18-759: Wireless Networks
Lecture 20: RFID

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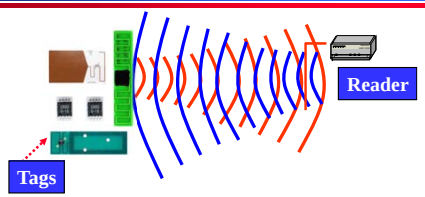
http://www.cs.cmu.edu/~prs/wirelessS16/

What is RFID ?

- Radio Frequency IDentification (RFID) is a method of remotely storing and retrieving data using devices called RFID tags and RFID Readers
- An enabling technology with many applications
  - Data can be stored and retrieved from the tag automatically with a Reader
  - Tags can be read in bulk
  - Tags can be read without line of sight restrictions
  - Tags can be write once read many (WORM) or rewritable
  - Tags can require Reader authentication before exchanging data
  - Other sensors can be combined with RFID
- Technology has been around for a long time
- Also has critics, e.g. privacy concerns

How Does It Work?



How does it operate?

- RFID tags are affixed to objects and stored information may be written and rewritten to an embedded chip in the tag
- Tags can be read remotely when they detect a radio frequency signal from a reader over a range of distances
- Readers display tag information or send it over the network to back-end systems

What is RFID?

- A means of identifying a unique object or person using a radio frequency transmission
- Tags (or transponders) that store information, which can be transmitted wirelessly in an automated fashion
- Readers (or interrogators) both stationary and hand-held read/write information from/to tags

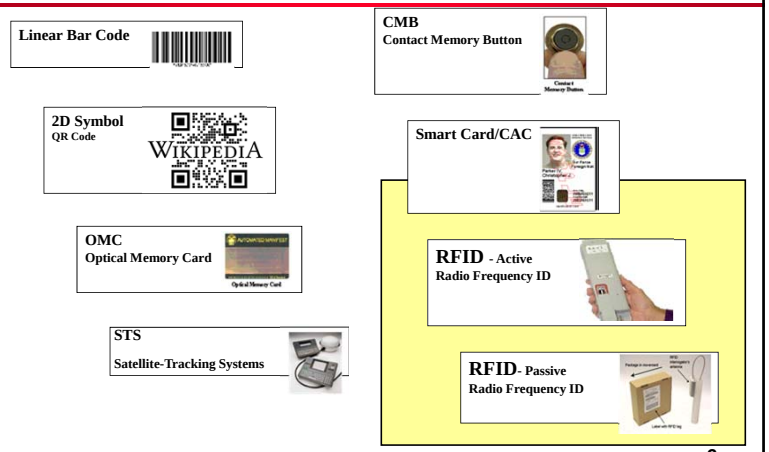
Internet of Things

- Objects in our environment equipped with networking capabilities
- Interaction types
  - between objects: Wireless Sensor/Actuator Networks
  - of a user or infrastructure with a (passive) object: reader device (dedicated device or mobile phone) and RFID tags
- Requires unique addressing scheme
  - Electronic Product Code:
    "unique across all physical objects in the world, over all time, and across all categories of physical objects"
    - urn:epc:id:sgtin:0614141.012345.62852
      10cc Syringe #62852 (trade item)

Applications

- **Operational Efficiencies**
  - » Shipping and Receiving
  - » Warehouse management
  - » Distribution
  - » Asset management
- **Total Supply Chain Visibility**
  - » Inventory visibility in warehouses
  - » In-transit visibility, asset tracking
  - » Pallet, case level
  - » Item, instance level
- **Shrinkage, counterfeit**
  - » Reduce internal theft
  - » Reduce process errors
  - » Avoid defensive merchandizing
  - » Product verification
  - » Origin, transit verification
- **Security, Regulations**
  - » Total asset tracking
  - » Defense supplies
  - » Container tampering
  - » Animal Tracking

Automated Identification Technology Suite



RF ID Types

- **Passive Tags: rely on an external energy source to transmit**
  - » In the form of a reader that transmits energy
  - » Relative short range
  - » Very cheap
- **Active Tags: have a battery to transmit**
  - » Has longer transmission range
  - » Can initiate transmissions and transmit more information
  - » A bit more like a sensor
- **Battery Assisted Passive tags are a hybrid**
  - » Have a battery transmit
  - » But need to be woken up by an external source

A Bit of History

- **Early technology was developed in the 40s**
  - » Originally used as eaves dropping devices
  - » Used reflected power to transmit (transponder), e.g. the membrane of a microphone
- **First RF IDs were developed in the 70s**
  - » Combines transmission based on reflected energy with memory – can now distinguish devices
- **Dramatic growth in last decade as a result of mandates**
  - » Big organizations (DOD, Walmart) requiring the use of RFIDs from their vendors for inventory control
- **Now used in increasingly larger set of applications**

Standards

- Passive tags operate in the LF, HF, and UHF unlicensed spectrum
- Transmission consists of a bit stream and a CRC
- Many standards exist, mostly incompatible
  - » Early standards mostly defined by the ISO
- In 2003 EPCGlobal was formed to promote RFID standards
  - » Defined a standard for the Electronic Product Code (EPC)
  - » Also defined standards for coding and modulation

Primary Application Types

Identification and Localization

- Readers monitoring entering and exiting a closed region
  - » security (RFID in identification cards)
  - » automatic ticketing (NFC on mobile phone)
- Readers tracking an RFID-tagged object
  - » business process monitoring (RFID tags on pallets)
- Tags marking a spatial location
  - » an NFC enabled mobile phone passes tags in the infrastructure whose location is known

Example: Smart Card

Public transport system in Singapore

- FeliCa Smart Card
- 2001 – 2009
- faster boarding times
- Other uses
  - small payments retail
  - identification
- Replaced by contactless card (RFID)

Example: NFC Shopping Zone

Three month trial in Seoul

- Payments in shops
- Smart ordering in restaurants: tap a tag to order a drink
- Smart posters to download coupons and advertising information
- Movie ticket purchasing and ticket checking
- Bus timetable information and real-time service status
- Loyalty stamps from a store
- Electronic receipts delivered directly to NFC phones as a legal replacement for paper receipts

Near Field Communication (NFC)

- Combines the functionality of
  - an RFID reader device
  - and an RFID transponder into one integrated circuit.
- Integral part of mobile devices (e.g. mobile phones), NFC components can be accessed by software to
  - act as a reading/writing device …
  - or to emulate a RFID tag.
- Operates at 13.56 MHz (High frequency band) and is compatible to international standards:
  - ISO/IEC 18092 (also referred to as NFCIP-1),
  - ISO/IEC 14443 (smart card technology, "proximity coupling devices"),
  - ISO/IEC 15693 ("vicinity coupling devices").
- Projected (2008): in 2012 20% of phones NFC enabled
  - Driven by NFC Forum (founded by Nokia, Philips, and Sony in 2004)
  - http://www.nfcworld.com/nfc-phones-list/#available

N-Mark trademark of NFC Forum

NFC Devices

Modes of operation

- Smart Card emulation (ISO 14443):
  - phone can act as a contactless credit card
- Peer-to-peer (ISO 18092)
  - transfer electronic business cards between devices
- Read/Write
  - allows NFC devices to access data from an object with an embedded RFID tag
  - enables the user to initiate data services such as the retrieval of information or rich content (e.g. trailers and ring tones).

Example: contactless payment applications
Sony FeliCa, Asia
MIFARE, Europe
Google Wallet

(c) Google

Comparison: Technologies

RFID EPC Gen-2 tag

- UHF, electro-magnetic coupling
- Identifier EPC global code
- Kill command

NFC device (NFCIP-2)

- HF inductive coupling
- Phone memory + 96 bytes – 8kb locable for read-only

Comparison: Main Applications

RFID

- Retail
- Logistics
- Supply chain management
  - accurate inventories
  - product safety and quality

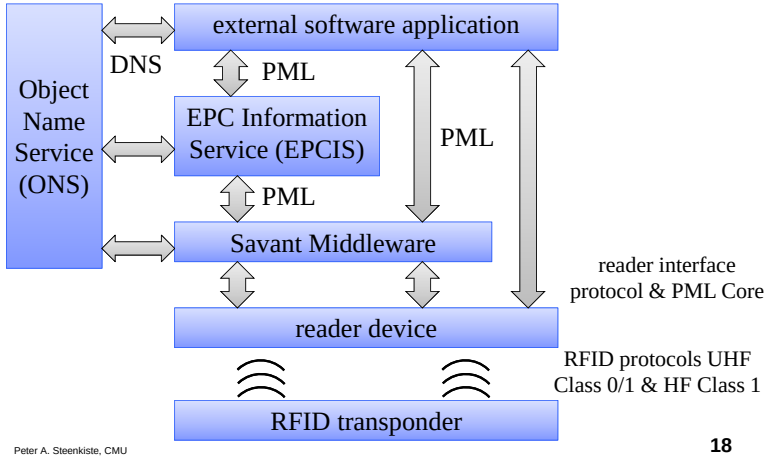
NFC

- mobile payment
- mobile ticketing
- pairing of devices (esp. Bluetooth devices)
- download of information from "smart posters"

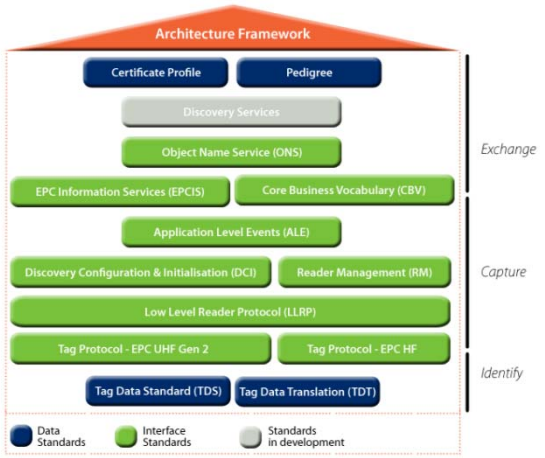
Electronic Product Code (EPC)

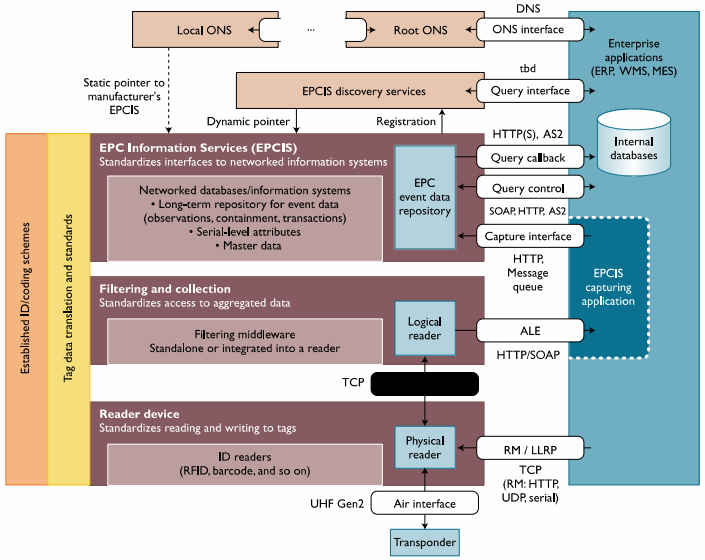
- **"A Universal identifier for physical objects"**
  - **EPC is designed to be unique across all physical objects in the world, over all time, and across all categories of physical objects.**
  - **It is expressly intended for use by business applications that need to track all categories of physical objects, whatever they may be.**
  - **urn:epc:id:sgtin:0614141.012345.6285210cc Syringe #62852 (trade item)**
- **Combine**
  - **EPC data located on the RFID tag**
  - **reader's middleware**
  - **locate EPC Information Services (EPCIS), using Web Services like SOAP and WSDL**

EPC Network Concept (2001)



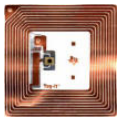
EPC Standards (2012)





From: http://www.im.ethz.ch/publications/tech_standards_realworld_epc.pdf

What information does an RFID tag contain?



Gen 2 tags have four memory banks

Bank 0	Bank 1	Bank 2	Bank 3
Reserved Memory •32-bit Kill Password •32-bit Access Password *(64 bits)*	EPC Memory •16-bit CRC •16-bit Protocol Control •96-bit EPC *(128 bits)*	Tag Identification Memory * •8-bit Class Identifier •12-bit Tag Designer •12-bit Tag Model Number •32-bit Serial Number (optional) *(0, 32, or 64 bits)*	User Memory * •User-defined format *(0 or more bits)*

The CBP "GDTI-96" bit unique number

A 64-bit TID memory bank contains a tag serial number that uniquely identifies a tag.

* *TID and User Memory banks are not initialized on some Gen 2 tags*

What information does an RFID tag contain?

Memory Bank 1 of the RFID Tag

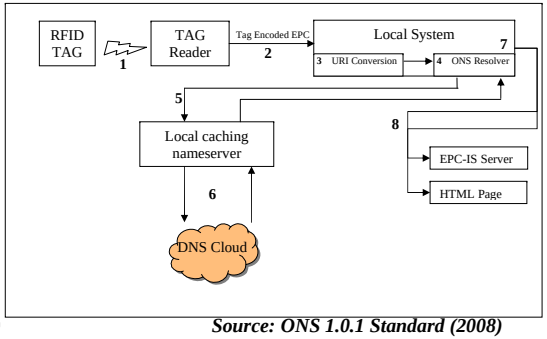
EPCglobal/GS1 allocated and managed.

An organization could define and filter up to 10,000 document types. Example: the number 1 = motorcycle , 2 = auto, etc. Defined by Card/Tag Issuer

Header	Filter Value	Partition Value	Company Prefix	Document Type	Serial Number
8 bits	3 bits	3 bits	27 bits	14 bits	41 bits
0010 1100 [Static, Binary value]	High-level filter option	Determines Company Prefix length	Equates to eight digits to uniquely identify an organization such as DHS/CBP, DoS, WA State, etc.	Equates to four digits, allowing up to 10,000 document types	Allows for over 2 trillion unique values

Object Name Service (ONS)

- **Purpose: resolve tag queries by accessing relevant databases and internet pages**
- **Operation: given EPC return one or more URLs**



Source: ONS 1.0.1 Standard (2008)

Passive RFID Tags

- **Power supply**
  - » **passive: no on-board power source, transmission power from signal of the interrogating reader**
  - » **semi-passive: batteries power the circuitry during interrogation**
  - » **active: batteries power transmissions (can initiate communication, ranges of 100m and more, 20$ or more)**
- **Frequencies**
  - » **low frequency (LF): 124kHz – 135 kHz, read range ~50cm**
  - » **high frequency (HF): 13.56 MHz, read range ~1m**
  - » **ultra high-frequency (UHF): 860 MHz – 960 MHz (some also in 2.45GHz), range > 10m**

Standards

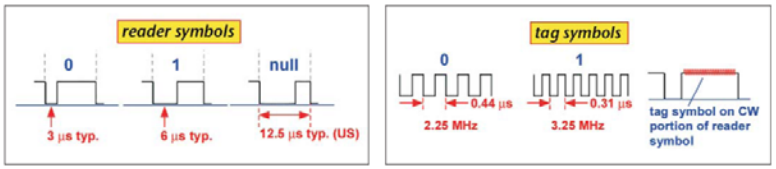
- ISO 18000: multipart standard for protocols in LF, HF, and UHF bands
- UHF: EPCglobal Class1 Gen-2
- HF:
  - » ISO 14443 (A and B) for "proximity" RFID
  - » ISO 15693 for "vicinity" RFID (basis for ISO 18000 part 3)
- Near-Field Consortium (NFC): NFCIP-1/ECMA340, ISO 18092) compatible with above:
  - » transcends tag-reader model
  - » NFC device can operate as reader or tag
  - » in particular: mobile phones that support NFC

Transmission methods

- LF and HF: inductive coupling
  - » coil in the reader antenna and a coil in the tag antenna form an electromagnetic field
  - » tag changes the electric load on the antenna.
- UHF: propagation coupling: backscatter
  - » tag gathers energy from the reader antenna
  - » microchip uses the energy to change the load on the antenna and reflect back an altered signal
  - » Different modulations used by reader and tag

PHY Layer

- Depends on the frequency band used
- Different modulations used by reader and tag
  - » Different constraints, e.g. power and complexity
  - » E.g. cannot used amplitude modulation for HF tag (why?)
- Example of EPCGlobal symbols for UHF



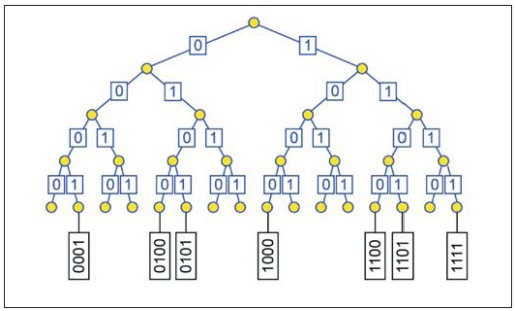
What does an RFID tag look like inside a card?

MAC Layer

- Typically assumed that only one reader is present, i.e. no need for MAC on the reader
- MAC for tags is a challenge: very high concentrations of tags are present in many contexts
  - » And tags are dumb, i.e. cannot have sophisticated protocols
- Two types of schemes used (standard):
  - » Binary tree resolution: reader explores a tree of relevant tag values
  - » Aloha: tags transmit with a random backoff

Binary Tree Resolution

- Send requests to tags with ids that start with a certain string
- Narrow down search until one tag responds



Reader Networks: Colorwave

Channel assignment in a multiple reader network: coloring the network graph with a greedy coloring algorithm

- » Frame-based protocol:
  - – short reader network coordination slots where "colors" (channels) are negotiated (color selection)
  - – long reader-to-tag transmission slots
- » Distributed Color Selection (DCS)
  - – if (timeslot ID % max colors) == current color then transmit to tags
  - – if collision occurred then choose new random color and kick (off wave)
  - – if kick received then choose new random color
- » Adjust # of channels: variable-maximum DCS

Privacy

- Tracking
  - » depends only on unique id (even if random)
  - » today:
    - – automated toll-payment transponders
    - – loyalty cards
  - » future: pervasive availability of readers
- Inventorying
  - » Invisible items become visible
  - » Libraries
  - » Passports
  - » Human implantation: VeriChip
    - – medical record indexing
    - – physical access control

Privacy for Business Networks

- Major concern for industry:
  - » supply chain visibility
  - » supply chains and business networks are business assets
- Example provenance checking: competitors could know
  - » depending on how detailed the information associated is:
    - – where an object and its parts where manufactured
    - – when it was manufactured
    - – by which sub-contractors
  - » who are the suppliers of a company
  - » which companies are the customers of a company

Reading ranges

- Nominal read range (RFID standards and product specifications):
  - » 10cm for contactless smartcards (ISO 14443)
- Rogue scanning range: sensitive reader with more powerful antenna or antenna array
  - » 50cm
- Tag-to-reader eavesdroppeing range: range limitations for passive RFID result primarily from the need to power the tag
  - » eavesdropping on communication while another reader is powering the smartcard: > 50cm
- Reader-to-tag eavesdropping: readers transmit at much higher power

Authentication

- RFID tags uniquely identify objects
- Many proposals to use tags for authentication
  - » Passport or driver's licence
  - » Identification of stolen goods
- Attacks
  - » Counterfeiting: scanning and replicating tags
- Proposals
  - » EPC:
    - – simple bitstring
    - – no access-control
  - » VeriSign:
    - – digital signing
    - – against forging but not cloning

Security Concerns

- Specific disadvantages due to limitations
  - » Encryption algorithms are too complex to be implemented on tags
  - » Low-cost RFID might be identifiable by a unique “radio fingerprint”
- But also specific advantages:
  - » Tags are slow to respond, maximum no. of read-out operations
  - » Adversary has to be physically close
  - » Unique radio fingerprint could strengthen authentication

Privacy Protection Concepts

- Kill and sleep commands
- Renaming
- Relabeling and separation of identifier and product type
- Pseudonym set
- Periodic re-encryption of unique identifiers
- Activity monitoring and proxying: Watchdog Tag, RFID Guardian
- Distance measurement for determining trust
- Blocking