18-452/18-750
Wireless Networks and Applications
Lecture 21: RFID and NFC

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http://www.cs.cmu.edu/~prs/wirelessS20/

Working with Zoom

- You should be able to see my cursor move
  - This features should be on be default
- I may use annotations for some slides
  - Again this should work automatically
- Please use the Raise Your Hand feature
  - But I will typically answer question between slides
  - On my system:
    - Click on "Participants" at the bottom of the screen
    - You should then see a blue hand that you can click
- Mute your microphone, please
- Details depend on your set up

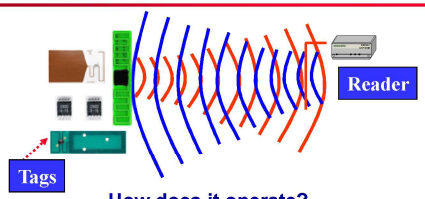
Plan, outline

- RFIDs
  - Concept and applications
  - EPC and backend processing
  - PHY and MAC
  - Security
- Near Field Communication
- Schedule discussion

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 receive a radio frequency signal from a reader and use the energy to respond
- Can operate 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) store information, that can be retrieved wirelessly in an automated fashion
- Readers (or interrogators), either stationary and hand-held, can read/write information from/to the tags

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

Linear Bar Code

2D Symbol
QR Code

OMC
Optical Memory Card

STS
Satellite-Tracking Systems

CMB
Contact Memory Button

Smart Card/CAC

RFID - Active
Radio Frequency ID

RFID- Passive
Radio Frequency ID

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
  - » Transmission based on reflected energy using information in memory – readers can now distinguish devices
- Dramatic growth since then driven by industry
  - » Potential for significant gains in areas
  - » Big organizations (DOD, Walmart) requiring the use of RFIDs from their vendors for easy inventory control
- Set of applications expanded rapidly

Standards

- Passive tags operate in the LF, HF, and UHF unlicensed spectrum
  - 30-300 KHz, 3-30 MHz, 300-3000 MHz
  - Distance drop with frequency
- Transmission consists of a bit stream and CRC
- Many standards exist, mostly incompatible
  - » Early standards mostly defined by the ISO
  - » Widely used standard: ISO/IEC14443
- 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)
  - » Merchandise in stores
  - » NFC in phones
- 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)

How Smart are RFIDs?

- Basic tags simply reply with a fixed bit string – "read" the tag
  - » "I am Groot"
  - » Already useful!
- Gradual move to richer functionality
  - » Changing the state on the tag – "write"
    - – E.g., keep track of a balance
  - » Privacy and security: encryption, access control, …
    - – E.g., different parties and read and write the tag
  - » Add computing capabilities (more general than crypto)
- Next step is processors that operate entirely based on harvested ambient energy
  - » Vibrations, RF, solar, …

Example "Oyster" Card

- Balance is maintained on the card
  - » Cryptographically secured
- The "reader" updates the balance as you enter/leave the metro station
  - » Enter: record when and where you boarded
  - » Leave: update balance on the card
  - » These operations are local
- Readers record all trips and periodically send information to servers
  - » Auditing trail, lost cards, etc.
  - » Riders can check their balance online

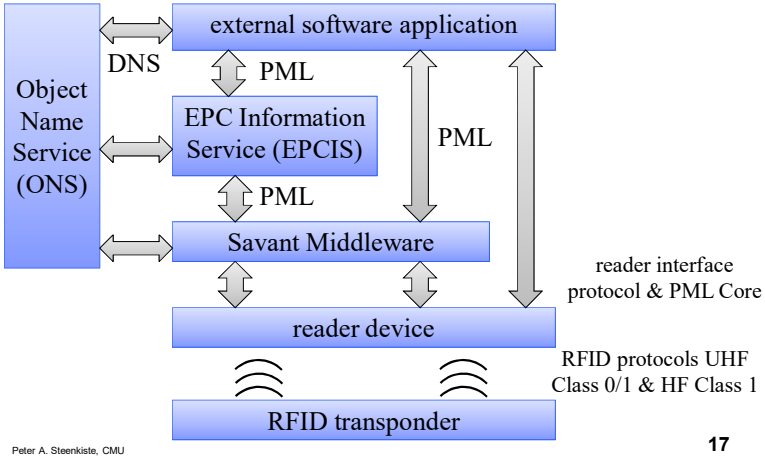
Plan, outline

- RFIDs
  - » Concept and applications
  - » EPC and backend processing
  - » PHY and MAC
  - » Security
- Near Field Communication

Electronic Product Code (EPC)

- "A Universal identifier for physical objects"
  - » Designed to be unique across all physical objects in the world, over all time, and across all categories of objects.
  - » Intended for use by business applications that need to track all diverse physical objects, whatever they may be.
  - » urn:epc:id:sgtin:0614141.012345.6285210cc Syringe #62852 (trade item)
- Combined multiple components
  - » EPC data located on the RFID tag
  - » Reader's middleware
  - » Locate EPC Information Services (EPCIS), using Web Services like SOAP and WSDL
- Not exciting but standardization is critical to wide-spread adoption

EPC Network Concept (2001)



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*

Example to illustrate concept

Passive RFID Tags

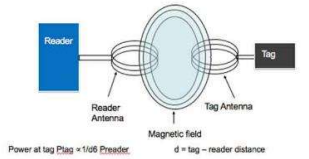
- **Power supply**
  - passive: no on-board power source, transmission power from signal of the interrogating reader
  - semi-passive: batteries power the circuitry during interrogation, once woken up by external signal
  - active: batteries power transmissions (can initiate communication, ranges of 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

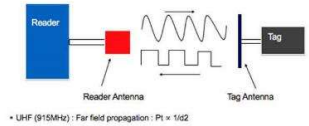
Standards

- **ISO 18000: multipart standard for protocols in LF, HF, and UHF bands**
- **For example, HF:**
  - ISO 14443 (A and B) for "proximity" RFID
  - ISO 15693 for "vicinity" RFID (basis for ISO 18000 part 3)
- **Two classes:**
  - Class 0: read only
  - Class 1: read/write, can for example be used for tracking
- **Many more standards exist!**

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

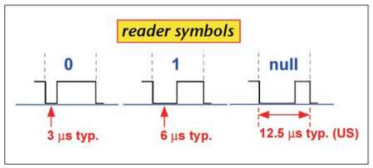


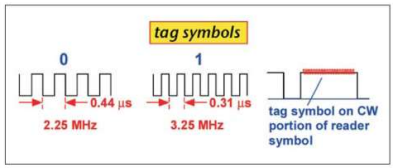


From: http://www.highfrequencyelectronics.com/Archives/Aug05/HFE0805_RFIDTutorial.pdf
https://rfid4u.com/rfid-basics-resources/inductive-and-backscatter-coupling/

PHY Layer

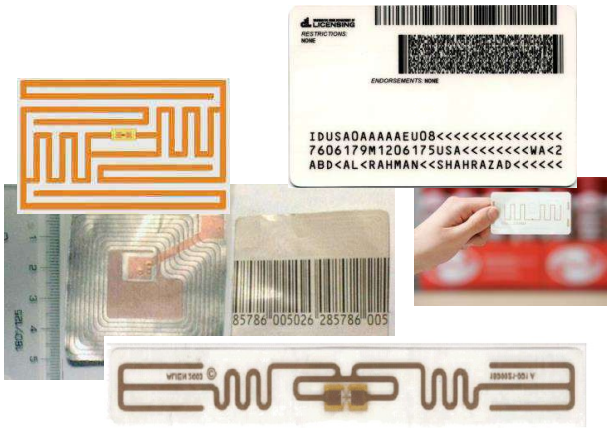
- **Depends on the frequency band used**
- **Different modulations used by reader and tag**
  - » Different constraints, e.g. power and complexity
  - » E.g. cannot used amplitude modulation for HF tag (why?)
- **Example of EPCGlobal symbols for UHF**





 From: http://www.highfrequencyelectronics.com/Archives/Aug05/HFE0805_RFIDTutorial.pdf

What does an RFID tag look like inside a card?

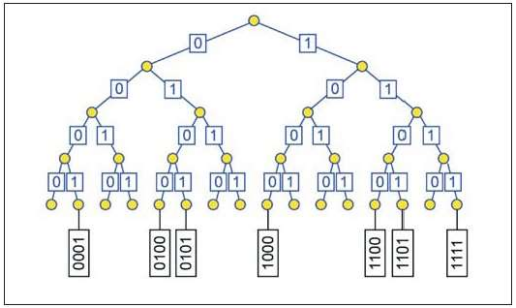


MAC Layer

- **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 (carrier sense, RTS/CTS, ..)
  - » Must also deal with multiple readers operating in the same environment
- **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



General Security Concerns

- RFID tags raise a number of security concerns:
  - » Privacy risks, e.g., eavesdropping
  - » Cloning and forging of tags
- Specific disadvantages due to tag limitations
  - » Some encryption algorithms may be too complex to be implemented on tags
- But also specific advantages:
  - » Tags are slow to respond, maximum no. of read-out operations
  - » Short transmission range means that an adversary has to be physically close

Privacy Concerns

- 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 implants: 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 may be able to get a lot of information
  - » 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

- Controlling reading range can limit privacy risk
- 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 eavesdropping range: need to power the tag limits range for passive RFIDs
  - » Eavesdropping on communication while another reader is powering the smartcard: > 50cm
- Reader-to-tag eavesdropping: readers transmit at much higher power

Use for Authentication

- RFID tags uniquely identify objects
- Many proposals to use tags for authentication
  - » Passport or driver's licence
  - » Identification of stolen goods
- Counterfeiting attack
  - » Scanning and replicating tags
- Possible options
  - » EPC:
    - – Simple bitstring
    - – No access-control
  - » VeriSign:
    - – Digital signing
    - – Against forging but not cloning

Plan, outline

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Near Field Communication (NFC)

- One device combines the functionality of
  - » An RFID reader device
  - » An RFID transponder (tag)
  - » Bit rates ranging from 106 Kbs to 424 Kbs
- Integral part of mobile devices (e.g. mobile phones) NFC components can be accessed by software to
- 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").
- Use of NFC is growing fast
  - » Driven by NFC Forum (founded by Nokia, Philips, and Sony in 2004)
  - » http://www.nfcworld.com/nfc-phones-list/#available

NFC Devices

Modes of operation

- Smart Card emulation (ISO 14443):
  - » Phone can act as a contactless credit card
  - » Information can be generated rather than pre-stored
- Reader mode
  - » Allows NFC devices to access data from an object with an embedded RFID tag
  - » Enables the user to initiate data services, i.e., retrieval of rich content, advertisements, ..
- Peer-to-peer (ISO 18092)
  - » Allows two way communication between NFC devices
  - » NFC can act as smart tag, i.e., generates information

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

(c) Google

Active and Passive Communication Modes

- Passive communication: one device acts as a reader and the other as a tag
  - » Reader generates a field while the other responds
  - » The second device can be a tag or another NFC device
- Active communication: both devices alternatively act as readers
  - » Allows fairly general two way communication
  - » Both devices must have a battery
- Since NFC devices can read and write, they must check for collisions
  - » Compare received signal with transmitted signal

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"

Remaining Schedule

Week	Mo	Tu	We	Th	Fr
Mar 23	P2 CP1 L23		P2 meetings L24	HW3	
Mar 30	Draft		Draft		
Apr 6	P2 CP2		P2 meetings		
Apr 13	Surveys		Surveys	HW4	
Apr 20					
Apr 27	Project Talks		Course Review		P2 Final Report

P2, Homework and Survey Discussion

- Identifying and ordering any hardware you need is a top priority
  - » I can provide (limited) support, but you need to get approval before ordering
- There will be two more homeworks
- Past experience shows that starting late on your survey talk is a really bad idea
  - » Make sure you send me a solid draft 2 weeks before the presentation
- Make sure you practice a few times
  - » Time management, coordination with partner, tweak slides, ….

Some Thoughts about Surveys

- Many students use the google templates, which are generally poorly designed (24pt)
  - » No slide numbers
  - » Tiny font sizes (12pt) – I want to be bigger! (18pt)
  - » 50%-80% of the slide is empty
  - » Use the space wisely!
- Outline generally looks like:
  - » Background: why useful, challenges, design options, etc.
  - » Discussion on the three papers:
    - – What is the key idea – this should be clear (figure!)
    - – Some sample results illustrating benefits
    - – You do not have to cover the full paper!!
  - » Personal opinion on pros or cons (global or per paper)

Schedule Flexibility

- Flexibility in when we have lectures
- Some limited flexibility in the survey and project dates
- One possibility: Move final to last day of class and have projects due in finals week
  - » Final would be two hours long
  - » Plus: more time to work on projects
  - » Less time to study for the final, but all course material would have been presented at least two weeks before the final
  - » Short discussion now, poll if there seems to be strong enough interest