers Controlled via external software like middleware Software applications for user Typical for supply chains and logistics
Hybrid architecture	Mixture of autonomous and centralized

Source: [25]

When categorizing RFID systems according to areas of applications, one may refer to discussed reference model [6], other can use categories proposed by RFID Journal [7], IDTechEx Knowledgebase [8] or Xiowei et al. [24] (see tab. 7).

Important investment cost of RFID implementation is the cost of tags. Sometimes it is fixed investment cost, but sometimes tags are single use (e.g. logistics labels). According to this two types of systems could be listed: closed-loop and open loop.

Researchers claim that full benefits of RFID will be possible with adoption of the technology along supply chains and enabling tracking movements between supply chain echelons. Currently vast majority of implementations was conducted within one organization. When thinking about RFID, one should be aware also on privacy issues related to the technology. It is especially important for applications were individual customers are exposed to RFID. This is for example the case of retail applications, where tags are sew in clothes as labels. Retailers are informing customers on use of RFID. Also

Tab. 7. Types of RFID systems according to areas of applications

RFID Reference model [6]:	
– access control and tracking & tracing of individuals – logistical tracking & tracing – sport, leisure and household	– eHealth care – loyalty, membership and payment – product safety, quality and information – production, monitoring and maintenance
RFID Journal [7]:	
– Internet of Things – apparel – defense – energy – health care – logistics – manufacturing – retail	
IDTechEx Knowledgebase [8]:	
– airlines and airports – books, libraries, archiving – healthcare – laundry – manufacturing passenger transport, automotive – retail, consumer goods	– animals and farming – financial, security, safety – land and sea logistics, postal – leisure, sports – military oil gas extraction, mining, research, other
Xiaowei et al. [24]:	
– retailing industry – CPG (consumer packaged goods) – smart shelf operations – RFID in health care industry – travel and tourism industry	– retailing industry-apparel – RFID used in fitting room – food and restaurant industry – logistics industry – military

Source: own

Tab. 8. Types of RFID systems according to possible reuse of tags

Systems' types	Description
Closed loop	Tags are circulating within organization or supply chain. e.g. tagging of returnable transport items (e.g. pallets) or assets (e.g. forklifts). Replenishment could be necessary; usually ca. 10-20% of total amount of tags yearly
Open loop	Tags are never coming back to an organization. Each time items must be tagged e.g. stickers applied on cartons with finished goods.

Source: own

security issues, often related to privacy, are of important concern. There is much effort of scientists and practitioners for privacy and security issues [26-28].

3. Conclusion

RFID is still evolving, but nowadays many standards already exist. There are many possible use cases, applications etc. There are also many variants of technology. It is always a question about environment, when deciding on RFID application. There are many possible criteria to classify RFID systems. For example different frequencies may be used depending on needs and situation of particular organization. RFID is enabling technology, that enables creation of solutions delivering new values and enables error-prone, automatically collected data in real time. In this paper, existing standards, applications, different frequencies etc. were analyzed and discussed to show their interrelations. Altogether, typology of RFID systems was presented according to eight different criteria.

One may use presented typology, to find a system working in environment similar to his. Decision on technology variant depends on expected reading distances, objects population, business processes etc. Presented typology may serve for researchers and practitioners as a compendium on RFID. It systematize knowledge and give guidelines for specialist, engineers, managers and decision makers, who are considering RFID application and are the very first step of getting insight into technology state-of-art.

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PhD Eng. Bartlomiej GLADYSZ
Institute of Production Systems Organization
Faculty of Production Engineering
Warsaw University of Technology
02-524 Warsaw, ul. Narbutta 86
tel./fax: (00 48) 22 234 81 26
e-mail: b.gladysz@wip.pw.edu.pl