RFID: Technology and Applications

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Ref: www.it.iitb.ac.in/~sri/talks/rfid-05.ppt

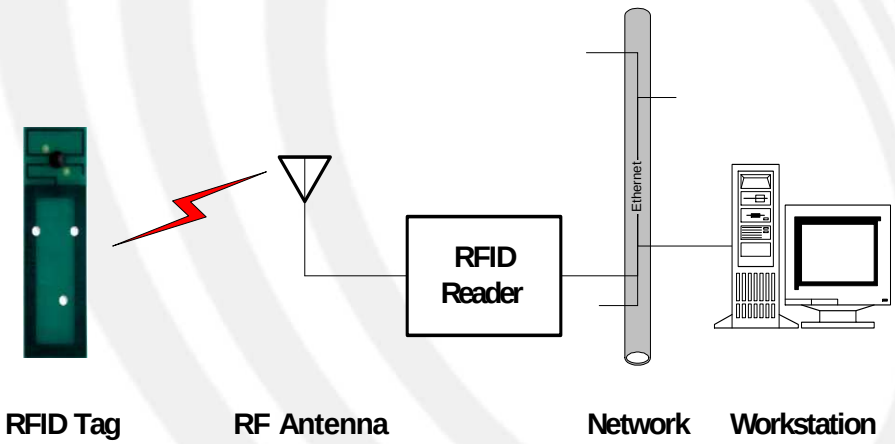
Outline

- Overview of RFID
  - Reader-Tag
  - Potential applications
- RFID Technology Internals
  - RF communications
  - Reader/Tag protocols
- Conclusion

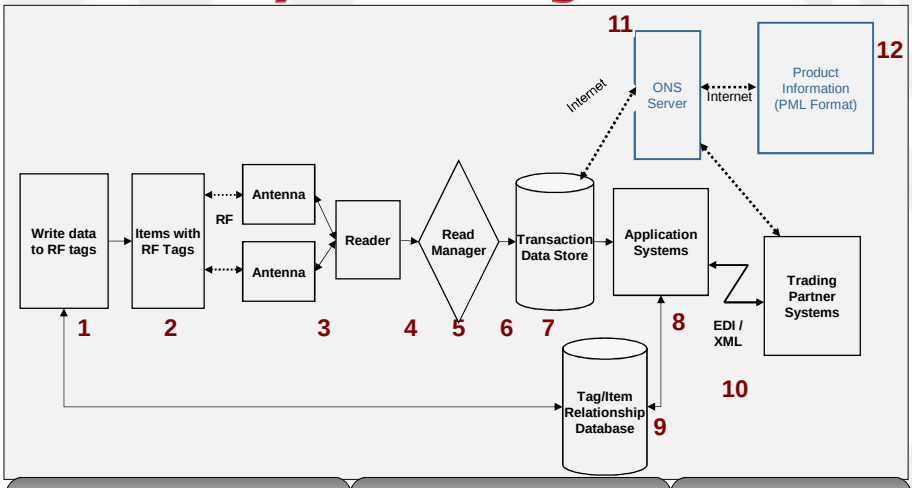
What is RFID?

- RFID = Radio Frequency IDentification.
- An ADC (Automated Data Collection) technology that:
  - uses radio-frequency waves to transfer data between a reader and a movable item to identify, categorize, track..
  - Is fast and does not require physical sight or contact between reader/scanner and the tagged item.
  - Performs the operation using low cost components.
  - Attempts to provide unique identification and backend integration that allows for wide range of applications.
- Other ADC technologies: Bar codes, OCR.

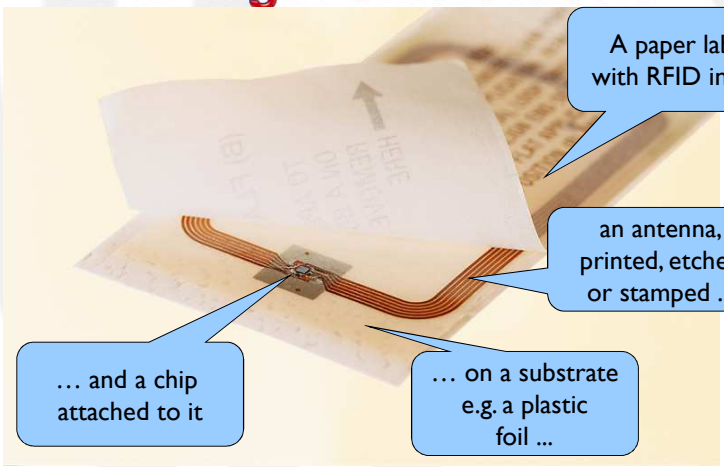
RFID system components



RFID systems: logical view

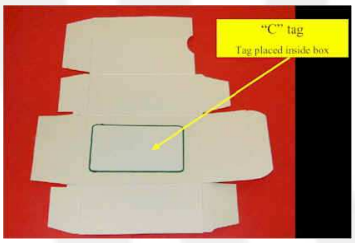


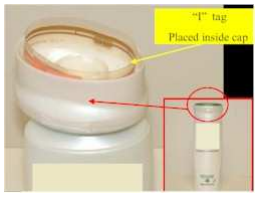
RFID tags: Smart labels



Source: www.rfidprivacy.org

Some RFID tags



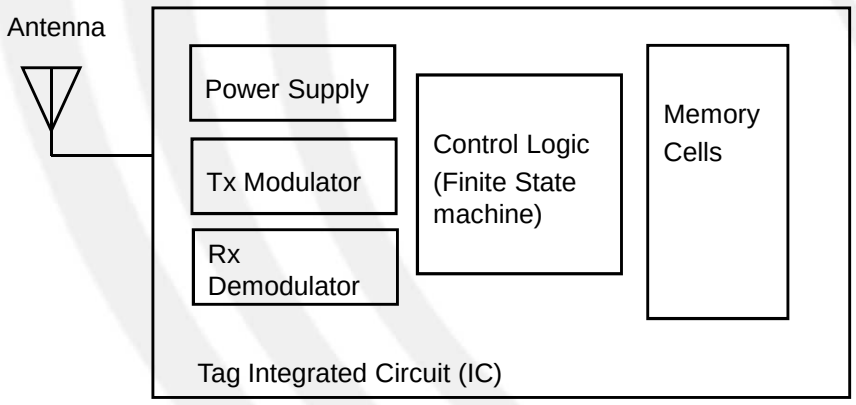


Source: www.rfidprivacy.org

RFID tags

- Tags can be attached to almost anything:
  - Items, cases or pallets of products, high value goods
  - vehicles, assets, livestock or personnel
- **Passive Tags**
  - Do not require power – Draws from Interrogator Field
  - Lower storage capacities (few bits to 1 KB)
  - Shorter read ranges (4 inches to 15 feet)
  - Usually Write-Once-Read-Many/Read-Only tags
  - Cost around 25 cents to few dollars
- **Active Tags**
  - Battery powered
  - Higher storage capacities (512 KB)
  - Longer read range (300 feet)
  - Typically can be re-written by RF Interrogators
  - Cost around 50 to 250 dollars

Tag block diagram



RFID tag memory

- Read-only tags
  - Tag ID is assigned at the factory during manufacturing
    - Can never be changed
    - No additional data can be assigned to the tag
- Write once, read many (WORM) tags
  - Data written once, e.g., during packing or manufacturing
    - Tag is locked once data is written
    - Similar to a compact disc or DVD
- Read/Write
  - Tag data can be changed over time
    - Part or all of the data section can be locked

RFID readers

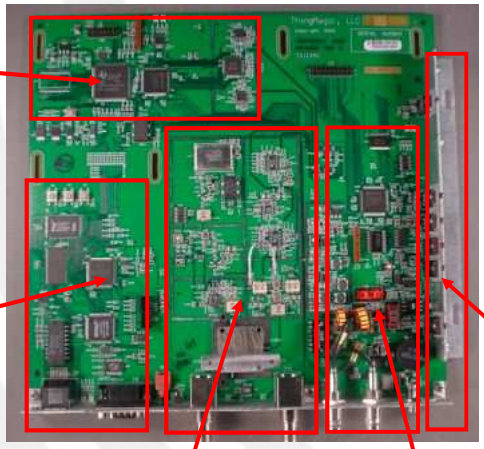
- Reader functions:
  - Remotely power tags
  - Establish a bidirectional data link
  - Inventory tags, filter results
  - Communicate with networked server(s)
  - Can read 100-300 tags per second
- Readers (interrogators) can be at a fixed point such as
  - Entrance/exit
  - Point of sale
- Readers can also be mobile/hand-held

Some RFID readers

Source: www.buyrfid.org

Reader anatomy

Digital Signal Processor (DSP)



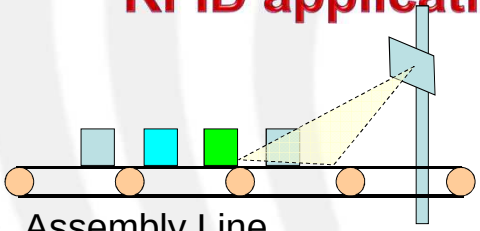
Network Processor

Power Supply

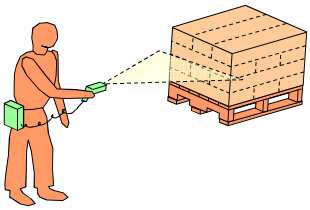
915MHz Radio

13.56MHz Radio

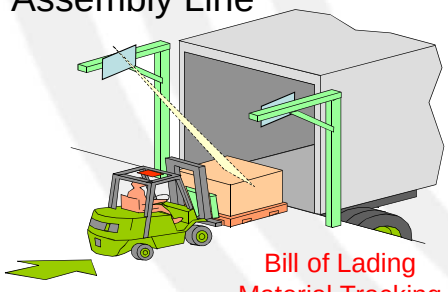
RFID application points



- Assembly Line



- Handheld Applications



Bill of Lading
Material Tracking

- Shipping Portals

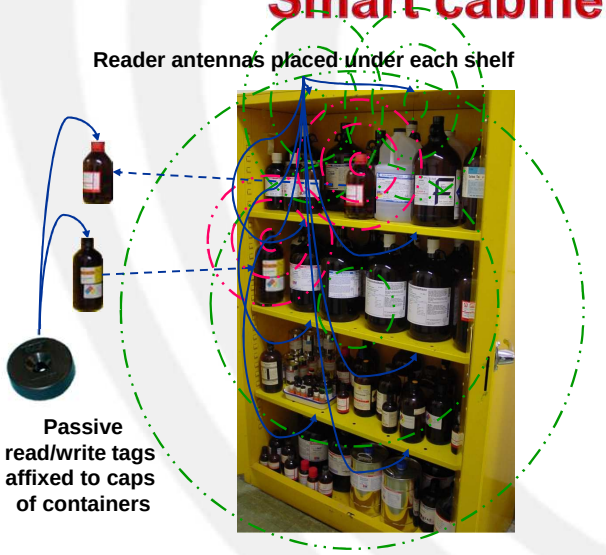
RFID applications

- Manufacturing and Processing
  - Inventory and production process monitoring
  - Warehouse order fulfillment
- Supply Chain Management
  - Inventory tracking systems
  - Logistics management
- Retail
  - Inventory control and customer insight
- Security
  - Access control
  - Counterfeiting and Theft control/prevention
- Location Tracking
  - Traffic movement control and parking management
  - Wildlife/Livestock monitoring and tracking

Smart groceries

- Add an RFID tag to all items in the grocery.
- As the cart leaves the store, it passes through an RFID transceiver.
- The cart is rung up in seconds.

Smart cabinet



1. Tagged item is removed from or placed in "Smart Cabinet"
2. "Smart Cabinet" periodically interrogates to assess inventory
3. Server/Database is updated to reflect item's disposition
4. Designated individuals are notified regarding items that need attention (cabinet and shelf location, action required)

Source: How Stuff Works

Smart fridge

- Recognizes what's been put in it
- Recognizes when things are removed
- Creates automatic shopping lists
- Notifies you when things are past their expiration
- Shows you the recipes that most closely match what is available

Smart groceries enhanced

- Track products through their entire lifetime.

Source: How Stuff Works

Some more smart applications

- "Smart" appliances:
  - Closets that advice on style depending on clothes available.
  - Ovens that know recipes to cook pre-packaged food.
- "Smart" products:
  - Clothing, appliances, CDs, etc. tagged for store returns.
- "Smart" paper:
  - Airline tickets that indicate your location in the airport.
- "Smart" currency:
  - Anti-counterfeiting and tracking.
- "Smart" people ??

RFID advantages over bar-codes

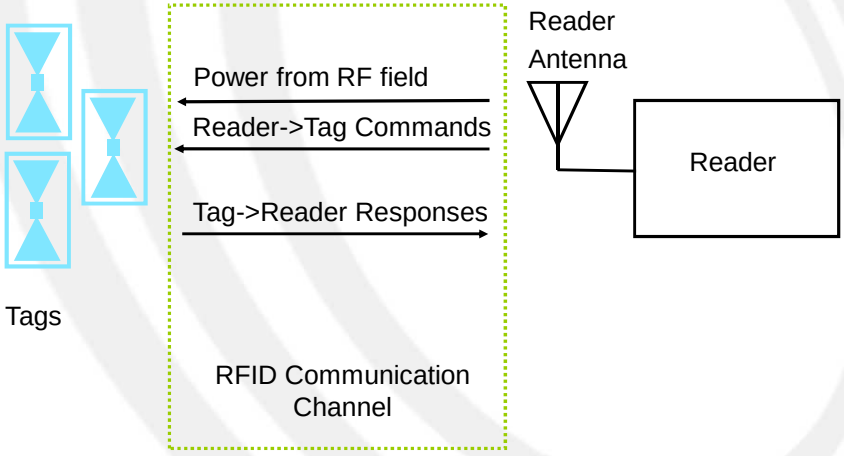
- No line of sight required for reading
- Multiple items can be read with a single scan

- Each tag can carry a lot of data (read/write)
- Individual items identified and not just the category

- Passive tags have a virtually unlimited lifetime
- Active tags can be read from great distances

- Can be combined with barcode technology

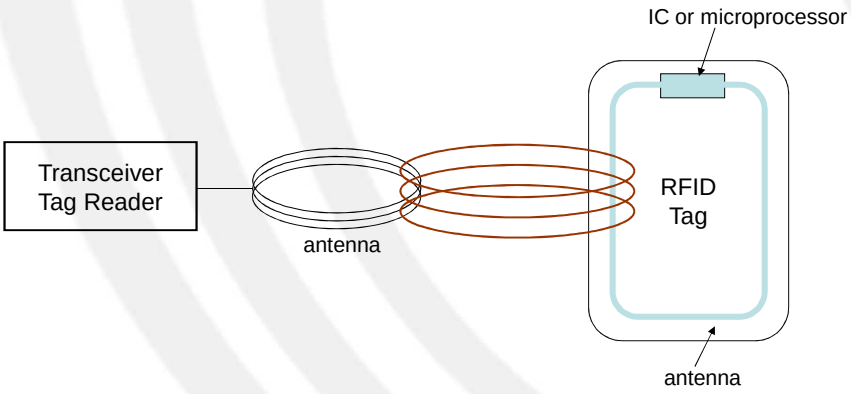
RFID communications



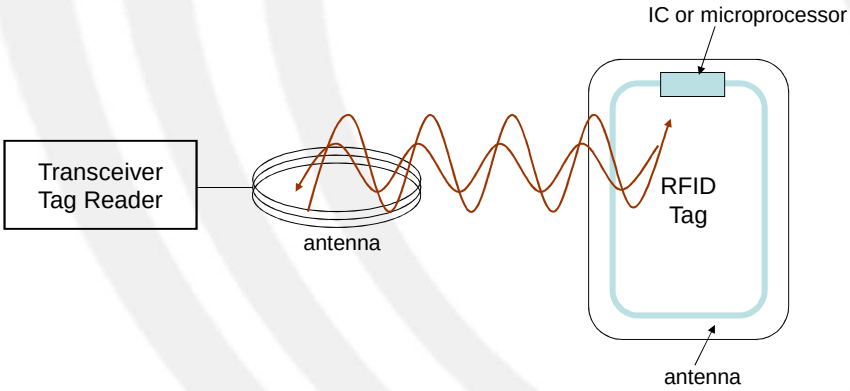
RFID communication

- Host manages Reader(s) and issues Commands
- Reader and tag communicate via RF signal
- Carrier signal generated by the reader
- Carrier signal sent out through the antennas
- Carrier signal hits tag(s)
- Tag receives and modifies carrier signal
  - "sends back" modulated signal (Passive Backscatter – also referred to as "field disturbance device")
- Antennas receive the modulated signal and send them to the Reader
- Reader decodes the data
- Results returned to the host application

Antenna fields: Inductive coupling



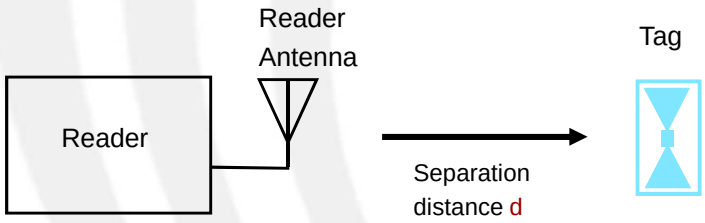
Antenna fields: Propagation coupling (Backscatter)



Operational frequencies

Frequency Ranges	LF 125 KHz	HF 13.56 MHz	UHF 868 - 915 MHz	Microwave 2.45 GHz & 5.8 GHz
Typical Max Read Range (Passive Tags)	Shortest 1"-12"	Short 2"-24"	Medium 1'-10'	Longest 1'-15'
Tag Power Source	Generally passive tags only, using inductive coupling	Generally passive tags only, using inductive or capacitive coupling	Active tags with integral battery or passive tags using capacitive storage, E-field coupling	Active tags with integral battery or passive tags using capacitive storage, E-field coupling
Data Rate	Slower	Moderate	Fast	Faster
Ability to read near metal or wet surfaces	Better	Moderate	Poor	Worse
Applications	Access Control & Security Identifying widgets through manufacturing processes or in harsh environments Ranch animal identification Employee IDs	Library books Laundry identification Access Control Employee IDs	supply chain tracking Highway toll Tags	Highway toll Tags Identification of private vehicle fleets in/out of a yard or facility Asset tracking

Reader->Tag power transfer



Q: If a reader transmits Pr watts, how much power Pt does the tag receive at a separation distance d?

A: It depends-

UHF (915MHz) : Far field propagation : $Pt \propto 1/d^2$

HF (13.56MHz) : Inductive coupling : $Pt \propto 1/d^6$

Limiting factors for passive RFID

1. Reader transmitter power Pr (Gov't. limited)
2. Reader receiver sensitivity Sr
3. Reader antenna gain Gr (Gov't. limited)

4. Tag antenna gain Gt (Size limited)
5. Power required at tag Pt (Silicon process limited)
6. Tag modulator efficiency Et

Implications

- Since $Pt \propto 1/d^2$, doubling read range requires 4X the transmitter power.
- Larger antennas can help, but at the expense of larger physical size because $G\{t,r\} \propto Area$.
- More advanced CMOS process technology will help by reducing Pt.

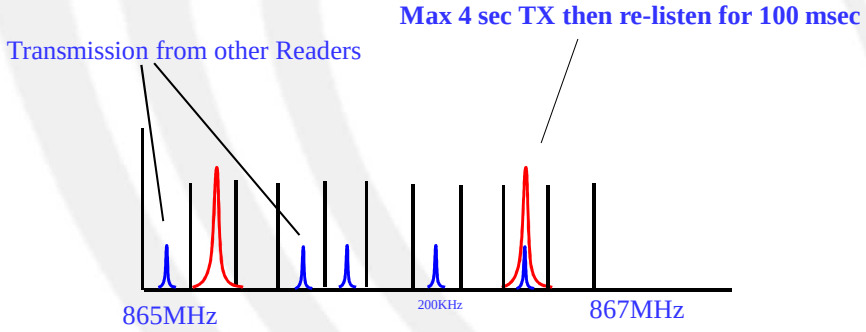
- At large distances, reader sensitivity limitations dominate.

RF effects of common materials

Material	Effect(s) on RF signal
Cardboard	Absorption (moisture) Detuning (dielectric)
Conductive liquids (shampoo)	Absorption
Plastics	Detuning (dielectric)
Metals	Reflection
Groups of cans	Complex effects (lenses, filters) Reflection
Human body / animals	Absorption, Detuning, Reflection

Communication protocols

- Listen before talk
- Mandatory listen time of >5 msec before each transmission

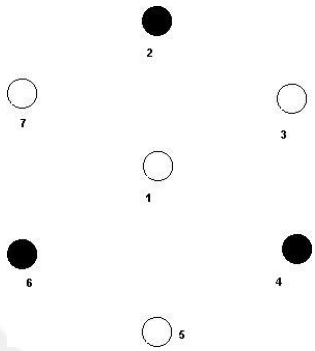


TDMA based solution

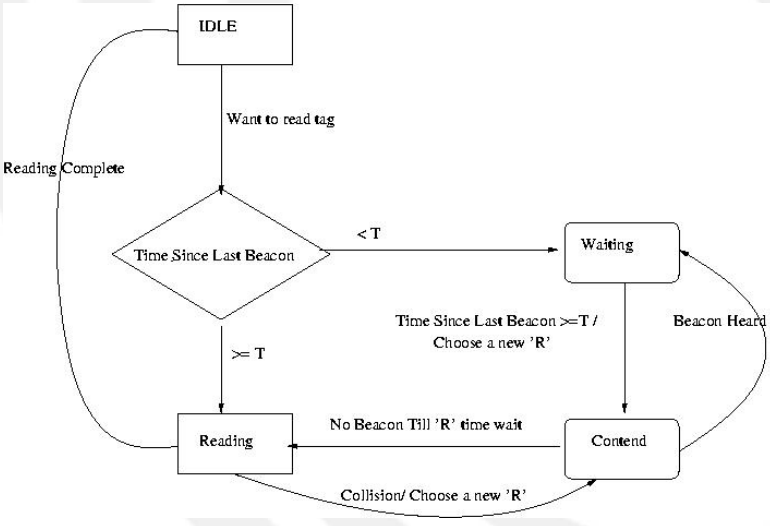
- Assign different time slots and/or frequencies to nearby readers
  - Reduces to graph coloring problem (readers form vertices)
- Only reader to reader interference
  - Assign different operating frequencies
- Only multiple reader to tag interference
  - Assign different time slots for operation
- Both types of interference
  - First allot different time slots, then frequencies

Beacon based solution

- A reader while reading tag, periodically sends a beacon on the control channel
- Assumptions
  - Separate control channel between readers
  - The range in the control channel is sufficient for a reader to communicate with all the possible readers that might interfere in the data channel



Beacon based solution (contd.)



Multiple Tags

When multiple tags are in range of the reader:

- All the tags will be excited at the same time.
- Makes it very difficult to distinguish between the tags.

Collision avoidance mechanisms:

- Probabilistic:
  - Tags return at random times.
- Deterministic:
  - Reader searches for specific tags.

Tag Collision Problem

- Multiple tags simultaneously respond to query
  - Results in collision at the reader
- Several approaches
  - Tree algorithm
  - Memoryless protocol
  - Contactless protocol
  - I-code protocol

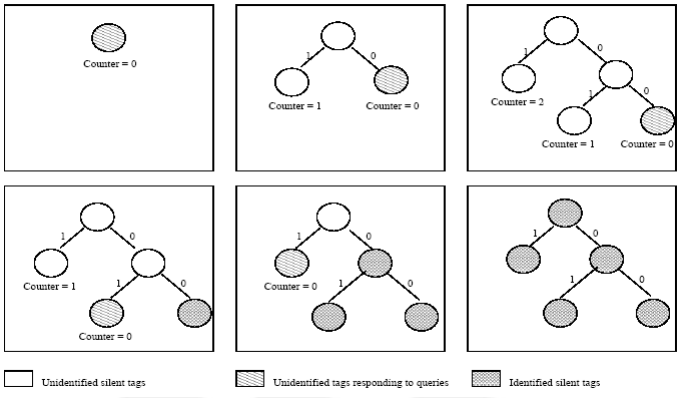
Tree Algorithm

- Reader queries for tags
- Reader informs in case of collision and tags generates 0 or 1 randomly
- If 0 then tag retransmits on next query
- If 1 then tag becomes silent and starts incrementing its counter (which is initially zero)
- Counter incremented every time collision reported and decremented every time identification reported
- Tag remains silent till its counter becomes zero

Tree Algorithm – Example

Reader informs tags in case of collision and tags generate 0 or 1

•If 0 then tag retransmits on next query, else tag becomes silent and starts a counter. Counter incremented every time collision reported and decremented otherwise.



Tree Algorithm - Complexity

- Time Complexity – *O(n)* where n is number of tags to be identified
- Message Complexity
  - n is unknown – *θ(nlogn)*
  - n is known - *θ(n)*
- Overheads
  - Requires random number generator
  - Requires counter

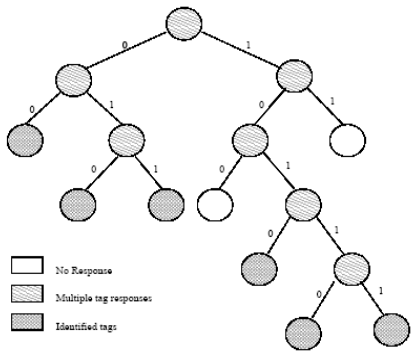
Memoryless Protocol

- Assumption: tagID stored in *k* bit binary string
- Algorithm
  - Reader queries for prefix *p*
  - In case of collision queries for *p*0 or *p*1
- Time complexity
  - Running time – *O(n)*
  - Worst Case – *n*(k + 2 – logn)*
- Message Complexity – *k*(2.21logn + 4.19)*

Memoryless Protocol – Example

- Reader queries for prefix *p*
- In case of collision, reader queries for *p*0 or *p*1
- Example: consider tags with prefixes: 00111, 01010, 01100, 10101, 10110 and 10111

Step	Query Prefix	Response
1	0	Collision
2	1	Collision
3	00	00111 (Identified)
4	01	Collision
5	10	Collision
6	11	No Response
7	010	01010 (Identified)
8	011	01100 (Identified)
9	100	No Response
10	101	Collision
11	1010	10101 (Identified)
12	1011	Collision
13	10110	10110 (Identified)
14	10111	10111 (Identified)

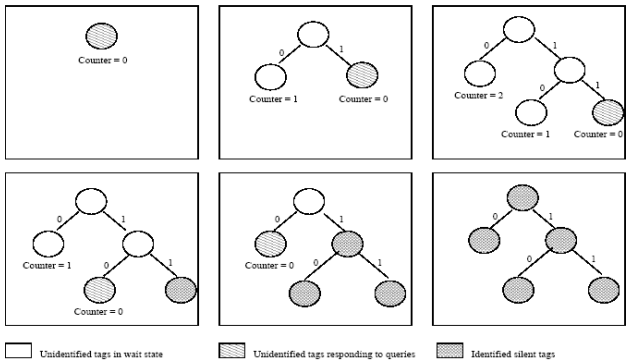


Contactless Protocol

- Assumption: tagID stored in *k* bit binary string
- Algorithm
  - Reader queries for (i)th bit
  - Reader informs in case of collision
    - Tags with (i)th bit 0 become silent and maintain counter
    - Tags with (i)th bit 1 respond to next query for (i+1)th bit
- Time complexity – $O(2^k)$
- Message complexity – $O(m(k+1))$, where m is number of tags

Contactless Protocol – Example

- Reader queries for (i)th bit
- Reader informs in case of collision
  - Tags with (i)th bit 0 become silent and maintain counter
  - Tags with (i)th bit 1 respond to next query for (i+1)th bit
- Example: tags with prefixes: 01, 10 and 11



I-Code Protocol

- Based on slotted ALOHA principle
- Algorithm
  - Reader provides time frame with *N* slots, *N* calculated for estimate *n* of tags
  - Tags randomly choose a slot and transmit their information
  - Responses possible for each slot are
    - Empty, no tag transmitted in this slot – c_0
    - Single response, identifying the tag – c_1
    - Multiple responses, collision – c_k

I-Code Protocol

- New estimate for *n* : lower bound

  $\varepsilon_{lb}(N, c_0, c_1, c_k) = c_1 + 2c_k$

- Using estimate *n*, *N* calculated
- *N* becomes constant after some time
- Using this *N* calculate number of read cycles *s* to identify tags with a given level of accuracy *α*

N slots	1	4	8	16	31	64	128	256
n_low	-	-	-	1	10	17	51	112
n_high	-	-	-	9	27	56	129	∞

- Time complexity – $t_0*(s+p)$
  - t_0 is time for one read cycle
  - *p* number of read cycles for estimating *N*
- Message complexity – $n*(s+p)$

How much data?

Consider a supermarket chain implementing RFID:

- 12 bytes EPC + Reader ID + Time = 18 bytes per tag
- Average number of tags in a neighborhood store = 700,000
- Data generated per second = 12.6 GB
- Data generated per day = 544 TB
- Assuming 50 stores in the chain,
  - data generated per day = 2720 TB
- Stanford Linear Accelerator Center generates 500 TB

Points to note about RFID

- RFID benefits are due to automation and optimization.
- RFID is not a plug & play technology.
- “One frequency fits all” is a myth.
- Technology is evolving but physics has limitations.
- RFID does not solve data inconsistency within and across enterprises.
- Management of RFID infrastructure and data has been underestimated.

RFID Summary

Strengths	Weaknesses
➢ Advanced technology ➢ Easy to use ➢ High memory capacity ➢ Small size	➢ Lack of industry and application standards ➢ High cost per unit and high RFID system integration costs ➢ Weak market understanding of the benefits of RFID technology
Opportunities	**Threats**
➢ Could replace the bar code ➢ End-user demand for RFID systems is increasing ➢ Huge market potential in many businesses	➢ Ethical threats concerning privacy life ➢ Highly fragmented competitive environment

Some Links

- http://www.epcglobalinc.com/
- http://www.rfidjournal.com/
- http://rfidprivacy.com/
- http://www.rfidinc.com/
- http://www.buyrfid.com/

Thank You