

Radio Frequency Identification

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Abstract—The major parts of Radio Frequency Identification (RFID) are detailed along with the uses and opposition to RFID. A brief summary of Chapter 11 “Radio Frequency Identification” from *Wireless# Guide to Wireless Communications* is included.

Index Terms—RFID, EPC, UPC,

I. INTRODUCTION

It's a typical Saturday morning and like every Saturday morning you have a few errands to run. Your first stop is the gas station where you fill up your car with gas. You realize you don't have your wallet, but you really don't care. In fact you really never use your wallet except to keep a few dollar bills that have been there for months. With a swipe of your hand over reader and punching in an access code, your gas purchase is automatically added to your credit card statement.



Fig 1. RFID grocery cart [1]

Your next stop is the supermarket where you shop for the week's groceries. With your RFID cart loaded with the grocery list, you quickly breeze down the aisle.

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Whenever it beeps, you know you are at a shelf that has an item you need. As you find the items, you bag them on the spot. The check out line is empty. In fact, you can't remember the last time it was more than one person ahead of you. At the checkout station, you pause for only a couple of seconds while all the contents of your cart is quickly scanned and totaled. No need to put the items on the conveyer belt. Again, with the swish of your hand over the reader, your bill is paid and you are done.

Back at home you place the perishables in the refrigerator. As you do so, the large LED screen built into your refrigerator adds the new items and displays item name, quantity, and expiration date.

II. BAR CODES AND RFID

While all this may sound fanciful, RFID is the technology that can make this a reality today. Radio Frequency Identification (RFID) is a high-tech version of the ubiquitous and limited use barcodes labels found on almost every commercial product sold today. Bar codes are a series of varying width vertical bars that translate into numbers, letters, or other characters. Bar codes contain no data, just a product number that doesn't change. A bar code reader or scanner reads the number which is then cross-referenced in a database. The database entry will contain product information such as product type, vendor, price, and description. Any changes to the product information are done in the database, not the bar code. Bar codes are very cheap to manufacture. On electronic goods, bar codes may be stickers. On cereal boxes or packaging, they are just printed ink lines.

Bar codes do have some disadvantages. They do not single out individual items. One million boxes of Cheerios will all have the same bar code. Reading a bar code requires each item to be individually read by a scanner or reader that requires line-of-sight. Additionally, the bar code must be oriented the correct way to be read. In most cases this also means that each item must be individually handled.



Fig. 2. Bar code types [2]

Many businesses survive on the thinnest of profit margins. Lost, misplaced, and expired products can severely cut into profits. Suppose a pallet of Christmas ornaments is mistakenly shipped at a local Target in September. The ornaments are not needed at the time and a dedicated space has not yet been determined for the Christmas merchandise. The ornaments are placed in an out-of-the-way area until they are needed. Halloween and Thanksgiving products pass through the warehouse and the pallet of ornaments gets moved around or placed behind pallets of items needed first. The Christmas shipments finally arrive in mass and dedicated space is finally allocated. However, the pallet of ornaments was forgotten and not found until mid January. The result is lost sales, lost profit, and a pallet of ornaments taking up much needed shelving space.

III. RADIO FREQUENCY IDENTIFICATION

In today's mass-produced, world-wide containerized shipping, and just-in-time delivery, bar codes can't keep pace. RFID is quickly gaining momentum as the solution. Many people consider RFID as being just the cool looking tag with the maze-like antenna. However, the tag is only one part that makes up a total RFID system. An RFID system consists of tag, tag antenna, reader, software and EPCglobal network services.

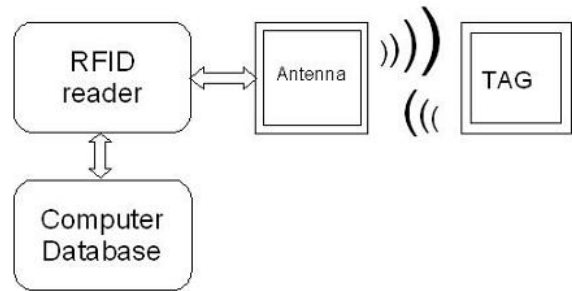


Fig. 3. Parts of RFID system [3]

A. RFID Tags

RFID tags are also known as transponders and typically include an integrated circuit that contains memory, a simple microprocessor, and an antenna. There are three types of RFID tags: passive, active, and semi-active. Passive tags are the most common and the least expensive to manufacture. They consist of an antenna and a microchip. Passive RFID tags do not have batteries. When the reader scans a passive tag, the electromagnetic waves from the reader create a current in the tag which in turn powers up the microchip. The microchip then transmits what information is stored in the tag's internal memory [4].

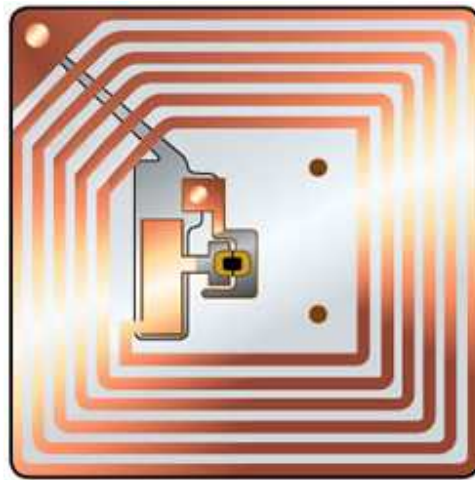


Fig. 4. RFID tag [5]

1-bit tags are passive devices used in retail stores to prevent theft. They are attached or hidden into items such as clothing, books, and boxes. If they are not removed or deactivated, they will activate an alarm when it passes the readers installed at a store's egress [6].

Active tags have an internal battery that powers the microprocessor and the memory. On the positive side, active tags can transmit a signal further. However, there are some definite negatives. Active tags have a shorter life due to the eventually run down of the battery. While passive tags only cost a few cents, active tags can be \$20.00 or more each [7]. Active tags will not appear on low cost or individual items.

Instead, they are more likely to be found on pallets and containers.

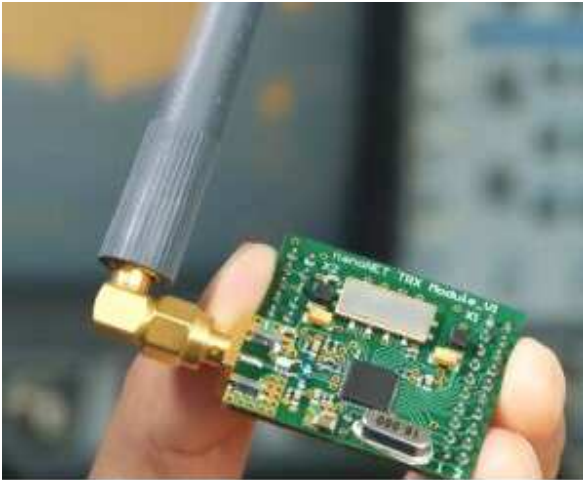


Fig 5. Active tag [8]

The third type of tag is the semi-active tag which has a built-in battery that powers the circuit only after it is energized by the reader. Semi-active tag batteries can last several years. Electronic toll devices such as E-ZPass are examples of semi-active tags.



Fig. 6. Semi-active RFID tag [9]

Sensory RFID tags have sensors that can record or monitor environmental conditions, liquid levels, and product tampering. Passive sensory tags are power up when a reader interrogated the tag. Active tags may have replaceable batteries.

There are two classes of RFID tag memory. Class 0 tags are read-only and contain the electronic product code (EPC) that was written on the tag when it was manufactured. Class 1 tags are read/write and may have WORM (write once, read many) capability or flash memory [10].

Depending on application, the memory in the tag can vary from 16 bits to hundreds of kilobits. Tags with lesser memory provide basic information about the item but not much more. In the RFID industry, basic tags are considered “license plate” types. However, those with large programmable memory can be used in a variety of ways. One use is as an electronic manifest on a shipping container. For example, suppose the US Army has a field filled with shipping containers it uses as storage at a base in Iraq. Inside one of them are 5,000 boxes of parts for fixing Hummers. Attached to the outside of the container is an extended memory tag which contains a list of the entire contents. A soldier with a reader interfaces with the tag and the contents of the container is downloaded to the scanner. The soldier sees that the shipping container has three radiators. The soldier takes the radiator, deducts the quantity from his reader and then uploads the changes to the tag.



Fig. 7. RFID tags on cargo containers [11]

In this example, the tag has found a new use. Instead of representing one item, the expanded memory tag can represent the entire content of the shipping container. The tag’s memory functions as a database. These tags work well in locations where there is limited or no access to a network that would normally contain the information [12].

The Aerospace industry is using extended memory (64Kb EPC Class 1 Gen 2) RFID tags to track the lifecycle of parts. 64Kb tags hold about 8000 readable characters. The part tag tells when the part was “born,” used, repaired, and by extension, when it needs to be replaced. Such tracking will help companies conform to safety and regulatory standards [13].

B. RFID Tag Antennas

Every RFID tag must have an antenna to transmit data to the reader. Antenna design and shape is varied as snowflakes. In fact, some antennas have patterns reminiscent of snowflakes. How an antenna looks or is designed is dependant on its application.

Linear and circular are the two main types of tag antennas. Linear antennas have greater range but less accurate reads. Circular antennas have greater read accuracy but more restricted range. Larger tag antennas can be read from greater distances than smaller sized ones. Size, design, and even

thickness must also consider the radio frequency used to read the tags [144].

C. RFID Readers or Interrogators

RFID readers or interrogators are the devices that interface with the tag and the computer network. In addition to reading the data from a tag, some readers can write data to the tag. Readers also provide the temporary power that activates passive tags.



Fig. 8. Motorola MC9090-G RFID handheld reader [15]



Fig. 9. Motorola XR440 Fixed RFID Reader [16]

RFID readers vary widely. Some have handheld units with a narrow focus antenna so that only one item or one pallet can be read at a time. When the handheld is placed in its holder, the data is uploaded to the computer network. Some stores have readers at their warehouse doors that scan every RFID tag as it enters and leaves. Wal-Mart is putting readers next to the trash compactors to read the RFID tags on the discarded boxes. In the last two examples, the reader is a detached reader antenna. The rest of the reader is part of the network.



Fig. 10. Motorola AN200 RFID antennas [17]



Fig. 11. RFID portal reader [18]

The example of the grocery cart in the checkout stall illustrate one of the advantages of RFID over bar codes. Bar codes must be scanned by the reader, so there must be line-of-sight and close proximity with each item. With RFID tags, the reader does not have to see the tag. The tagged item can be hidden in the middle of the shopping cart or hidden inside the product container. Proximity is dependent upon size and location of the tag, the reader's antenna, and the power transmitted.

When the reader is turned it sends out a signal that will interrogate each item in the cart with an RFID tag. The tag will provide information such as manufacturer, product type, and serial number. This information is fed into the grocery store computer network where current price is retrieved. Additionally, the store's inventory and accounting databases are automatically updated.



Fig. 12. RFID grocery checkout [19]

In a typical grocery cart there will be several items that are the same, such as two gallons of 2% Safeway milk and three loaves of Safeway white enriched bread. Because each RFID tag contains a serial number each item can easily be distinguished for each other. The computer system knows that the serial number should only be recorded once.

The readers must also be designed so that the right items are interrogated. The reader should not be able to read the items in the grocery cart behind the one currently in the check out stall. This can be solved by lowering the power, focusing the reader antenna, or enclosing the cart being scanned.

D. RFID Software

RFID software is as varied at the tags and readers. However, most systems have three basic software components: system software, middleware, and business application software [20].

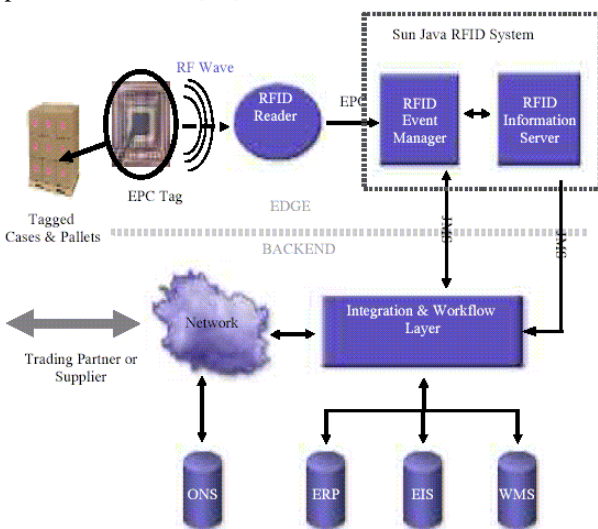


Fig. 13. Sun Java System RFID software [21]

“System software is usually stored in read-only memory (ROM) or flash memory and is present in both the tag and the reader. System software is executed by the microprocessor in each device and is used to control hardware functions, implement communication protocols (including collision control, error detection and correction, authorization, authentication, and encryption), and control the flow of data between tags and readers” [22].

Middleware reformats the data from the readers so that it can be read by the network business applications. Middleware is usually run on the computer network and is the link between the readers and the business software.

E. EPCglobal Network Services



Fig. 14. EPCglobal logo [23]

RFID systems use standards developed by EPCglobal Inc. The electronic product code (EPC) is the naming convention that is used in programming the tag. EPC allows each tag to have a unique code so that each tag can be recognized individually. The following is the breakdown of the code convention.

01	Header
0001B6F	Domain manager
0000F3	Object class
00002A9C3	Serial number [395]

“The EPC is either 64 or 96 bits long and included the following fields:

Header-Identified--the EPC version number

EPC Domain Manager--Identified the company using the EPC number. At 96 bits, this field can accommodate 268 million different companies

Object Class--The stock keeping unit (SKU) of a product, used to identify each type of product that a company manufactures or sells. At 996 bits, this field can represent up to 16 million unique types of products for each company.

Serial Number--A unique instance of the product. At 96 bits, for each object class there can be 68 billion unique serial numbers” [24].

When a barcode is scanned, the computer has to search a database to find the information about the product and the manufacturer. Cross-referencing is reduced when reading an EPC tag because the tag already contains the company identifier and the product type.

EPCglobal’s goals are more than just providing a standard. The company wants to be the focal point in the transaction point between member companies. The following is their vision of the RFID’s future:

1. EPC

Electronic Product Code (EPC) is an identification scheme for universally identifying physical objects via Radio Frequency Identification (RFID) tags and other means. The standardized EPC data consists of an EPC (or EPC Identifier) that uniquely identifies an individual object, as well as an optional Filter Value when judged to be necessary to enable effective and efficient reading of the EPC tags.

2. ID System (RFID Tags and Readers)

The ID System consists of EPC tags and EPC readers. EPC tags are RFID devices that consist of a microchip and an antenna attached to a substrate. The EPC is stored on this tag, which is applied to cases, pallets and/or items. EPC tags communicate their EPCs to EPC readers using Radio Frequency Identification. EPC readers communicate with EPC tags via radio waves and deliver information to local business information systems using EPC middleware.

3. EPC middleware

EPC middleware manages real-time read events and information, provides alerts, and manages the basic read information for communication to EPC Information Services as well as a company's other existing information systems. EPCglobal is developing a software interface standard for services enabling data exchange between an EPC reader or network of readers and information systems.

4. Discovery Services

A suite of services that enable users to find data related to a specific EPC and to request access to that data. Object Naming Service (ONS) is one component of Discovery Services.

5. EPC Information Services (EPC IS)

Enables users to exchange EPC-related data with trading partners through the EPCglobal Network.

Leveraging this technology, the EPCglobal Network will enable trading partners to minimize shrinkage and shortages, accelerate order processing and increase responsiveness to consumer demand by enabling real-time information about goods in their supply chain. In addition, it will provide increased efficiency in handling physical goods during processes such as receiving, counting, sorting and shipping.

Security is an important part of the EPCglobal Network. The EPCglobal Network uses industry recognized best practices to protect its data. In addition, the EPCglobal Network functions like an extranet with a federated data model. Data lives both

behind a Subscriber company's firewall and is only referenced by the data registry system at EPCglobal [25].

IV. COSTS

The grocery store scenario highlights two issues with RFID technology. The first is the cost of each tag. A five cent tag on a ten dollar purchase does not add much cost to the product. However, when the item is less than a dollar, such as an individual candy bar, the price of the tags becomes a significantly larger percentage of the sales price.

Secondly, grocery stores and hardware stores sell items the customer must package themselves such as produce, screws, and items in bulk bins. These items must be tagged on the spot or individually handled at checkout. Wal-Mart has stated it is contemplating item-level tagging. How this will be done and at what cost to the consumer remains to be seen.

V. HOW RFID WORKS

A passive tag does not contain a battery, thus it can only transmit when it receives power for the reader. The reader powers the tag by emitting a continuous wave which is captured by the tag's antenna. The tag modulates the wave with its data and reflects it back to the reader.

Communications between the tag and the reader are half-duplex. This means they take turns communicating with each other.

In most large operations there will be more than one RFID reader. To prevent interference between the readers, frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS) are used. In FHSS, the frequency changes after every segment of time. Where the frequency will be next is determined by the predefined hopping code. In DSSS a redundant code is transmit each data bit.

In the grocery store scenario, when the reader interrogates the cart, the tags are not read all at once. RFID used slotted terminating adaptive protocol (STAC) to stagger which card is read.

VI. RFID APPLICATIONS

Almost every article written stresses the unlimited uses of RFID technology. EPCglobal lists the following examples of RFID implementation.

Retail:

- Track and trace
- Product recalls
- Streamlined shipping and receiving
- Automated invoice reconciliation
- Shrinkage reduction
- Improved demand planning

Healthcare:

Red Cross: monitoring blood banks

Hospitals: monitoring medication routes from medicine cabinet to patient

Pharmacy: drug recall (product pedigree)

Prescription drugs: identifying counterfeit or falsely labeled medications

Logistics:

Asset utilization: asset (e.g., containers, trucks, etc.) management, tracking and maintenance

Improving operational efficiencies: volume planning and automated data capture through shipping route

Safety and security: shipment route tracing and positive identification of package contents

Automated customs

Automotive:

Capital asset management: container and tool Management

Part tracking: inventory management; assembly; theft control; brand authentication; distribution; recall; recycling

Vehicle related: car identification; access control; tire pressure

Food Industry:

Mad Cow Disease/Bird Flu: cow/bird pedigree, herd/flock history and details about the release into the food chain

Restaurants: responding to outbreaks of food poisoning

Department of Defense

Supplies and materials management: track and trace; streamlined receiving; etc.

Military assets management: asset utilization, tracking and maintenance

Airline:

Baggage handling [26]

A. Marathon Photographs

A coworker recently completed a marathon in Arizona. He and his friends trained for many months. This was also his first marathon in many years. In order to celebrate and remember his accomplishment, he purchased a package of race photos of himself for \$80.00. The photography company that provided the photos had cameras set up at various places along the course, most notably, the beginning, the midway point, and at the finish line.

It appears that the photographers indiscriminately snapped pictures of everyone that passed by. The company then went through the photographs and pulled the ones that had my friend's race number clearly visible. At best, the company used an optical character recognition program that scanned the photos for race numbers. Whatever the method

used, it took a couple of weeks for my friend to get a dozen not-so-great pictures.

The photography company also posted over 18,000 marathon pictures on its website. My friend spent an hour searching through 3,000 photos and found a few more pictures of himself that had been missed due to his race number being blocked by runners in front of him. Overall, my friend was happy he got the photos, but believes the company could have done a better job. None of the shots seemed to center him in the middle of the picture. And for the most part other runners were in the way. A second or two later and the shot would have been composed much better.

RFID could have helped this company tremendously. Each runner who pre-pays photo would receive an adhesive RFID tag that could be attached to the race number card or to his or her clothing. When the runner passes the reader, the photography would hear an audible beep signally a customer was approaching and the photographer could start shooting. An improvement would be to use tags that are coded with the purchaser's race number. On the photographer's laptop, the race number would display or be audibly heard. The photographer could then identify and take pictures of the specific customer.

One of the advantages would be the reduction time and money spent on the thousands of digital photos that would have to be taken, uploaded, scanned for race number, stored, and placed on the Internet. Additionally, the photo shots would have the paying customer at the center of the photos.

This is a rather simple example, but it exemplified the potential of RFID. Firstly, RFID can be used in almost everything we want to track, follow, and record. Secondly, RFID is the first technology that take tracking down to the individual item level and can personalize each item.

B. The Wal-Mart Way

No discussion of RFID would be complete with mentioning Wal-Mart and Sam's Club increasingly strong push for its suppliers to start using RFID. In late 2007, Sam's Club began asking 700 of its supplier to attach an EPC Gen 2 RFID tag to each pallet of similar product slated for the DeSoto, Texas distribution center [27].

Wal-Mart has placed RFID tags on the DeSoto store shelves and on the floor. RFID interrogators are installed on the forklifts. Thus, when a tagged pallet is placed on a tagged shelf, Wal-Mart can easily track the movement and placement of the pallet [28].

Wal-Mart is also asking supplies who are involved in Wal-Mart stores promotions to tag their pallets. During a promotion, a pallet of a product is strategically placed where it will receive customer attention. Store-employee with scanners will periodically scan the pallet's and floor's RFID tags. This allows the store to quickly determine if the correct product and quantities is displayed at the correct location and for the correct dates [29]. Not having enough display products can result in lost sells. Wal-Mart also has RFID readers on it

dock entrances and on the cardboard compactors. Large movements of product in the store and the destruction of many RFID boxes can indicate a successful promotion [30]. Wal-Mart estimates if a promotion is done correctly there can be up a 38 percent increase in sells [31].

In a letter dated January 7, 2008, Wal-Mart took a more aggressive stance. All suppliers to the DeSoto distribution center had to start tagging their pallets by January 31, 2008 or pay a \$2.00 per untagged pallet fee. By Oct 31, 2008 all single-item pallets going to four additional distribution centers must be tagged. Lastly, RFID tagging of individual items is expected by October 31, 2009 [32].

Analysts believe Wal-Mart started its RFID insistence with its Sam's Club stores for several reasons, most notably ease of implementation. Sam's Club is a warehouse retail chain. It has fewer stores (700) and fewer suppliers than the Wal-Mart stores. Additionally, Sam's Club customers tend to buy by the box or case and not by individual item. [33].

However, the writing is on the wall. If the Sam's Club implementation of RFID is successful--and most believe it will be successful—it will only be a matter of time before it is embraced by the thousands of Wal-Mart stores and insisted upon to its 15,000 suppliers [34].

VII. OPPOSITION TO RFID

Notwithstanding the promises or hype of RFID, there are safety and privacy concerns. RFID relies on radio waves which some believe can be harmful, particularly with implanted RFID tags.



Fig 15. An implanted RFID tag [35]

The greatest criticism comes from those with privacy concerns. Each RFID tag is unique and little would need to be done to track the activities, purchases, and whereabouts of individuals. The technology in the

marathon example could be used to track ones location in a shipping mall or on the road.

Data stored on a tag may not be encrypted and could be intercepted or hacked by unauthorized people. Baja Beachclub is a good example of how RFID can be used and the potential abuse that could ensue.

Baja Beachclub has two night clubs in Barcelona and Rotterdam. Seventy VIP guests have opted to have an RFID glass tube inserted into their upper arm. The passive tag contains a fixed code that when read by a portable reader, accesses the customers Baja Beachclub account information.



Fig. 16. RFID tag used at Baja Beachclub [36]

The customers tag is read when entering the club, when entering the VIP area, and when purchasing drinks. Most of the RFID customers are men who find using the tags more convenient than carrying a wallet full of money.

Opponents see lots of potential for abuse with having the implant. Tracking the customer within the club could easily extend to the streets. What if the town puts a reader on the street outside the club to catch drunk drivers? In the name of safety, the town could tap into Baja Beachclub's records and find out that a customer's purchased drinks would make him legally drunk. When the customer drives past the street reader, it alerts the police. Big Brother watching you is one step closer to reality.

Currently, the RFID code is only associated to Baja Beachclub's database. Customers must have a EUR 1500 credit, which for the current time is replenished by paying cash, credit card, etc. However, it wouldn't be hard to predict that this credit replenishment step could easily be simplified by tying the customers RFID number directly to a credit card or a bank account.

Using a credit card is a conscious activity and the user has to physically do something. At Baja Beachclub, a bar tender will brush the customer's shoulder to read the implanted tag. The customer sees this and knows what is happening. However, someone with an illicit reader could do the same thing without the customer even knowing.

ACKNOWLEDGMENT

For the present time, the following summation by the European Parliament presents the most even-handed response to the fears and concerns of RFID abuse.

In general, both user and maintainer of the RFID settings perceive RFID merely as an electronic key or wallet. The reason for this can be twofold. First of all, in all the cases it is clear who maintains the data and needs to comply with the guidelines on data protection. Second, many systems currently only cover a small area of a specific setting and run parallel to legacy systems. The RFID systems therefore only disclose small fragments of their users' identity, limiting the maintainers' possibilities for control.

In the near future this could be different. Once RFID systems work exclusively with RFID it will become easier to aggregate and analyze the data on the level of the whole user population. Further, once different RFID systems might become connected to each other, or other technologies such as GSM, GPS, CCTV and the Internet, a much richer image of its users will appear. This opens up many opportunities for maintainers of the RFID settings to gain control over their users and governments to use RFID data for police investigation.

Meanwhile, for the users it will become much less clear who is actually managing their identity in which setting, upsetting the power balance in the digital public space. This is not just an issue of protecting privacy or personal data, but it is more about securing personal freedom through the right balance between choice, convenience and control. We therefore formulate the following challenges ahead:

1. RFID users need to know what maintainers can and are allowed to do with RFID data.
2. RFID users should play a role in developing new RFID environments.
3. If personal data from different RFID settings are merged it should remain clear who is responsible for handling these data.
4. The Privacy Guidelines and the concepts of personal data and informational self determination need to be reconsidered in the light of an increasingly interactive environment.
5. Governments should take a clear stance on whether RFID bulk data will be mined for investigation purposes [37].

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