18-452/18-750
Wireless Networks and Applications
Lecture 22: RFID and NFC

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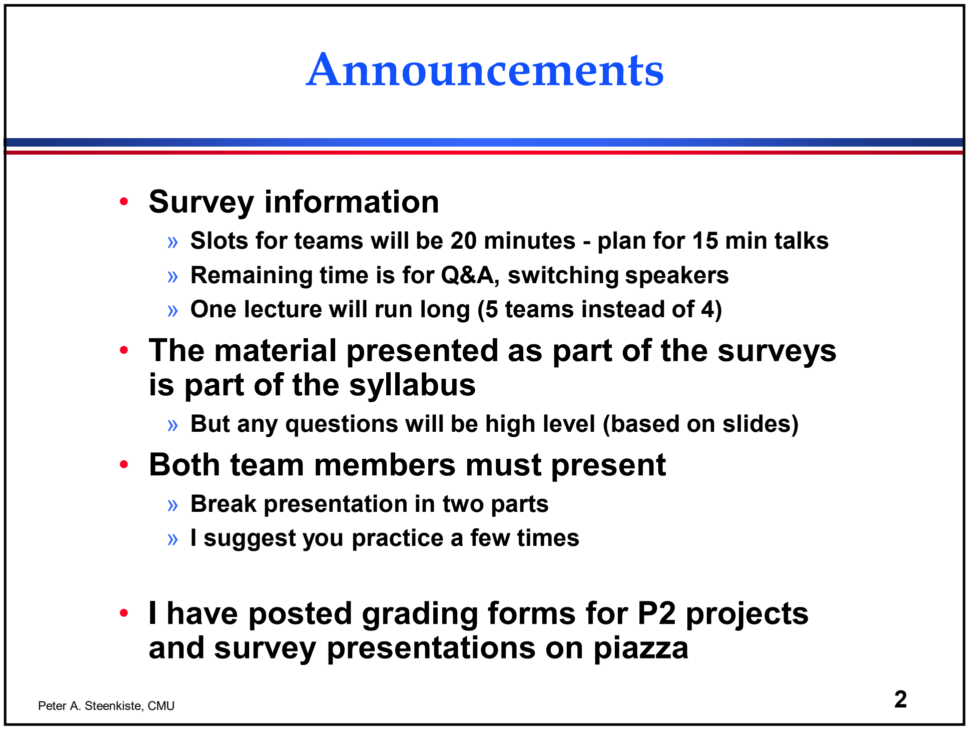
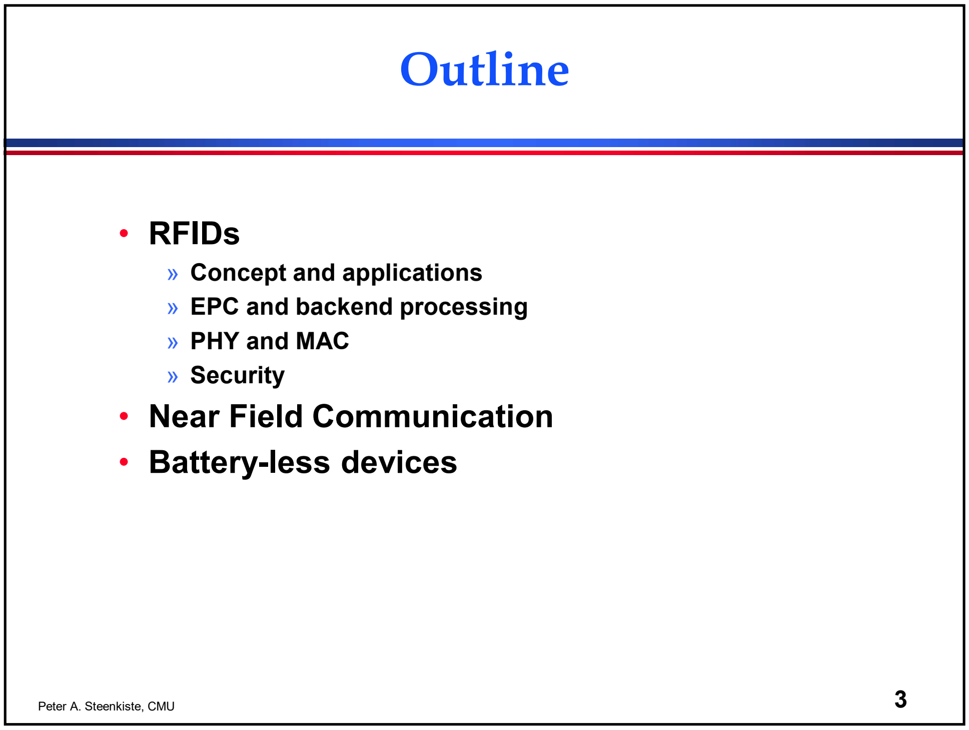
Spring Semester 2024
http://www.cs.cmu.edu/~prs/wirelessS24/



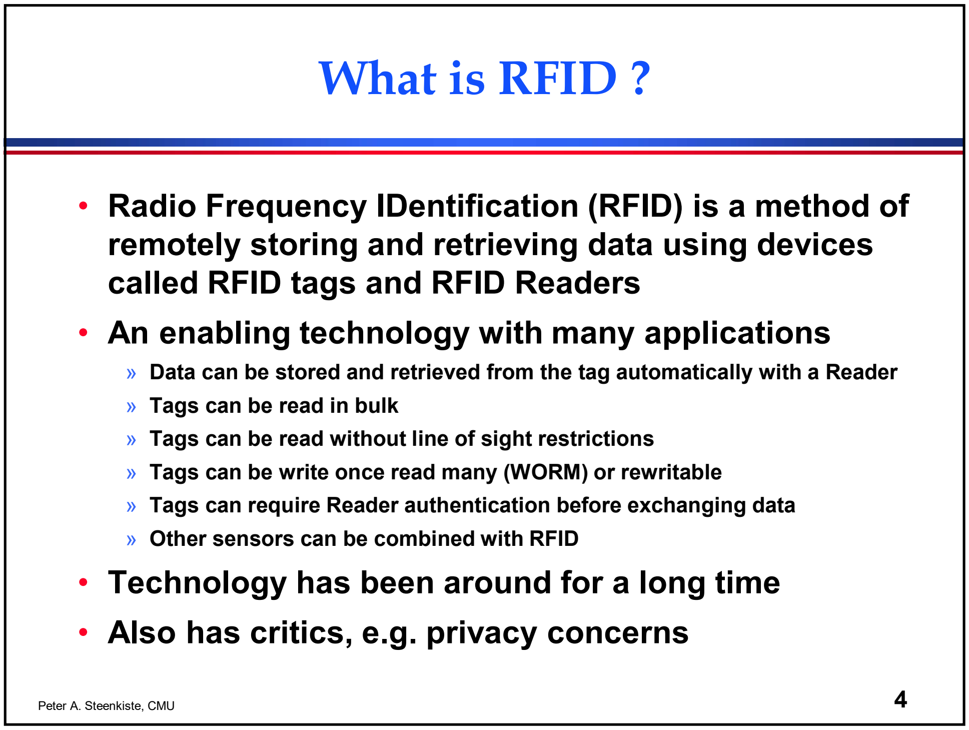
Announcements

- Survey information
  - » Slots for teams will be 20 minutes - plan for 15 min talks
  - » Remaining time is for Q&A, switching speakers
  - » One lecture will run long (5 teams instead of 4)
- The material presented as part of the surveys is part of the syllabus
  - » But any questions will be high level (based on slides)
- Both team members must present
  - » Break presentation in two parts
  - » I suggest you practice a few times
- I have posted grading forms for P2 projects and survey presentations on piazza



Outline

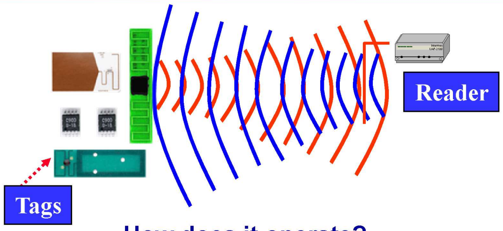
- RFIDs
  - » Concept and applications
  - » EPC and backend processing
  - » PHY and MAC
  - » Security
- Near Field Communication
- Battery-less devices



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

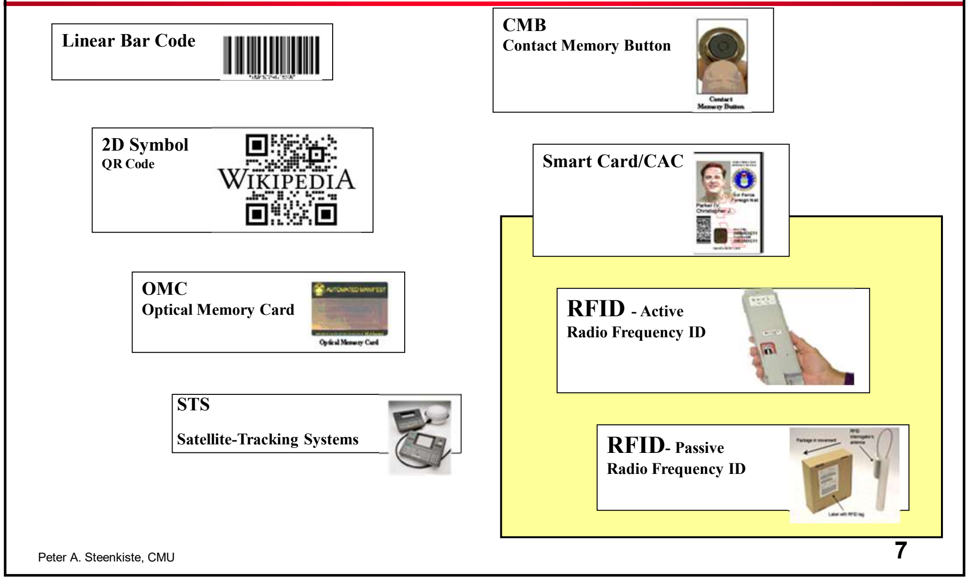
What is RFID?

- 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

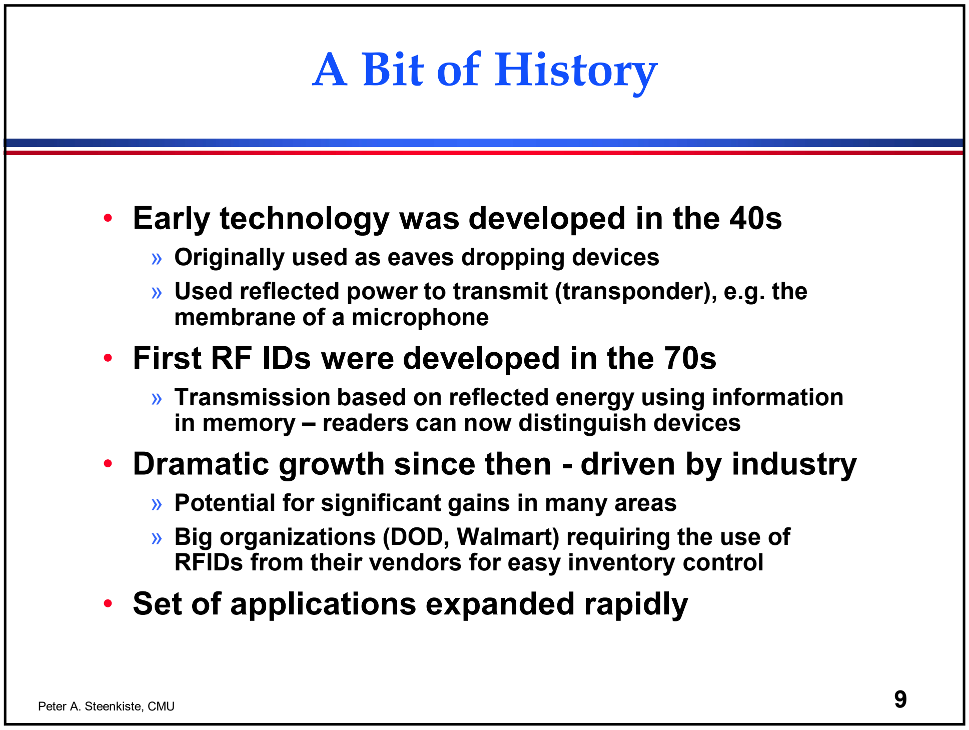
Smart Card/CAC

RFID - Active
Radio Frequency ID

RFID- Passive
Radio Frequency ID

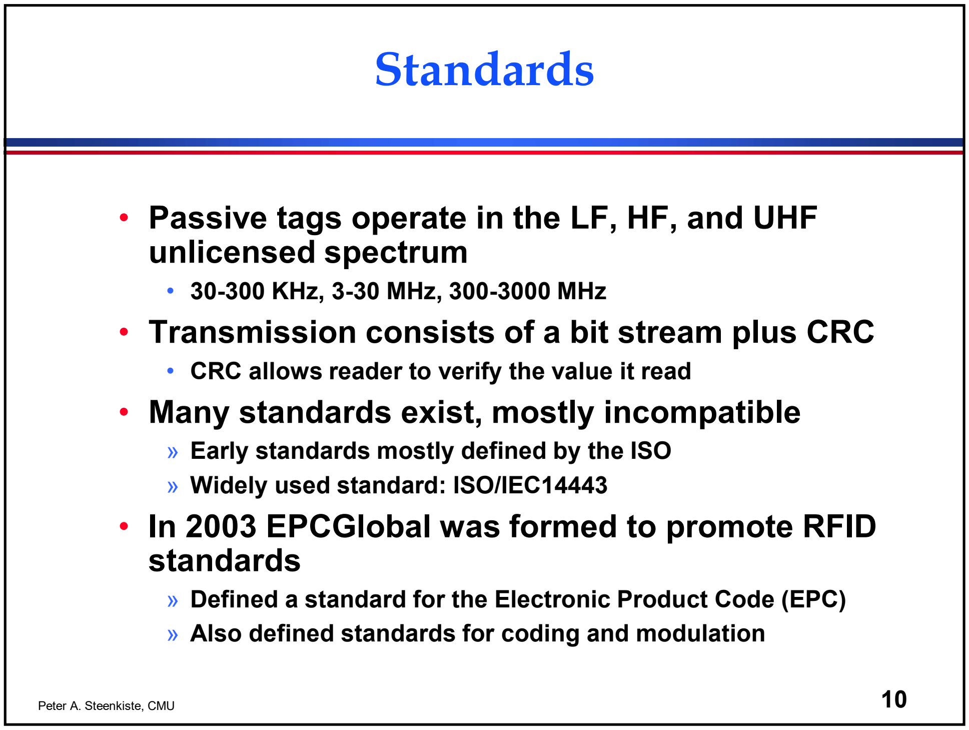
RF ID Types

- Passive Tags: rely on an external energy source to transmit
  - » In the form of a reader that transmits energy
  - » Relative short range
  - » Very cheap – used everywhere today!
- 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
  - » It has a battery to transmit
  - » But it needss to be woken up by an external source



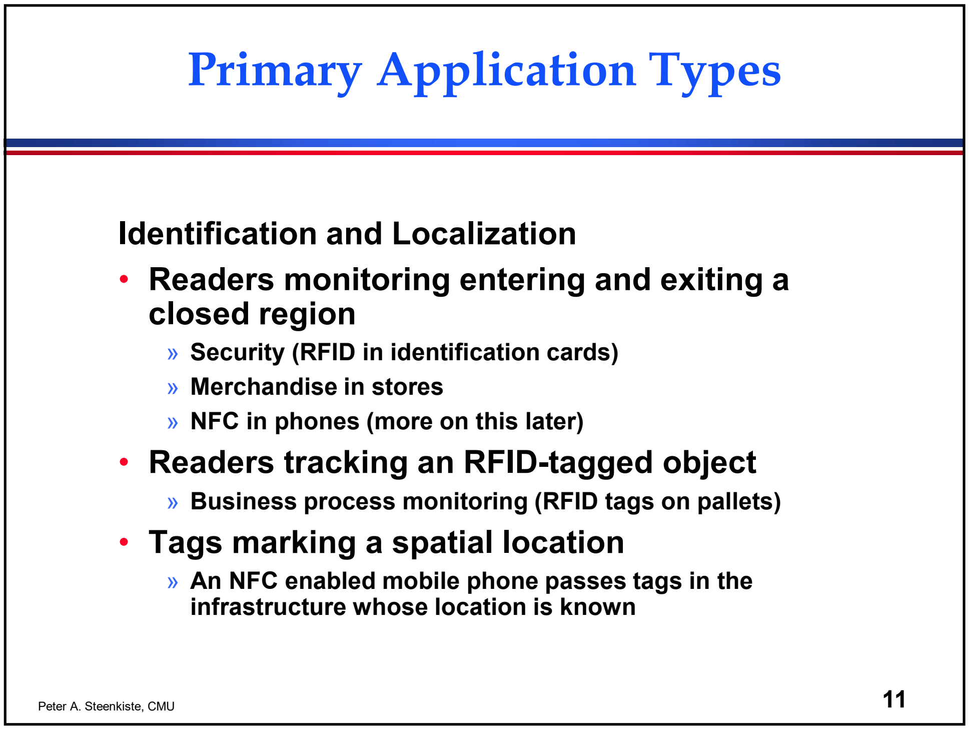
A Bit of History

- 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 many areas
  - » Big organizations (DOD, Walmart) requiring the use of RFIDs from their vendors for easy inventory control
- Set of applications expanded rapidly



Standards

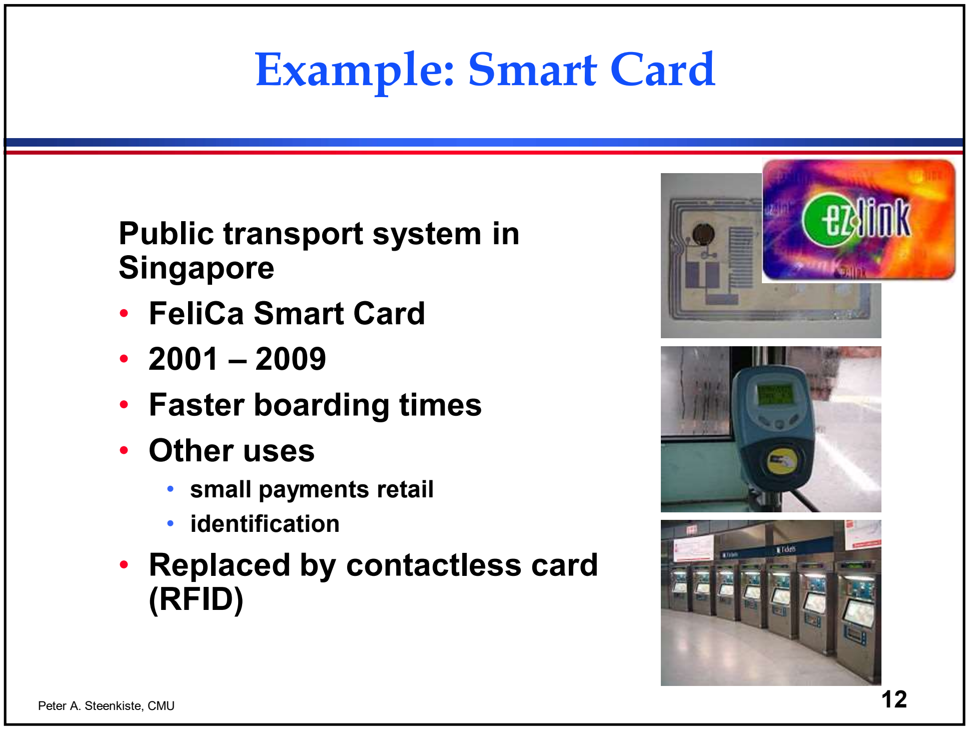
- Passive tags operate in the LF, HF, and UHF unlicensed spectrum
  - 30-300 KHz, 3-30 MHz, 300-3000 MHz
- Transmission consists of a bit stream plus CRC
  - CRC allows reader to verify the value it read
- Many standards exist, mostly incompatible
  - » Early standards mostly defined by the ISO
  - » 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 (more on this later)
- 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 based on the trip
  - » These operations are entirely at the reader
- Readers record all trips and periodically send updates to a server about the balance of cards
  - » Auditing trail, lost cards, etc.
  - » Riders can check their balance online

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  - PHY and MAC
  - Security
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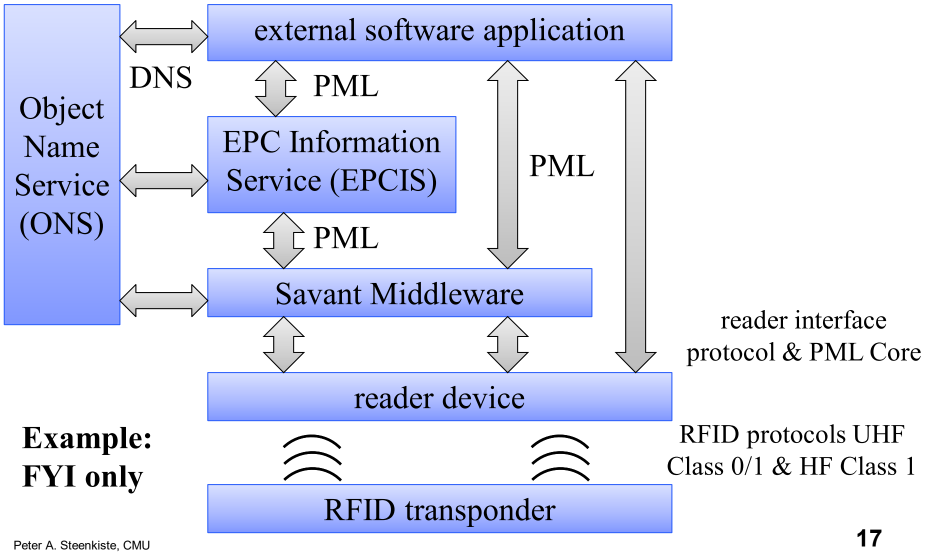
- Battery-less devices

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.
  - Trade item: urn:epc:id:sgtin:0614141.012345.6285210cc Syringe #62852
    - URN: Universal Resource Name (instance of a URI)
- Combined multiple components
  - EPC data is stored on the RFID tag – read using reader
  - 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)



Object Name Service (ONS)

DNS

external software application

PML

EPC Information Service (EPCIS)

PML

PML

Savant Middleware

reader interface protocol & PML Core

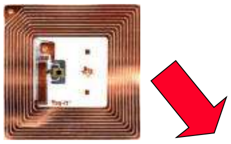
reader device

RFID protocols UHF Class 0/1 & HF Class 1

RFID transponder

Example: FYI only

What information does an RFID tag contain?



Gen 2 tags have four memory banks

Bank 0	Bank 1	Bank 2	Bank 3
<u>Reserved Memory</u> •32-bit Kill Password •32-bit Access Password *(64 bits)*	**<u>EPC Memory</u>** •16-bit CRC •16-bit Protocol Control •96-bit EPC *(128 bits)*	**<u>Tag Identification Memory *</u>** •8-bit Class Identifier •12-bit Tag Designer •12-bit Tag Model Number •32-bit Serial Number (optional) *(0, 32, or 64 bits)*	**<u>User Memory *</u>** •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
  - Note that channel width differs

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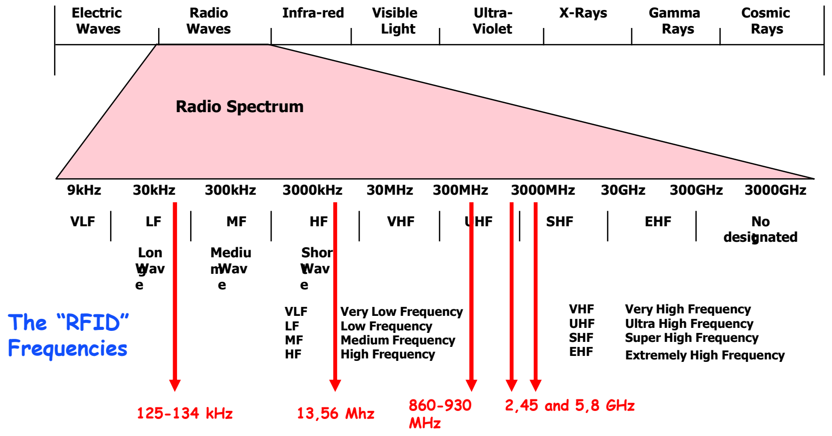
Frequency Bands Passive RFID Tags

Electromagnetic Spectrum



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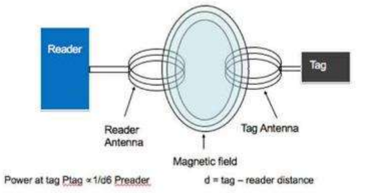
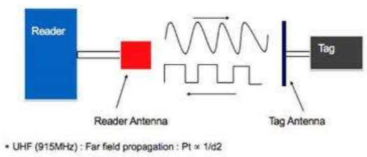
Transmission methods

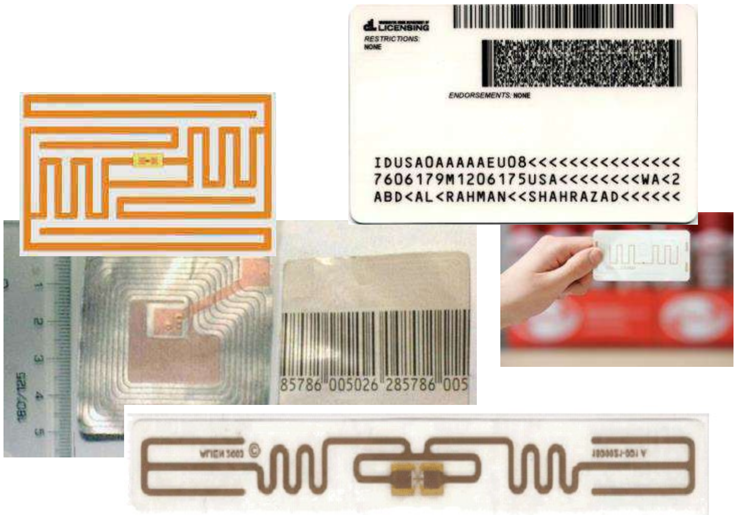
- **LF and HF: inductive coupling**
  - » Coil in the reader antenna and a coil in the tag antenna form an electromagnetic field
  - » Tag changes the electric load on the antenna.
- **UHF: propagation coupling: backscatter**
  - » Tag gathers energy received from the reader transmission
  - » Microchip 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/

What does an RFID tag look like inside a card?


LICENSING
RESTRICTIONS: NONE
ENDORSEMENTS: NONE
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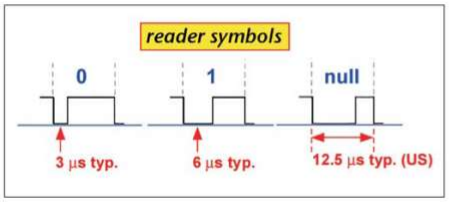
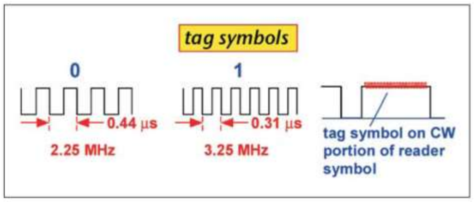
7606179M1206175USA<<<<<<<<WA<2
ABD<AL<RAHMAN<<SHAHRAZAD<<<<<<
85786 005026 285786 005

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 EPC Global symbols for UHF





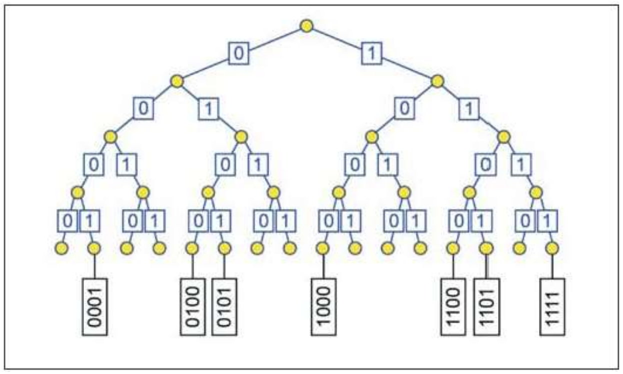
From: http://www.highfrequencyelectronics.com/Archives/Aug05/HFE0805_RFIDTutorial.pdf

MAC Layer

- Typically assumed that only one reader is present, i.e. no need for MAC on the reader
  - » Multiple readers: can use different frequency bands
- 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 tag values
  - » Aloha: tags transmit with a random backoff

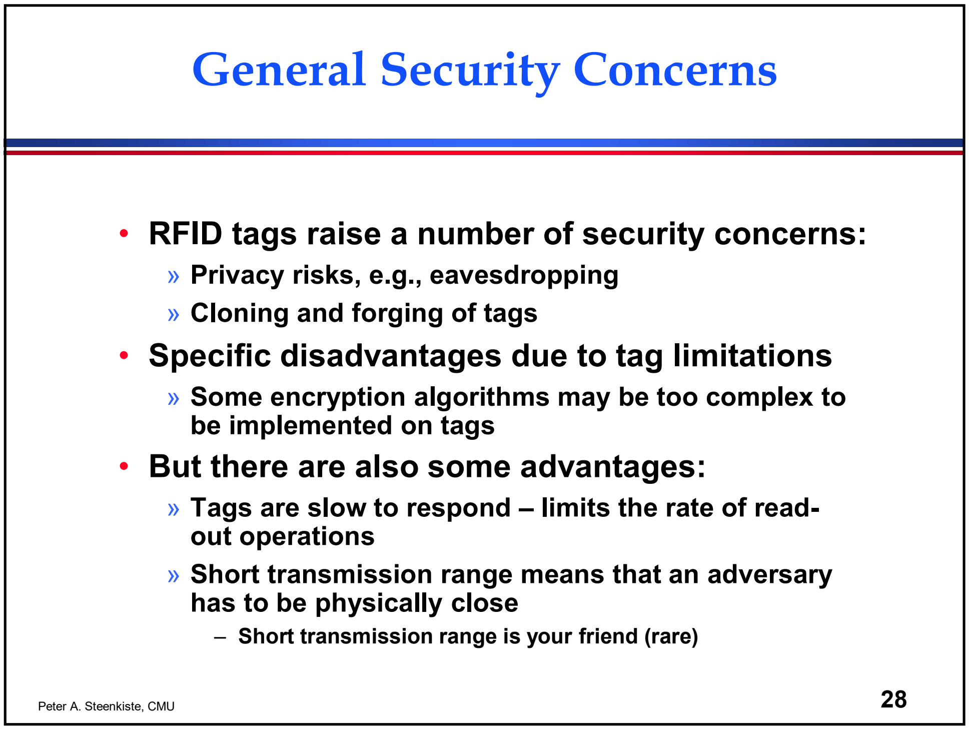
Binary Tree Resolution

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



Sketch of the Algorithm

- Do a breadth first search of all the nodes in the tree
- At each step:
  - » If multiple tags respond, continue the breadth first search
  - » If no tags respond: skip the subtree
    - – It does not contain any tags
  - » If one tag responds: you have found a tag! Ignore subtree
    - – It contains only one tag, which you have already found
- Example:
  - » Query root node -> multiple responses
  - » Query node 0 -> multiple response
  - » Query node 00 -> one response (tag 0001)
  - » Query node 01 -> multiple responses ….



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 there are also some advantages:
  - » Tags are slow to respond – limits the rate of read-out operations
  - » Short transmission range means that an adversary has to be physically close
    - – Short transmission range is your friend (rare)

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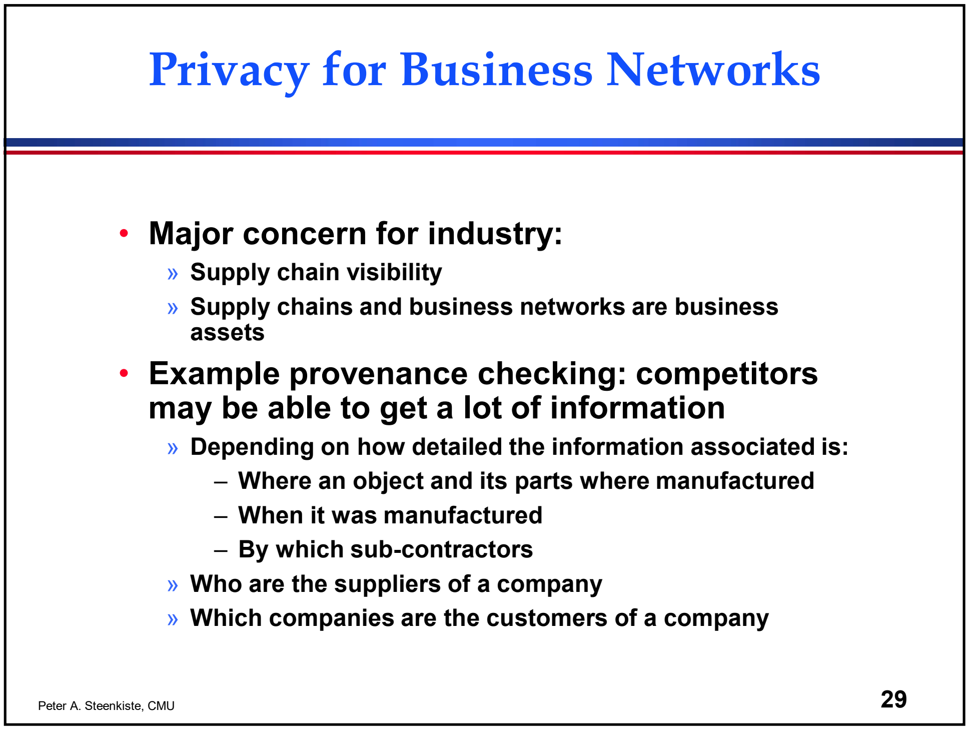

Privacy for Business Networks

- 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

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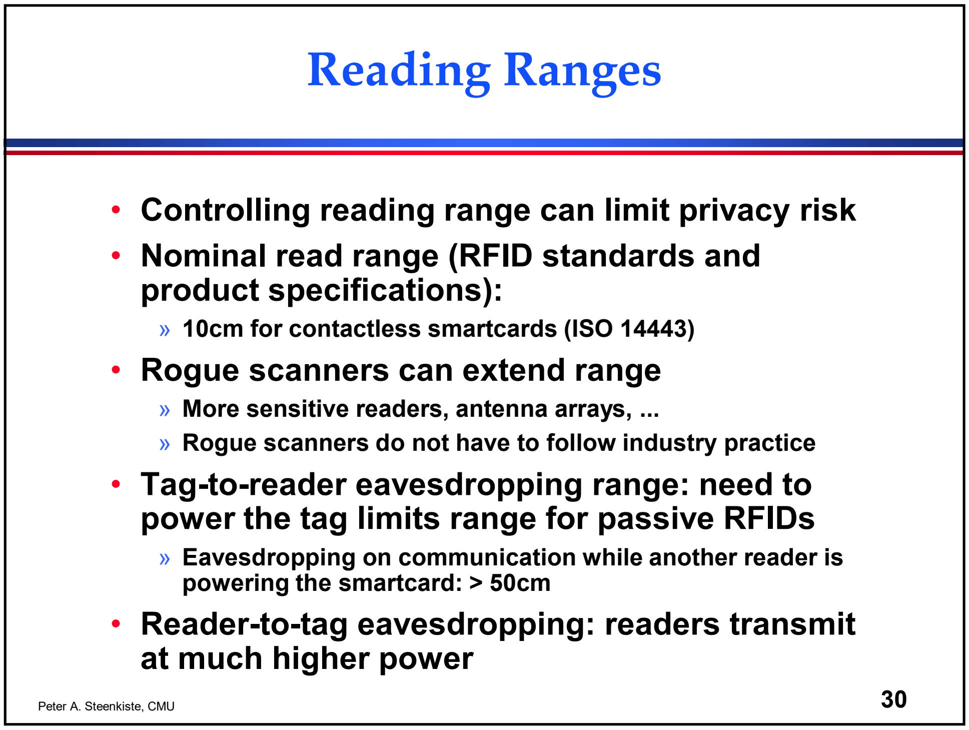
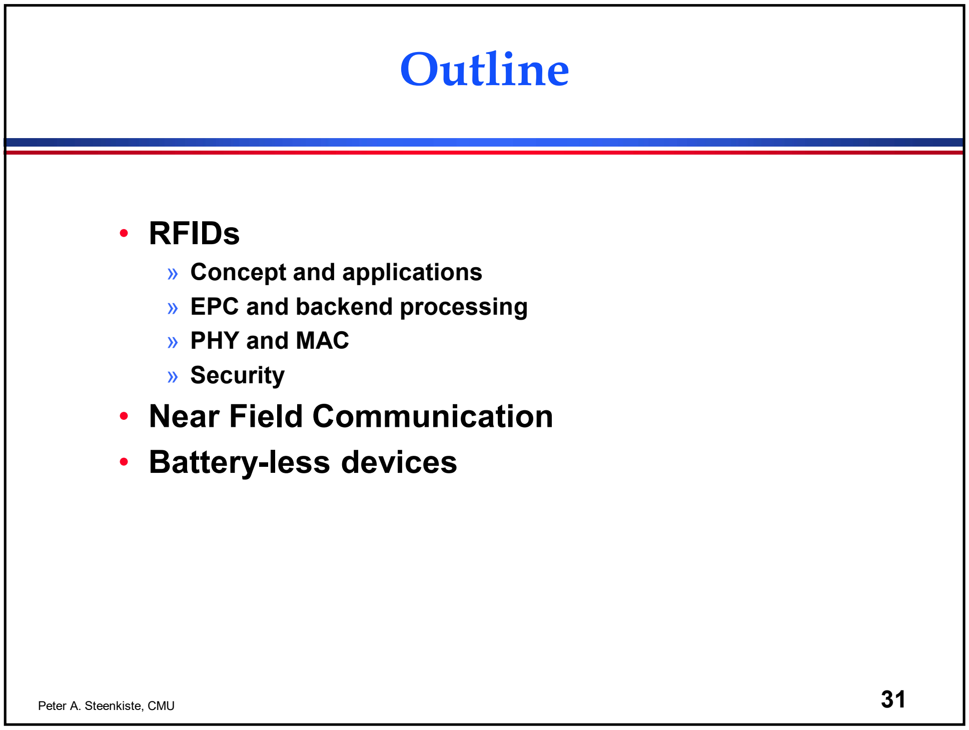


Reading Ranges

- Controlling reading range can limit privacy risk
- Nominal read range (RFID standards and product specifications):
  - » 10cm for contactless smartcards (ISO 14443)
- Rogue scanners can extend range
  - » More sensitive readers, antenna arrays, ...
  - » Rogue scanners do not have to follow industry practice
- 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



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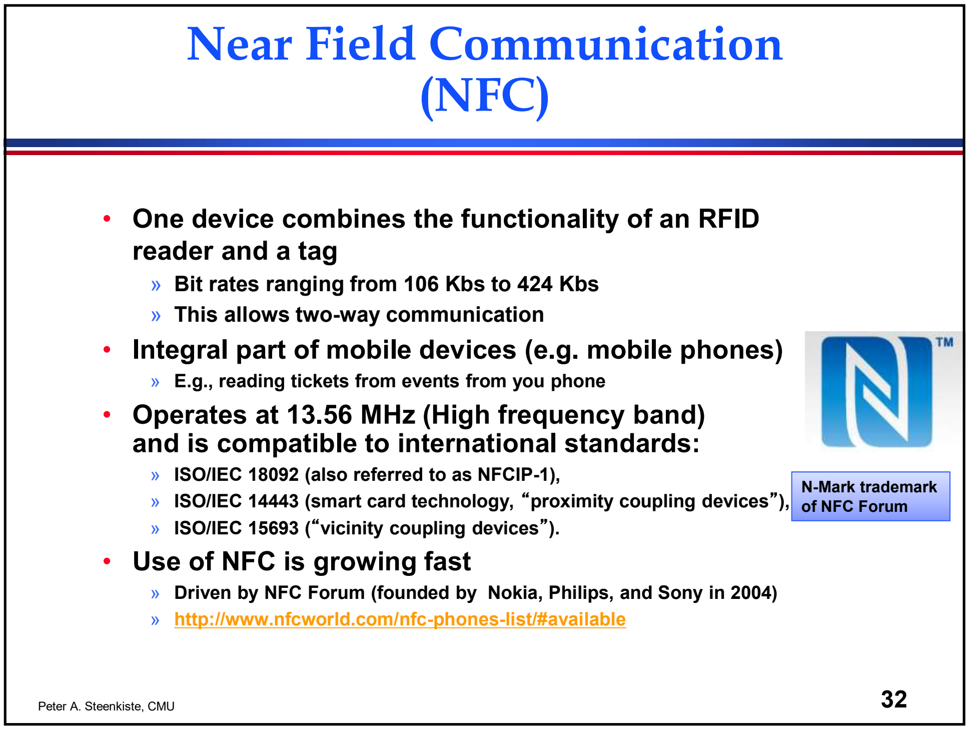

Near Field Communication (NFC)

- One device combines the functionality of an RFID reader and a tag
  - » Bit rates ranging from 106 Kbs to 424 Kbs
  - » This allows two-way communication
- Integral part of mobile devices (e.g. mobile phones)
  - » E.g., reading tickets from events from you phone
- 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

N-Mark trademark of NFC Forum

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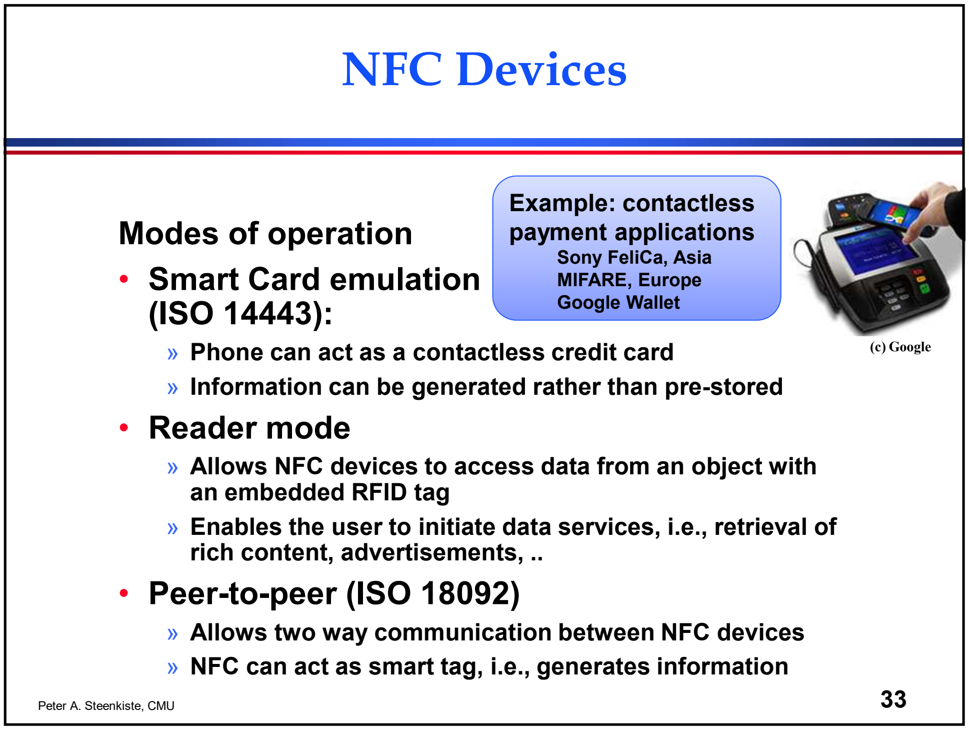

NFC Devices

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

(c) Google

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

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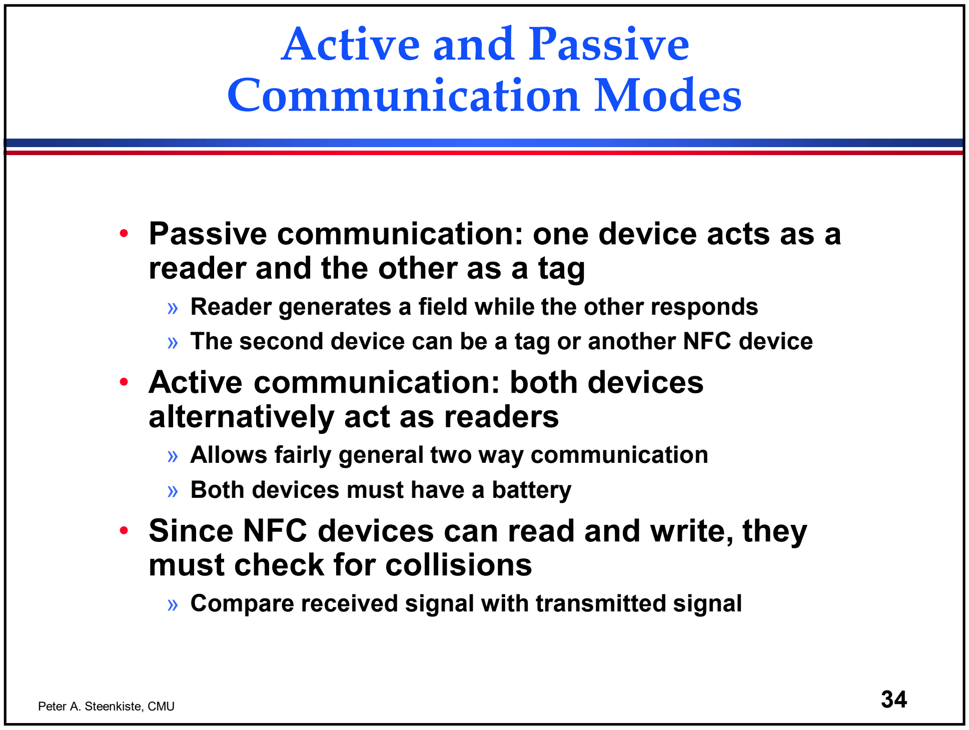
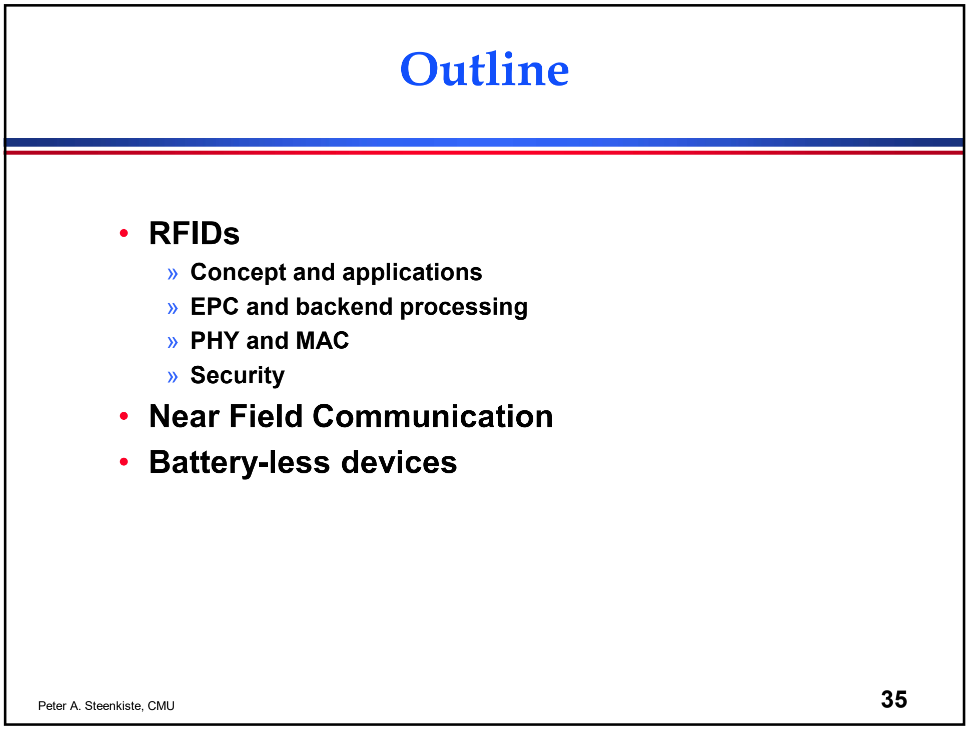


Active and Passive Communication Modes

- 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



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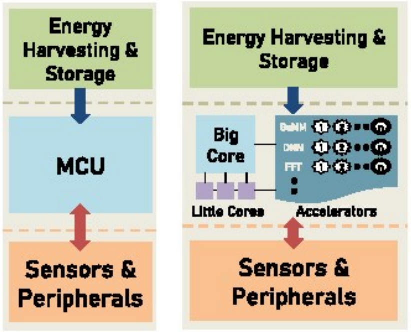
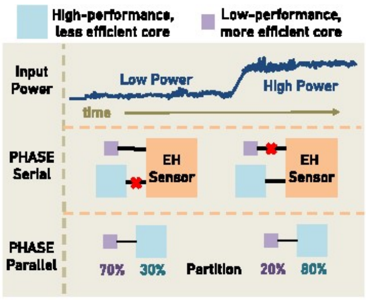
What is Next: Battery-less Devices



- Devices rely entirely on energy harvesting
  - » Solar, RF, …
- Battery can store limited amount of power
  - » Can be used when harvesting is slow or not possible
- Different architectures are being explored
- Goal is to have fairly general architectures

From: A Power-Aware Heterogeneous Architecture Scaling Model for Energy-Harvesting Computers, Desai, Lucia, IEEE Computer Architecture Letters, https://ieeexplore.ieee.org/document/9078058

Example Design



- Adapt level of activity to the available power
- For example, use simple but efficient cores when power levels are low
- Power hungry operations may have to wait
  - » E.g., send data