RFID:
radio-frequency identification

Gaetano Borriello

Department of Computer Science & Engineering
University of Washington

(some material courtesy of C. Diorio – Impinj, Inc.)

Basics

- Radio-frequency identification
  - Using radio frequency (RF) signals to identify (ID) an object
  - Does not require line-of-sight
- Tags are attached to an object
  - ID number in tag uniquely identify the object, not just its class
  - Current tags use 64 to 128 bits
  - Can include other information besides ID
    - Current state
    - Location
    - History

RFID Basics

- RFID systems comprise tags and readers
  - Tags are placed on objects
  - Readers interrogate tags
- Tags can be active or passive
  - Active tag: A tag with a battery
  - Passive tag: A tag that receives its power from the RF field

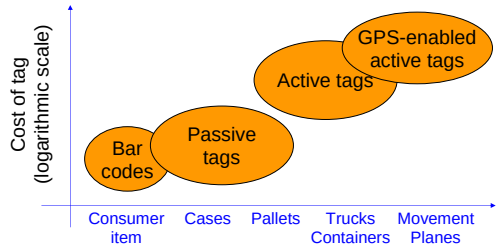
Active Tag

Passive Tag

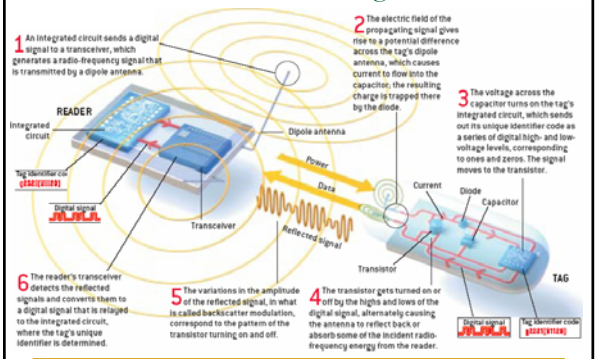
Passive vs Active Tags

	Passive Tag	Active Tag
Range	0.1–10 m	10–100 m
Power Source	RF field	Battery or Battery and RF field
Sensors (Temp, etc)	Typically no	Typically yes
Lifetime	Unlimited	Limited by battery
Cost	$0.05 – $1	$1 – $20
Size	Small	Large
Communications	Passive backscatter	Passive or active signaling
Examples	EPC tag, animal tracking, smart cards	Shipping-container tags

Different types of tags for different uses



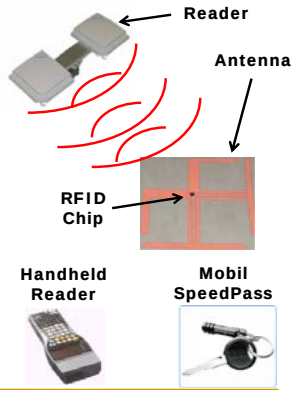
Communication between tag and reader



From Scientific American (1/2004)

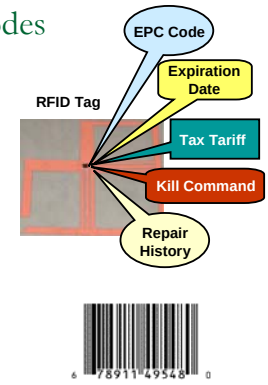
Passive RFID

- Reader sends RF interrogation signal
- Tag uses RF signal as power source
  - Tag comprises antenna and RFID chip
- Tag returns information by reflecting RF signal



RFID versus Bar Codes

- RFID can replace bar codes
  - Don't need line-of-sight
  - Harder to spoof
  - Don't smudge
  - Tags can be rewriteable
  - Unique serial numbers
- EPC can replace UPC
  - 96 bit code gives 12,200,000,000,000,000,000 unique identifiers for every human being alive today

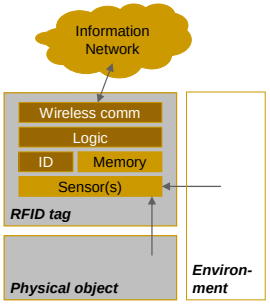


The pieces of an RFID system

- Tag
  - Carries the ID number and very limited processing capability
- Reader
  - Tag communicates ID to "reader"
  - Readers emit RF and are regulated – differently around the world
- Networking infrastructure
  - Reader is connected to a network and communicates IDs to interested parties
- Databases
  - Collect the "read events" and log them with time/place
- Applications and their user interfaces
  - Browse the database looking for correlations and patterns

RFID tag

- Tag must contain
  - Unique ID
    - Static
    - Differentiates attached object from all others
  - Wireless communication
  - Power harvesting
  - Logic (very limited!)
- Tag may contain
  - Writable user memory
  - Environmental sensors (temperature, pressure, acceleration, etc.)

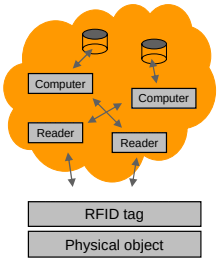


Tag classes (EPCglobal)

- Class-1: Identity Tags
  - Tag identifier (ID) including electronic product code (EPC)
  - A "kill" function that permanently disables the tag
  - Optional user memory with password-protected access control
- Class-2: Higher-Functionality Tags
  - Extended ID
  - Extended user memory
  - Authenticated access control
- Class-3: Semi-passive Tags
  - An integral power source
  - Integrated sensing circuitry
- Class-4: Active Tags
  - Tag-to-tag communications
  - Active communications
  - Ad hoc networking capabilities

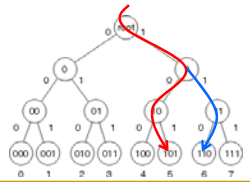
RFID reader

- Reader
  - Provide enough power to activate tags
    - Power varies as $1/d^2$
    - For passive tags, $1/d^4$ (round-trip)
  - Reads and writes tag information
  - Connects tag populations with
    - Information networks
    - Databases
    - Existing applications
  - Element of a distributed software platform



Tag-reader protocol

- Arbitration protocol for multiple tags
  - Reader asks for tags that start with 0 to respond
  - Reader asks for tags that start with 1 to respond
  - Repeat for as many bits in tag ID
    - Tags that start with 00…, 01…, 10…, 11…, and so on.



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Myriad Applications in Supply-Chain

- Automation
  - RFID will boost throughput
    - Barcode scanning is slow
    - Barcode is applied manually
  - RFID = agile supply chain
    - Reduces out-of-stock
    - Reduces shrinkage
    - Increases inventory control
- Package tracking
- Airline tickets, luggage
- Pharmaceuticals
- Anti-counterfeiting
- Asset tagging, archiving

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Market-Driven Technology

EPCglobal, WAL*MART, TARGET, Ahold, Carrefour, The Home Depot, METRO Group, United States Postal Service, UPS, The Gillette Company, Lowe's, Best Buy, Unilever, CVS/pharmacy, Pfizer, Canon, Coca-Cola, Procter&Gamble, Johnson&Johnson, Kodak, Abbott Laboratories, KRAFT

- 6 of top 7 retailers worldwide support RFID
  - > $1 trillion revenue
- More than 120 FMCG companies are supporting RFID
- More than 80 Pharma companies are supporting RFID

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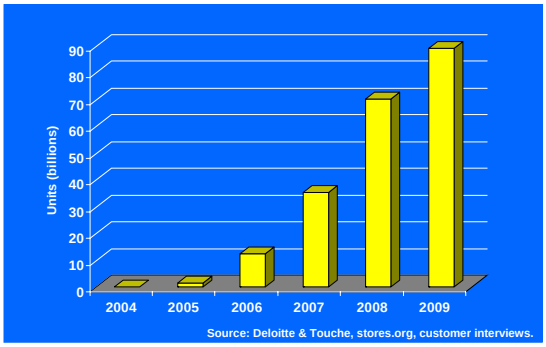
Projected Tag Volume



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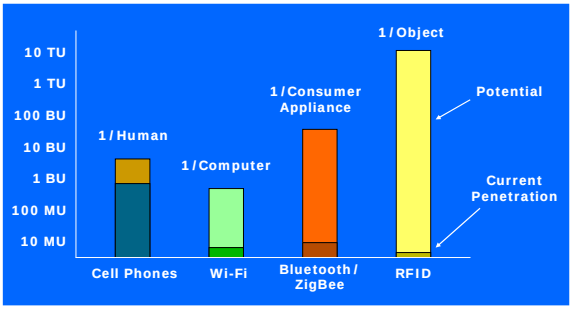
10 Trillion Tags?



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RFID background

- Radio-frequency identification (RFID)
  - Began with Hertz in 1886 – first application in aircraft (1942)
  - Has become practical with advances in IC and RF technologies
- Current applications
  - Tracking objects in the supply-chain
  - Some experiments with point-of-sale
  - Many proprietary, niche applications
- Adjacent technologies
  - Bar codes
  - Contact-less smart cards
  - Sensor networks
- Recently, RFID technologies have advanced rapidly
  - Poised for major penetration of supply chain
  - Wal-Mart and DoD mandating all suppliers provide tagged palettes
- Consumer concerns over privacy
  - Tags can be read from a distance without visible effort

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RFID numbers

SkyeTek Engineering

- Tags
  - 1cm (near-field) to 15cm (far-field) dimensions
  - $0.25-1.00 per tag (rapidly dropping)
  - On-board memory (8Kbits), sensing (few bits)
- Readers
  - Regulated power output (1W – similar to cell phone)
  - $100-200 (near-field) to $1-2K (far-field)
  - Limited range (up to 5m today)
  - Operate at 850-900MHz, moving to 2.4GHz

Alien Technologies

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Myths about RFID

- Tags can be tracked anywhere
  - Tags can only be read by readers within close proximity, readers make themselves “visible” when they read tags
  - Today, distances are within 5m, may be extended in the future to 10-20m
- Tag ID can be used to index data about a user
  - For the foreseeable future there will be many databases, under separate administrative domains
  - Database federation is a difficult problem but possible in principle
- Accuracy of reads
  - Readers and tags are susceptible to interference
  - Too many tags or tags moving too quickly are difficult to read

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A wide variety of tags

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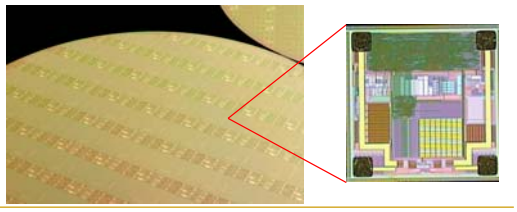
Example: Impinj ZumaRFID™ Chip

- World’s first field-rewritable tag
- 8m read range; 6m write range
- >500 tags/sec read rate; >15 tags/sec write rate
- Designed for dense-tag environments



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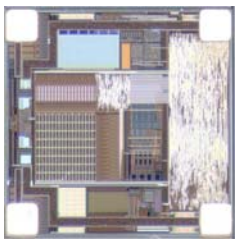
Example – Impinj ZumaRFID™ Chip



- A mixed-signal communication chip with an RF input/output and nonvolatile memory
- 41,798 transistors
  - Intel 8086: 29,000 transistors
- Consumes 8μW of power
- About the size of a grain of sand
- > 40,000 die/wafer

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Example – Impinj ZumaRFID™ Tags

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A wide variety of applications (partial list)

- Supply-chain tracking of inventory – visibility of location/condition
- Homeland security – container tampering
- Livestock history – where has that cow been?
- Pet ownership – tags injected under the skin
- Passport biometrics – match data in tag to measurement at port
- Access control – contactless smart card
- Electronic payment systems (tolls, point-of-sale) – automatic payment
- Tracking children and their belongings – Japanese/CA schools
- Marathons – track position of runners
- Games – theme park ride reservations, playground games
- Museums – security and index to information
- Luggage tracking in airports – no line-of-sight requirements
- Clothing – receipt-less returns, smart closet, consumer buying habits
- Libraries – tracking of books and reshelving assistance
- Hospitals – patient and medication tracking, automated checking
- Handicapped – shopping assistance for the visually-impaired
- Elder care – monitoring activities of daily living for short/long-term trends

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Positives

- Compared to bar codes
  - Unique object ID
  - No line-of-sight requirement
  - Writable tag memory
  - Sensing possibilities
- Compared to smart cards
  - No contact required, read at a distance
  - Can be read automatically
- Compared to active tags
  - No battery
  - Lower maintenance costs

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Negatives

- Compared to bar codes
  - Unique object ID
  - No line-of-sight requirement, can read surreptitiously
  - Higher cost (hard to beat ink on paper)
- Compared to smart cards
  - More difficult to control intent
- Compared to active tags
  - Limited range
  - More susceptible to interference

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Concerns

- Privacy
- Protests/boycotts
- Scale
- Pollution/recycling

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A Changing World

Within a few short years, every item in our everyday world will have an electronically accessible number

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What are we afraid of?

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It is even more serious . . .

- Ability to track objects
- Ability to track people through their objects
- Ability to mine associations
  - People to objects
  - People to people
- Fears
  - Targetted advertising
  - "Big Brother" government
  - Personal security

20th Century Fox (2002)

Privacy Issues

- In the press: "Police…[will be] able to walk around with RFID readers and collect the serial numbers from people's clothing…"
  - IEEE Spectrum, July 2004
- A more practical example: Assume retail stores use shelf readers to inventory their products
  - Consumers may carry:
    - RFID tagged clothing
    - RFID tagged money
    - RFID tagged retail items
  - How can a reader differentiate items ***and*** protect your privacy?
  - What benefits will outweigh privacy erosions?

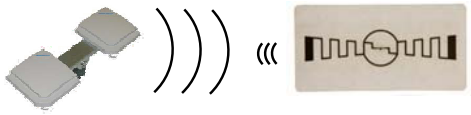
Summary of Privacy Vulnerabilities

- Enablers
  - Item tagging*
  - Interoperability
  - Broadcast range
  - Unique ID
  - After-purchase use*
  - Take into public venues*
  - Absence of security
  - * not imminent
- Threats
  - Radio snooping
  - Network snooping
  - Database cracking
  - Database selling
- RFID Exacerbations
  - Intimacy of data
  - Accumulation of data
  - Distribution of data
  - Data handling by untrained people

From Steven Shafer (Microsoft)

Reader must transmit

- Tags require power from reader to function
  - No data can be released without power output
  - RFID tags are NOT beacons
- Reader sniffers
  - Basically tags with an LED or beeper
  - Easy to police
- Require laws to limit use in public spaces



Reader/tag range

- Tag/reader antenna design is closely coupled
  - Power output of reader is collected by tag
- Tag can limit range with a small antenna that requires more power and pulls reader closer
  - Limits from how far away a tag can be read
  - Varies from direct contact to meters
- Reader can limit range with a small antenna that issues less power requiring tag to be closer
  - Handheld readers with smaller form-factors

Eavesdropping on tag/reader

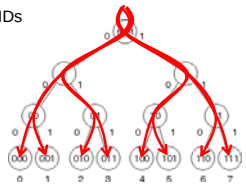
- Eavesdropper must be at least as close as reader or have a much larger antenna
  - Does not need to supply power, only listens
  - Difficult to detect
  - Need to protect communication protocol

Reader/tag communication protocol

- Reader is trying to read all tags in its range
  - Arbitration protocol to identify each one
  - Walks the binary tree of all possible tag IDs
- Tag doesn't have to respond immediately
  - Can ask reader to provide password first
  - Impact on number of tags that can be read
- Jamming
  - Antenna to interfere with reader antenna
  - Denial of service attack on reader
    - Respond as if all 2^{96} tags are present!

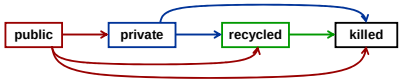
Blocker tags

- Proposed by RSA
- Respond to all interrogations from readers
  - Interrogations are part of arbitration protocol
  - Can be made selective to a portion of possible tags
- Floods reader with replies
  - Makes it search entire space of tag IDs
- Relatively easy to detect
  but not to locate or disable



Password-protected tags

- Proposed for EPCglobal Gen 2 standards



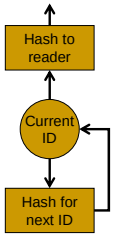
- Password protected tags
  - Only respond if reader provides correct password
    - Need a secret between reader and tag to prevent eavesdropping
  - How is password set?
  - Who keeps passwords?
  - Where are they kept?

Tag tracking

- Database lookup
  - Chain together IDs
    - A seen with B, B with C, C with D, and so on
      – all belong to same person
    - Two IDs of two people seen together several times
  - Track unique object IDs
    - Data mining – connect IDs to credit cards and other data
  - Collusion between readers to connect IDs
    - Database sharing among cooperating entities

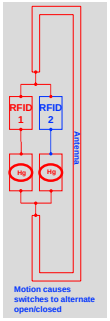
Scramble tags

- NTT DoCoMo
- Provide a different ID every time they are read
- ID sequence is predictable if you know where it started (only owner would know)
- How many reads since last time?



New functions for tags: ID + sensing

- Josh Smith – Intel Research Seattle
- WISP: wireless id + sensing platform
  - Compatible w/ RFID readers
  - Let RFID tags sense, not just identify!
  - Future: temperature, force, humidity, etc.



Writable tags

- Tags can include memory
- Data stored directly on tag for immediate access
  - No need for database
- Who gets to write?
- How is writing done? Can someone overhear?
- Cryptography is needed for secure tags
  - Similar issues as secure Internet transactions
- Limits on power available on tag
  - Today processing is too demanding
  - Better power harvesting is coming soon

Databases

- Where does data reside?
  - In the tag itself
  - In a database indexed by the tag ID
  - Multiple databases
    - Redundancy vs. partitioning
    - Synchronization
- Access control
  - How many passwords? Where are they kept?
  - Tension between automatic seamless use and security/privacy

Data mining

- What are the implications of tagging everything?
  - Can use other data to link tag data
    - E.g., unknown tag passes by a reader,
      credit card transaction nearby,
      same tag seen again later,
      same credit card used nearby that location,
      tag may belong to that person,
      next time I see tag it implies that person is present
- Motivation for password protected tags and scramble tags

Systems

- Today:
  - Readers simply dump data onto a database on the network
  - Vendors offer middleware to interface readers to applications
    - Doesn't address the problem of how to use the data
    - Doesn't provide bidirectional data flow
    - Doesn't allow conditional tag operations
- Future:
  - Need to solve the systems/network problems
    - Where does data reside (in reader, in DB, in tag itself)?
  - Are readers dumb terminals?
    - Cheap integrated reader/antenna with dedicated host(s)
  - Will smart readers mine tag data?
    - Look for new/changed objects
  - Network latency makes killing/writing specific tags difficult

Many privacy choices

- Need to understand technologies available and their true capabilities
  - Often more than we can imagine!
- Completely technological solutions are not possible
  - But is impossible to keep the genie in the bottle!
- Need coordination of law, fair-use practices, policing, and technology

UW CSE RFID Ecosystem

- Create a microcosm of a world saturated with identifiable objects
- Explore applications, systems, social implications
- Do it while there is still time to learn and adapt
- The Allen Center will be our RFID ecosystem
- Spur new applications and inter-disciplinary work

Applications

- Human activity inference (with Intel Seattle)
  - Applications to elder care
  - Infer activity from object being manipulated/moved
- Reminding
  - Tag important objects
  - Wrist-watch reminder when they are left behind
- San Francisco Exploratorium
  - Exhibit triggering
  - Personalized post-visit web page

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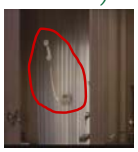
Elder Care (Matthai Philipose – Intel Research Seattle)

- What objects people use is a good indicator of what they are doing
- Track objects using WISPs and/or RFID bracelet reader
- Use to infer activities of daily living (ADLs)



Activity	Prior Work	SHARP
Personal Appearance		82/82
Oral Hygiene		70/78
Toileting		73/73
Washing up	95/84	100/93
Appliance Use		100/75
Use of Heating		84/78
Care of clothes and linen		100/73
Making a snack		100/78
Making a drink		75/60
Use of phone		64/64
Leisure Activity		100/79
Infant Care		100/58
Medication Taking		100/93
Housework		100/82

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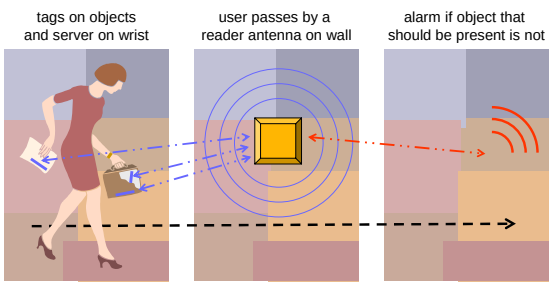
Reminding System



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Science Museum (SF Exploratorium eXspot)

- Interaction at Exploratorium: visitor tag + wireless readers at exhibits
  - Track visitor interest
  - Trigger exhibits (e.g., camera) and link artifacts to visitor
- Customized web page to spur further investigation later

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Education

- Computer Engineering capstone design (Spring '04)
  - Product prototypes based on consumer use of RFID
  - Collaboration with Industrial Design
  - Projects
    - Shopping assistant for the blind
    - Children's playground games
    - Foreign language tutor
    - Hospital work flow
  - See video: *http://www.cs.washington.edu/info/videos/asx/cse477_04sp_254k_320x240.asx*
- Law for a Technology Society (Fall '05)
  - Clinic for law students
  - Suite of laws for RFID privacy protection

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The big question

- What are the implications – for technology, business and society – of having a "number on everything"?
  - Merge physical and virtual worlds
  - Every object is an index into a world-wide database
  - Every object has its own history
  - Track object over its entire lifetime
  - Analyze trends in user habits
- We need a view into this future world

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