Politecnico di Milano

Advanced Network Technologies Laboratory

A primer on radio frequency identifaction

Agenda

A bit of context

Building blocks and hardware

Singulation arbitration protocols

RFID in Nutshell

Labels

Direct accessibility

Barcodes

0 36000 29145 2

Indirect accessibility
through binary codes
Optical reading (cm range)

Smart cards

EC to store/process
Galvanic/inductive reading

RFIDs

EM reading

To Enhance the concept of “bar-codes” for faster identification of assets (goods, people, animals)

Ingredients:

- Transition to electronic bar codes with wireless communication capabilities

- Transition form optical to wireless “readers”

RFID History

WW2 –
First passive RFID system: “roll plane” by Lufwaffe
First active RFID system: “Friend or Foe” systems by RAF

Theremin Bug (1945)

H. Stockman Paper (1948) – Communication by means of reflected power

RFID History

60s/70s: commercial deployment starts, Electronic Article Surveillance (EAS) in retail, LF identification of animals

First RFID Patent - 1973

80s: mass deployment starts, first read/write active systems with processors

90s: first passive systems with EEPROM, automatic toll systems

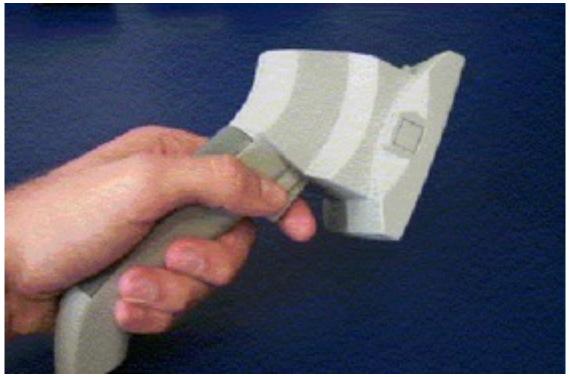
Auto-ID center founded at MIT – 1999: Standardization effort taken over by EPC Global (Electronic Product Code)

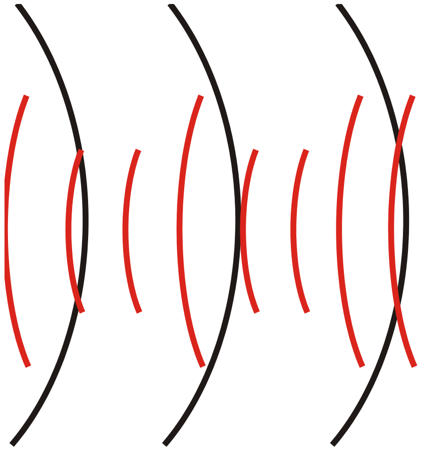
2000: conductive inks, low-power processors

2004: Walmart use case

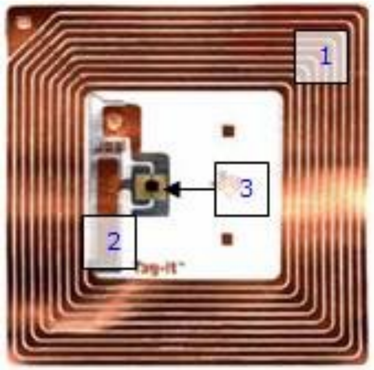
RFID Building Blocks

Reader





Tag



Memory
Processing Unit
Control Logic/Collision Arbitration Mechanism
Battery or Power Supply
Other Interfaces (Ethernet, WiFi)

Battery Scavenging circuitry (active or passive)
(E2PROM to store ID)
(Control Logic/Collision Arbitration Mechanism)
(sensors)
(processing unit)
(RF antennas)

Types of Tags (by power supply)

Passive

Operational power scavenged from reader radiated power

Short range (<1m), Low cost
Self sustaining

Semi-passive

Operational power provided by battery

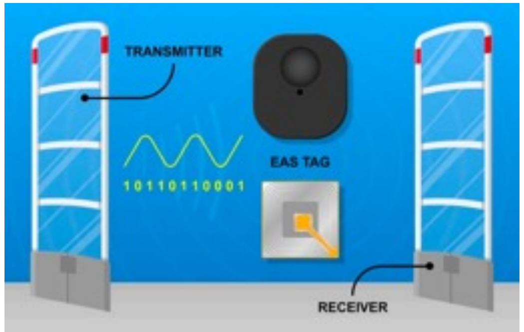
Medium range (tens of meters), need battery, avarage cost, long life

Active

Operational power provided by battery - transmitter built into tag

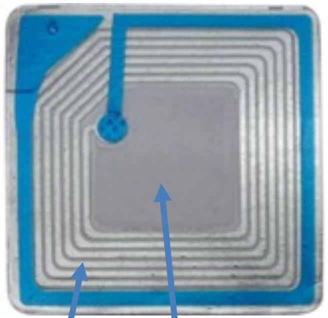
high range (hundreds of meteres), need battery, Limited lifetime

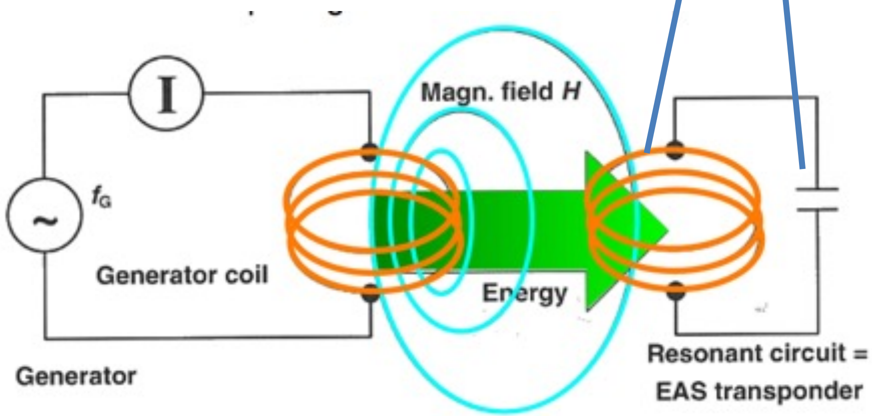
Types of Tags (by storage)



1-bit tags: used in EAS systems

- realized with magnetic material
- when tag gets close to reader, current variation is perceived at the reader
- multple detection impossible

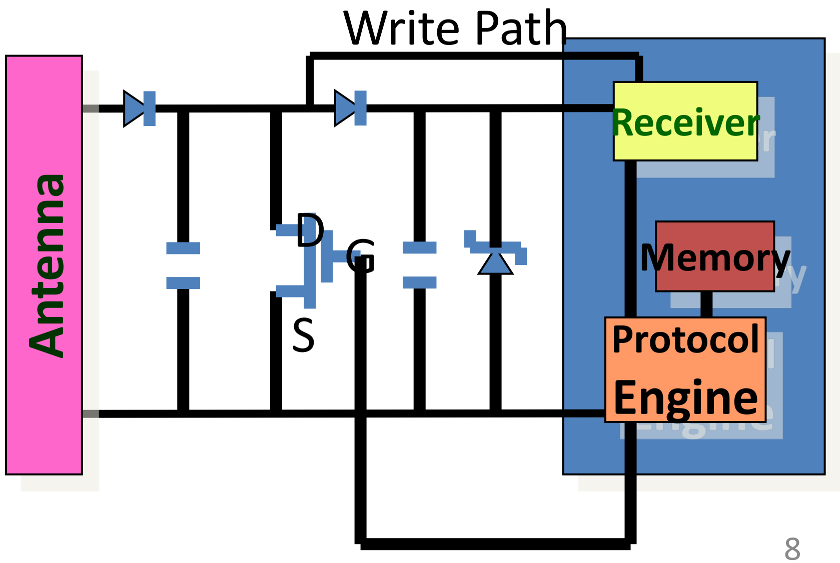




Tags with storage space

- Read only
- Read/write

RX/TX/modulation/demodulation circuitry
Unique Identifier



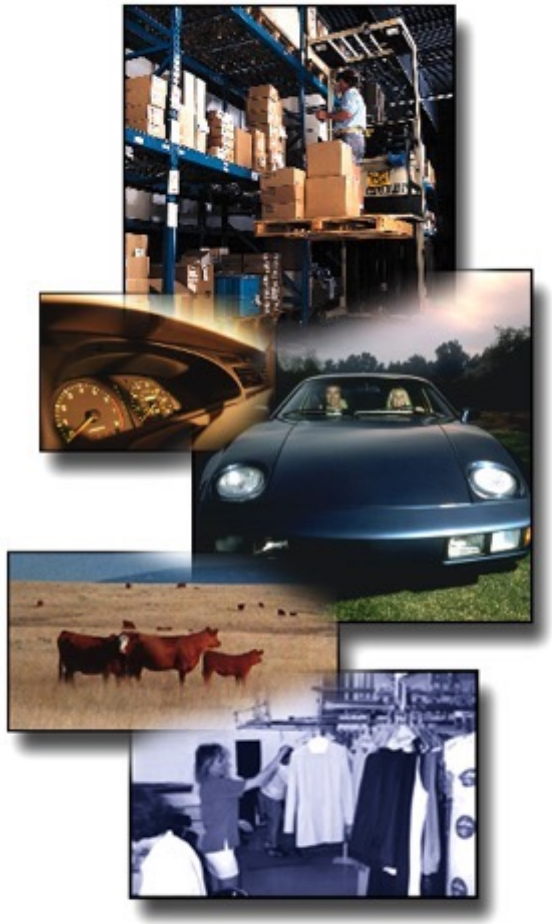
Tag classification

Class 0	UHFI read-only, preprogrammed passive tag
Class 1	UHF or HF; write once, read many (WORM)
Class 2	Passive read-write tags that can be written to at any point in the supply chain
Class 3	Read-write with onboard sensors capable of recording parameters like temperature, pressure, and motion; can be semipassive or active
Class 4	Read-write active tags with integrated transmitters; can communicate with other tags and readers
Class 5	Similar to Class 4 tags but with additional functionality; can provide power to other tags and communicate with devices other than readers

The Tags

Tags can be attached to anything:

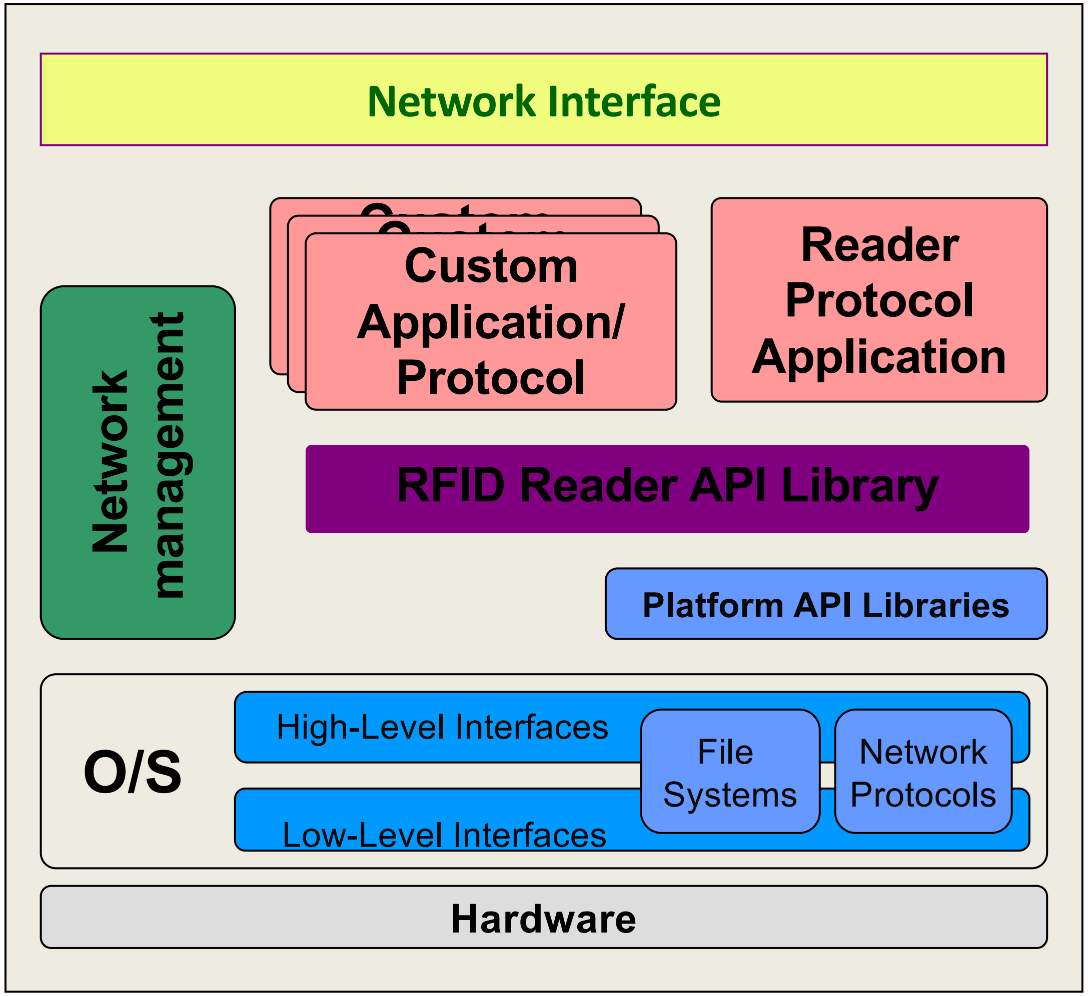
- pallets or cases of product
- Vehicles
- company assets or personnel
- People or animals
- Electronic appliances



Implementation challenges

Effective Energy Scavenging
Miniaturization/customization
Cost

Reader Radiography



Reader running examples

radio frequencies	
operating frequency	865 ... 868 MHz
transmit power	3 ... 400 mW
effective radiated power	
• for each external antenna maximum	1 100 mW
• minimum	10 mW
• maximum	200 mW
equivalent isotropically radiated power	
• for each external antenna maximum	
• minimum	
• maximum	
range maximum	4 m; With the internal antenna 1.6 m, extended ranges possible, see RF600 System Manual, range table: http://support.automation.siemens.com/WW/view/en/67384964
protocol with radio transmission	EPCglobal Class 1 Gen 2 V2 / ISO/IEC 18000-62/-63
transfer rate with radio transmission maximum	400 kbit/s
product feature multitag-capable	Yes
polarization	circular

interfaces	
number of external antennas	1
standard for interfaces for communication	Ethernet, PROFINET, OPC UA, EtherNet/IP, RS422
type of electrical connection	

RFID	
Type	Handheld RFID Scanner
Operating Frequency	UHF(Ultra High Frequency) 860MHz~960MHz
	HF(High Frequency) 13.56MHz
	LF(Low Frequency) 125KHz
Protocol	UHF: ISO18000-6C, EPC Class 1 Gen 2, ISO18000-6B
	HF: ISO14443A/B, ISO15693
Reading Range	UHF: 400 ~ 1300cm (Depend on tags and environment)
	HF: 5 ~ 20cm
	LF: 4 ~ 10cm
RSSI	Received signal strength indication
Anti-collision	Read up to 400 piece of tags simultaneously
Antenna Polarization	Circular Polarized
SDK	Free SDK provided attached to the Reader
System features	
Operating system	Microsoft® Windows CE® 6.0 or Android OS v2.2
Processor	SAMSUNG Cortex-A8(1GHz)

Communication features	
WiFi	802.11b/g
GPRS (GSM)	GSM/GPRS/EDGE: 850/900/1800/1900MHz
3G	WCDMA / CDMA2000
Bluetooth	Bluetooth 2.1 + EDR class 2
GPS	Integrated

Reader Implementation Challenges

Reader must deliver enough power from RF field to power the tag

Reader must discriminate backscatter modulation in presence of carrier at same frequency

High magnitude difference between transmitted and received signals

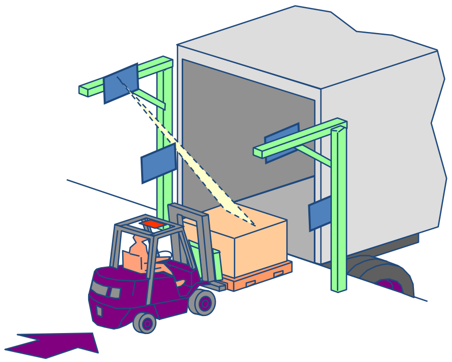
Integration with enterprise solutions

RFID Backend

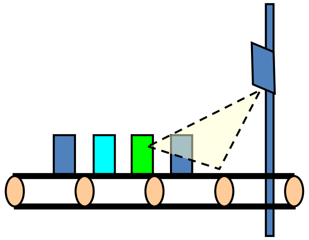
Middleware solutions to:

- manage high data volume produced by readers
- filter the data produced by the readers (remove redundancy, eliminate unwanted data, etc.)
- Store the data in a way that is meaningful for the specific application
- Let different readers be interoperable

Usage Models



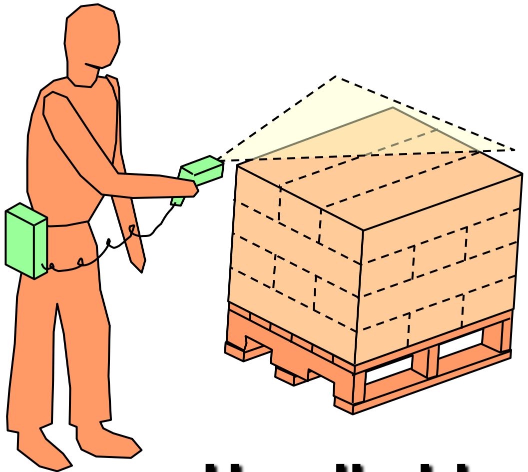
Dock Door



Conveyor Belt

Forklift

Printers



Handheld

Smart Shelves

Point of Sale

Performance measures

Reading range

«how far we can read»

Throughput

«how fast we can read»

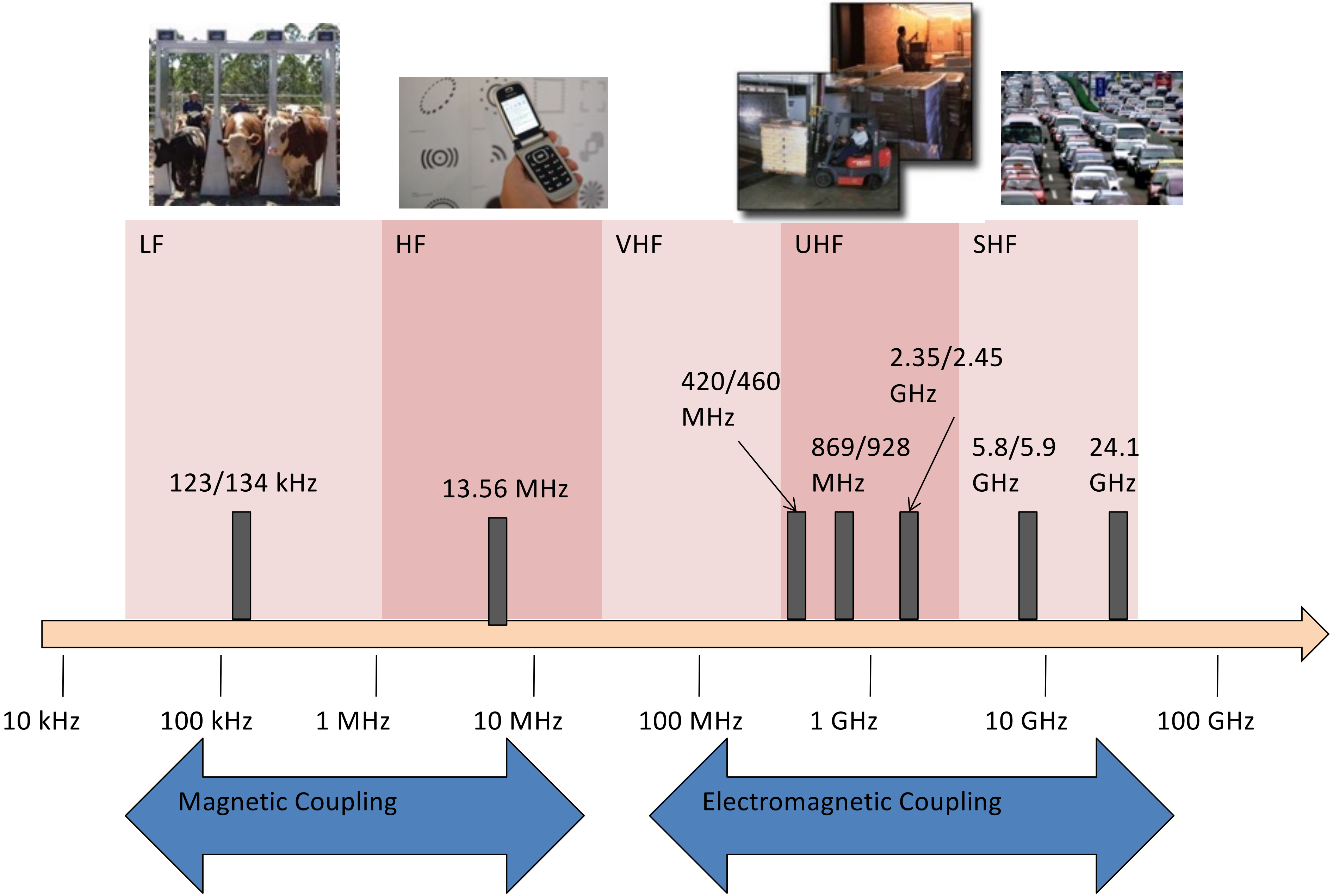
Robustness

«how robust the reading process»

Performance depends on:

- *Carrier frequency*
- *Emitted power*
- *Environment (propagation conditions)*
- *Concurrency (# of tags to be read simultaneously)*

RFID: Spectrum Snapshot



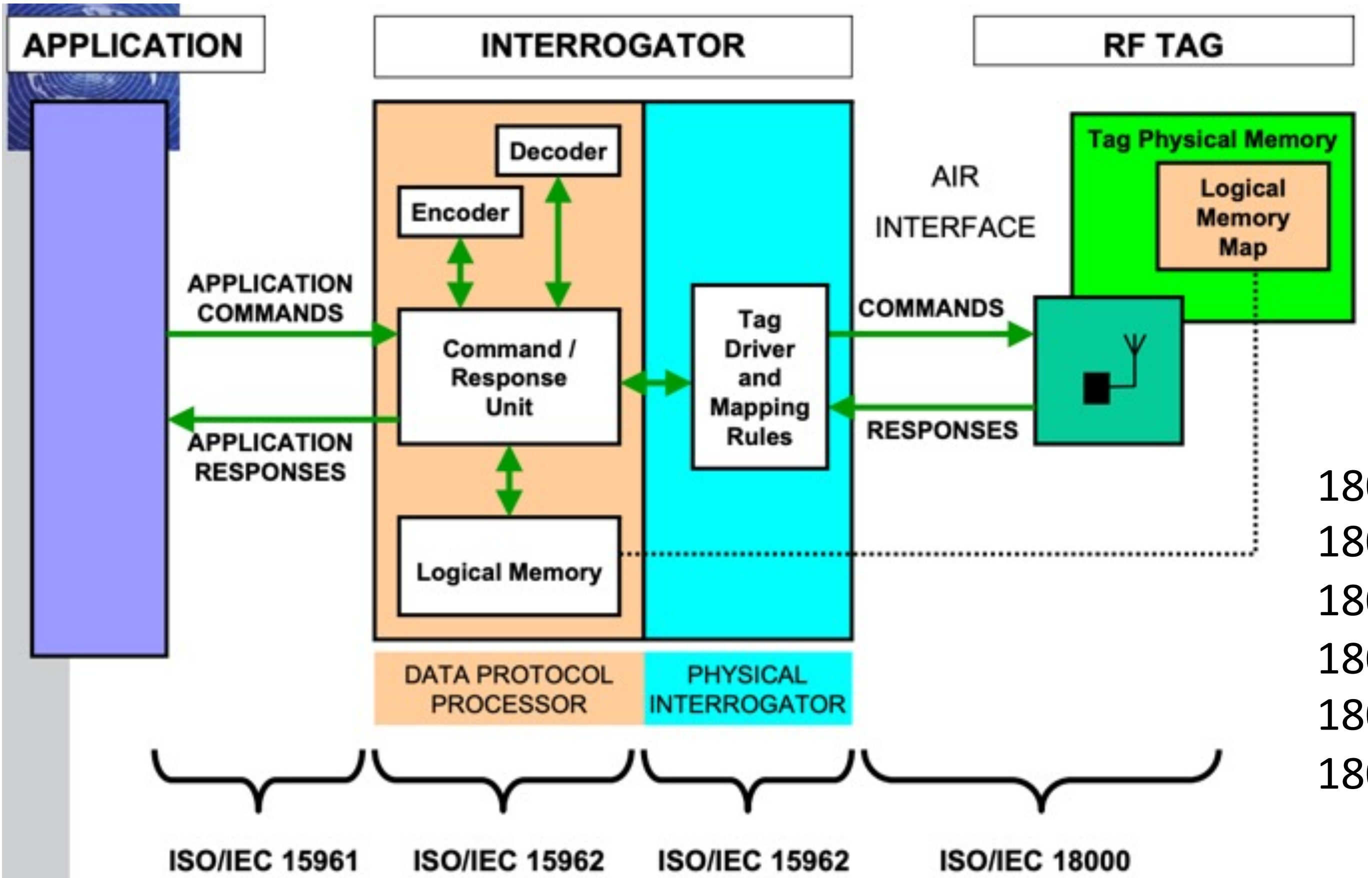
RFID Standards

Different standards available in the flields of:

- animal identification
- cards and personal identification
- containers ID

Standards dedicated to item management application developed by ISO/IEC

www.iso.org

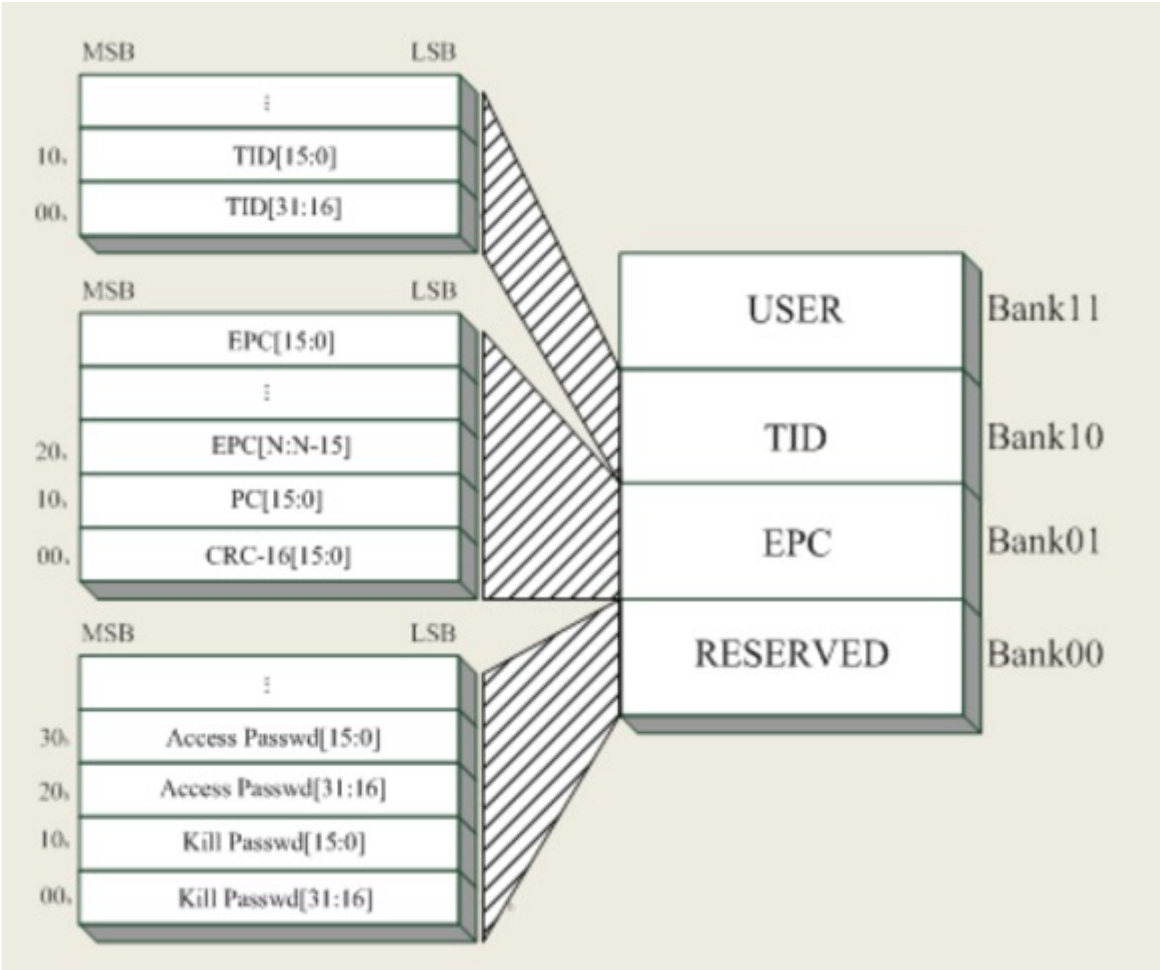


18000-1: General guidelines
18000-2: <135 KHz
18000-3: HF 13.56 MHz
18000-4: 2.45 GHz
18000-6: UHF 860-960 MHz
18000-7: 433 MHz

RFID Standards

GS1 – EPCGlobal initiative, *UHF C1 Gen 2 (900MHz)* ref standards (ISO 18000-6c)

www.gs1.org



RFID Standards

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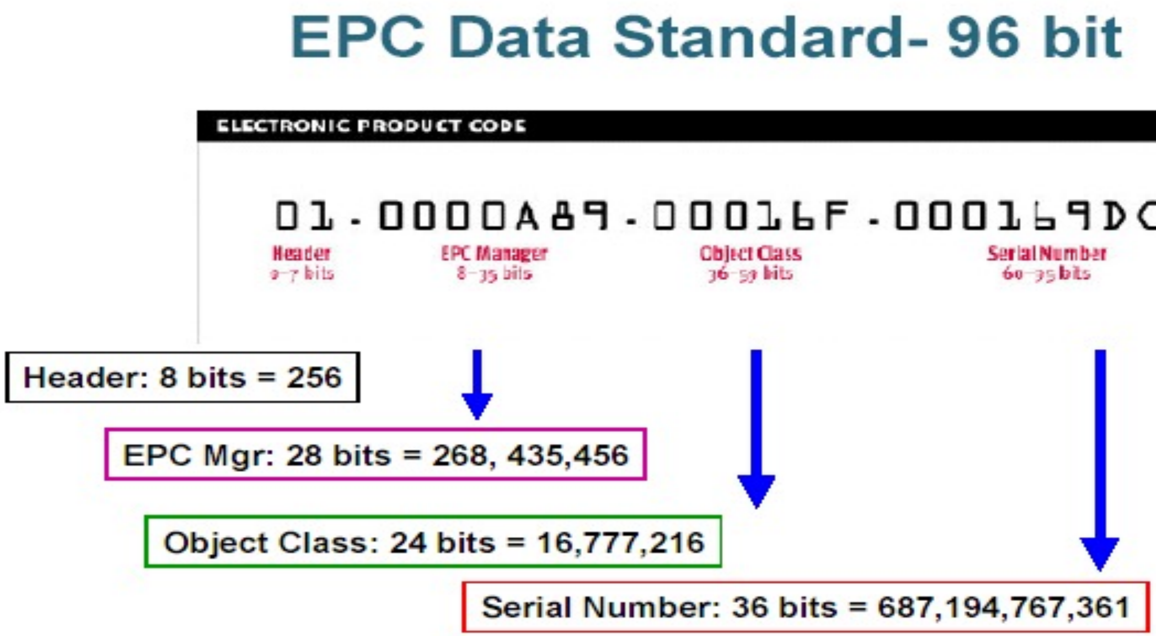
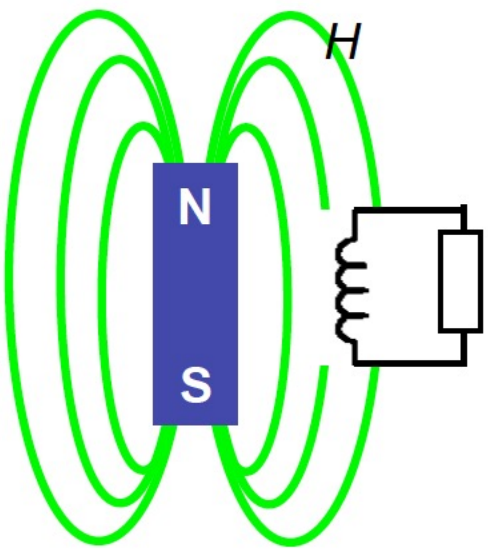


Header - Tag version number
EPC Manager - Manufacturer ID
Object class - Manufacturer's product ID
Serial Number - Unit ID

With 96 bit code, 268 million companies can each categorize 16 million different products where each product category contains up to 687 billion individual units

RFID: Physical Communication

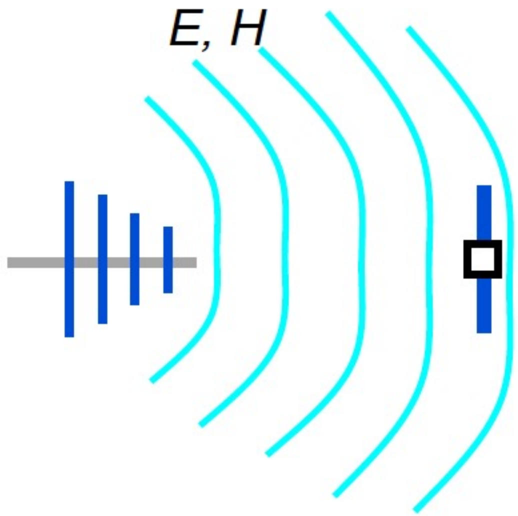
Near Field Model (HF)



125 kHz – 13.56 MHz

125 kHz	0.05 m
13.56 MHz	0.5 m

Far Field Model (UHF)



400 MHz – 2450 MHz

860 - 930 MHz	4-10 m
2450 MHz	1 m

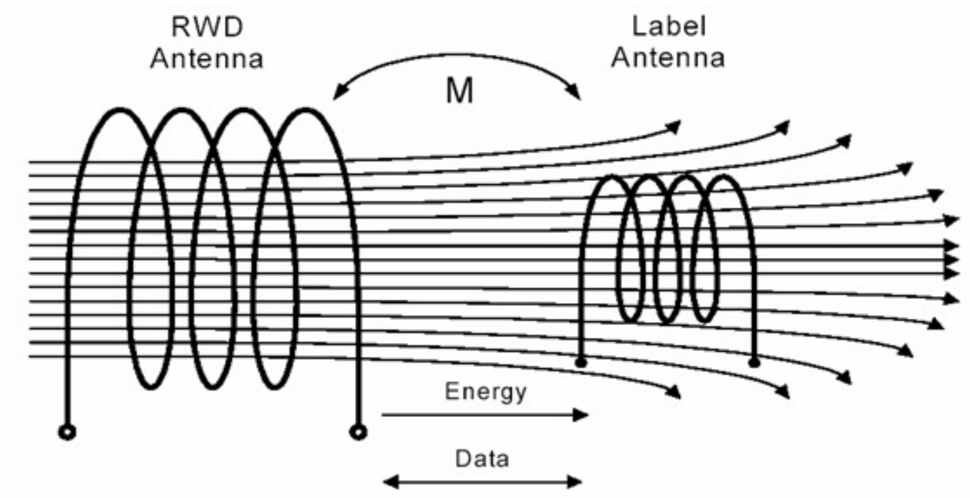
RFID HF – Inductive coupling

Inductive Coupling between two circuits (reader and tag)

Frequency Range 125kHz o 13,56 MHz

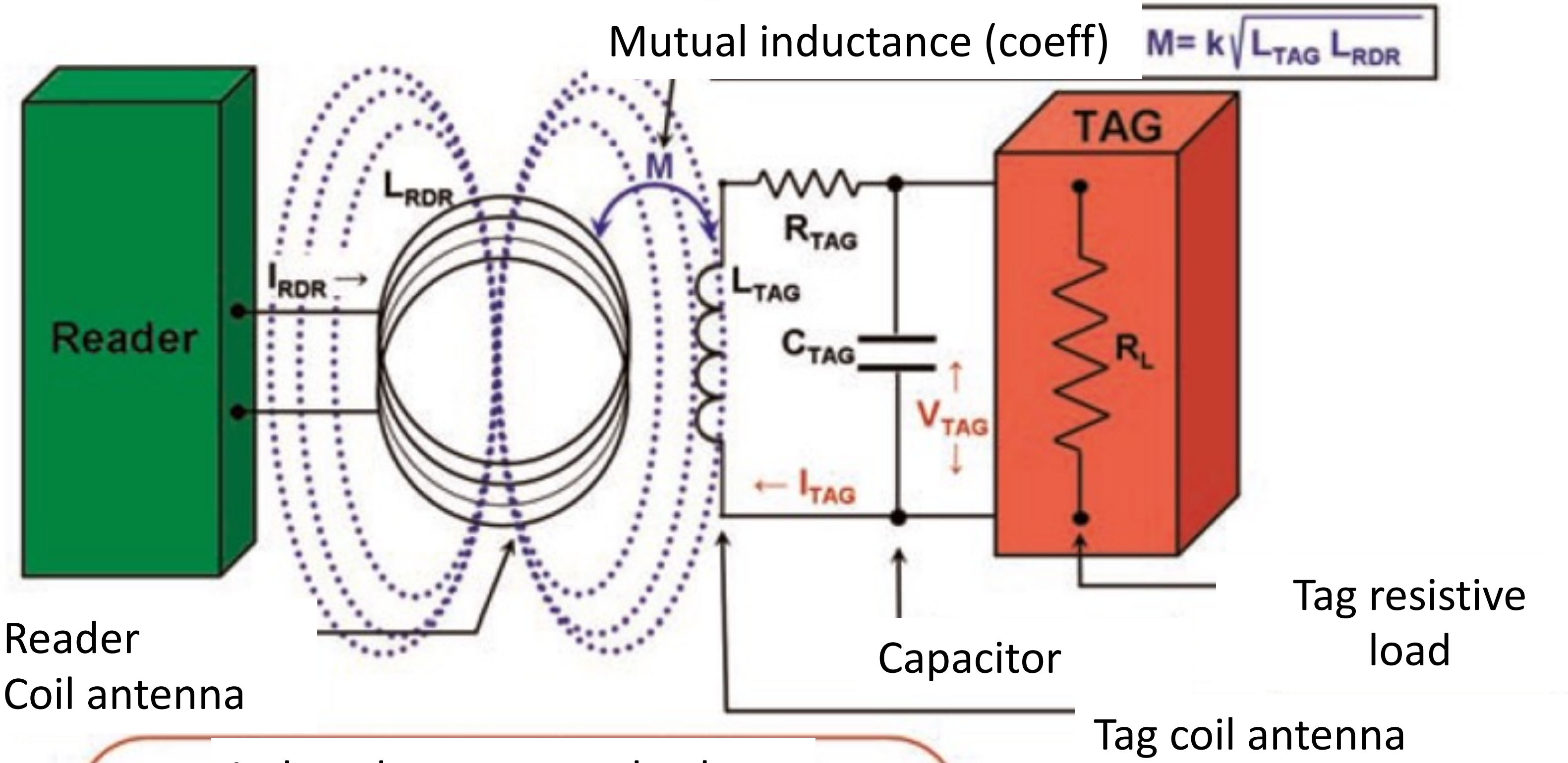
Reading range comparable to coil diameter
Functioning modes:

Duplex (concurrent charging and transmission)
sequential (charging and transmission decoupled)



RFID HF – Drill into inductive coupling (Reader to tag TX)

Same principle of transformers
Faraday’s law of induction



$$M = k\sqrt{L_{TAG} L_{RDR}}$$

Induced currents and voltage

$$I_{TAG} = \frac{j\omega M I_{RDR}}{R_{TAG} + Z_{TAG} + j\omega L_{TAG}}$$

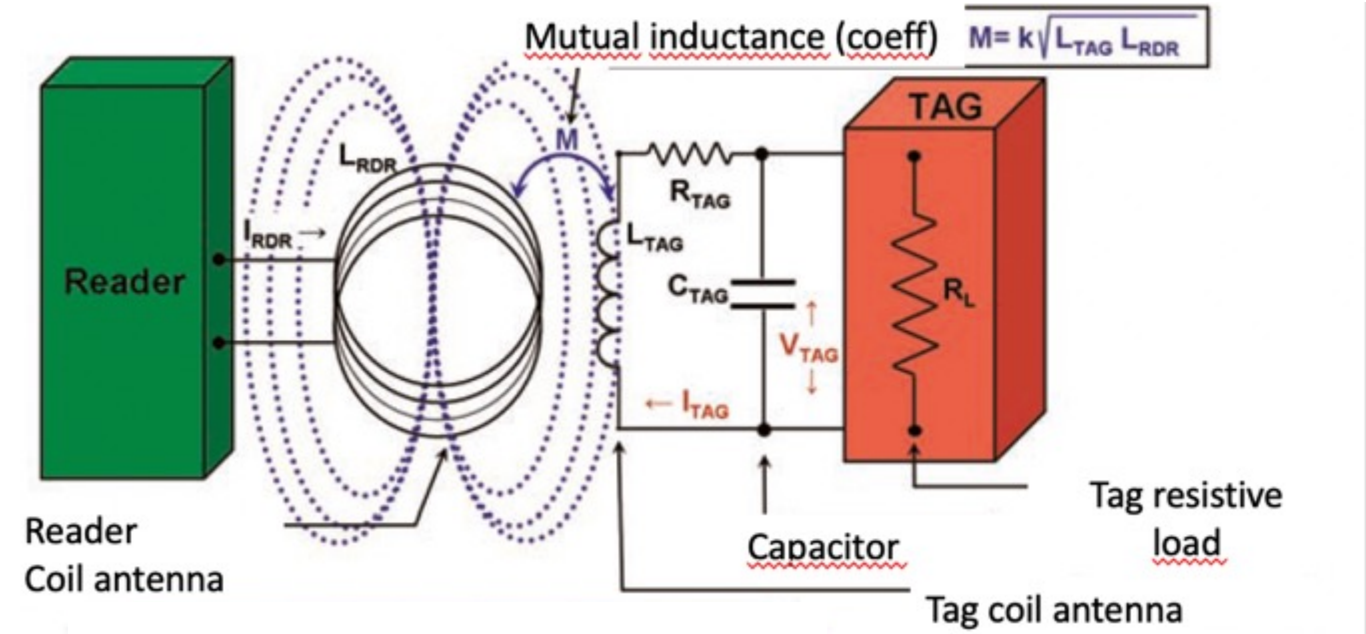
$$V_{TAG} = Z_{TAG}\, I_{TAG}$$

$$Z_{TAG} = C_{TAG} // R_L$$

Resonating frequency

$$f_0 = \frac{1}{2\pi\sqrt{L_{TAG} C_{TAG}}}$$

RFID HF – Drill into inductive coupling (Tag to reader TX)



$$V_{RDR} = \left[R_{RDR} + j\omega L_{RDR} + \frac{1}{j\omega C_{RDR}} + \underbrace{\boxed{\frac{\omega^2 M^2}{R_{TAG} + j\omega L_{TAG} + \dfrac{R_L}{1 + j\omega R_L C_{TAG}}}}}_{\text{Tag-induced contribution}} \right] I_{RDR}$$

Tag modulates its resistive load with the info to be sent

Voltage changes (modulated by the tag information) are triggered at the reader

RFID HF – Qualitative performance overview

Tag activation voltage (reading range) depends on
- Size of coil antennas (the larger the better)
- Tag/reader orientation
- Tag/reader chip hardware

In LF/HF magnetic field is scarcely affected by dielectric materials

Limited reading range 

Very sensitive to orientation 

Almost immune to the environment 

Moderate cost 

RFID UHF/SHF – Electromagnetic coupling

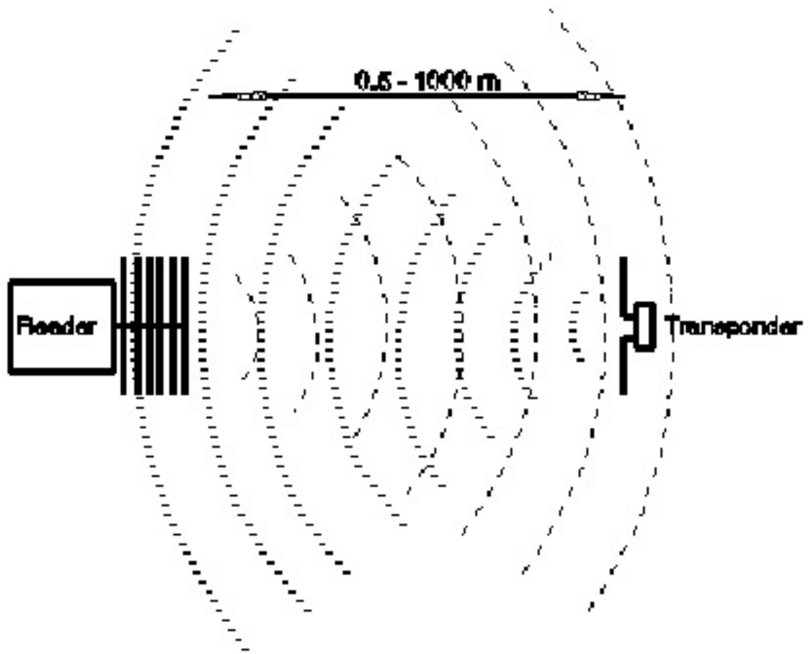
Far field operation model

Energy/power is scavanged by the tag through EM waves emitted by reader

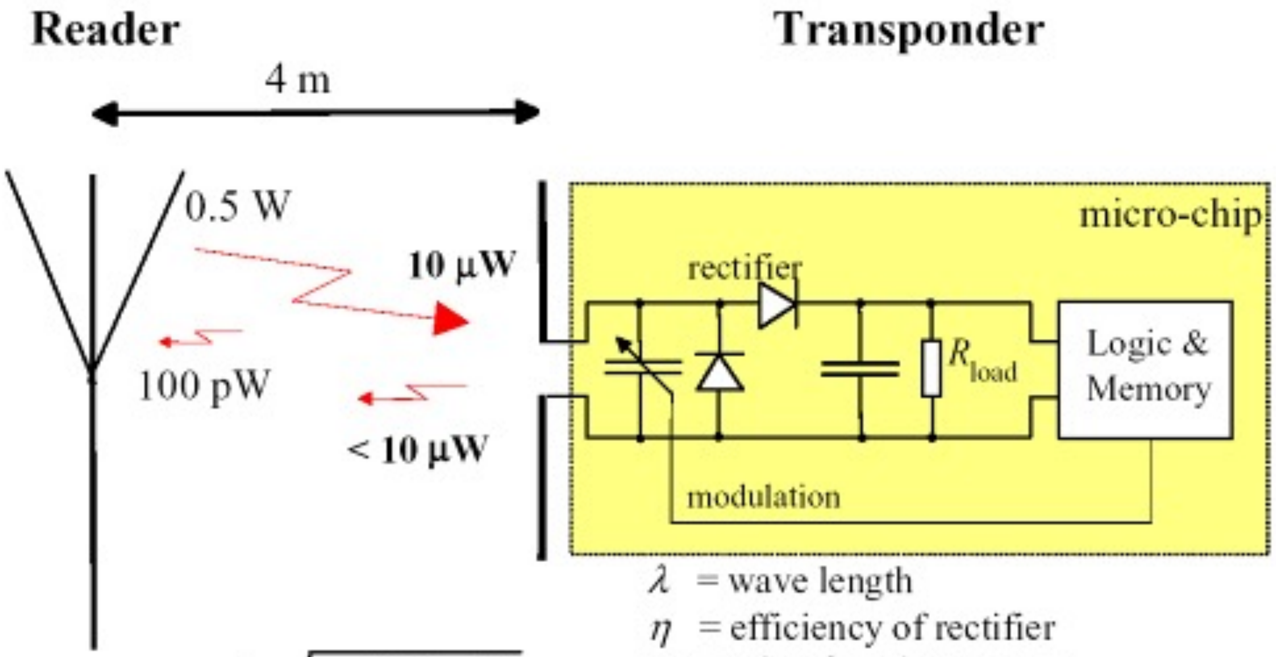
Transmission happens via backscattering by modulating the impedence

Tens of meters of read range

Bipolar antennas (few centimeters)

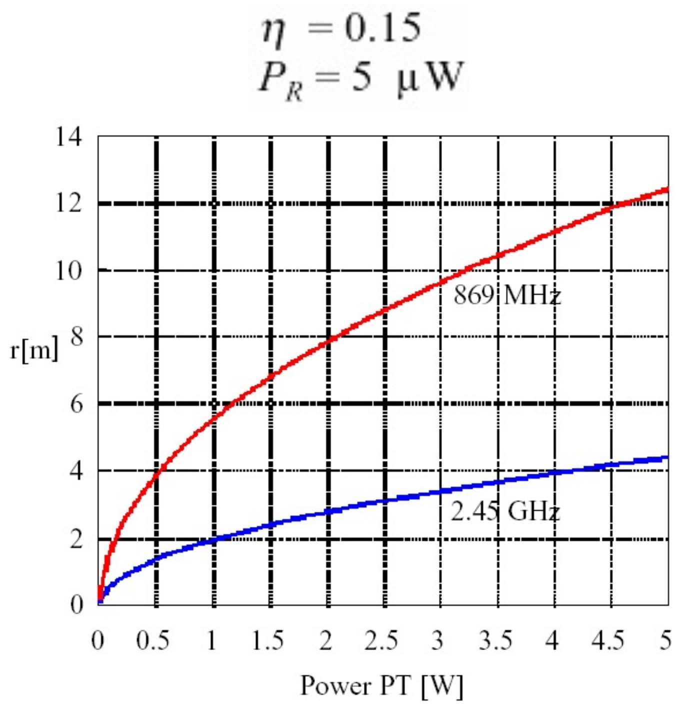


RFID UHF Drill into EM coupling



$$r_{max} = \frac{\lambda}{4\pi}\sqrt{\frac{\eta G_T G_R P_T}{P_R}}$$

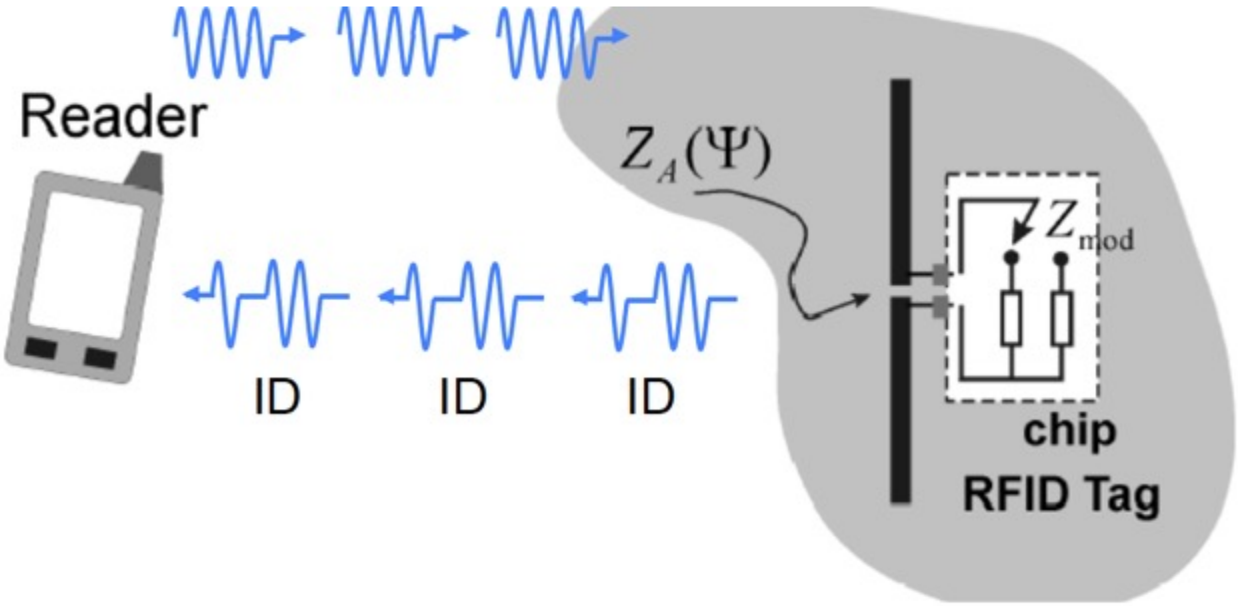
λ = wave length
η = efficiency of rectifier
G_T = gain of reader antenna
G_R = gain of transponder antenna
P_T = power transmitted by a reader
P_R = power required by a transponder

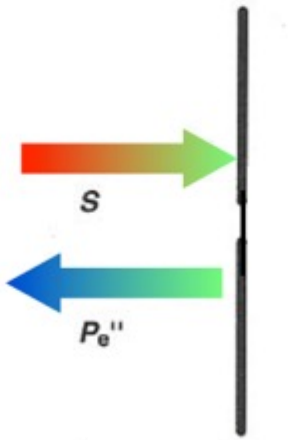


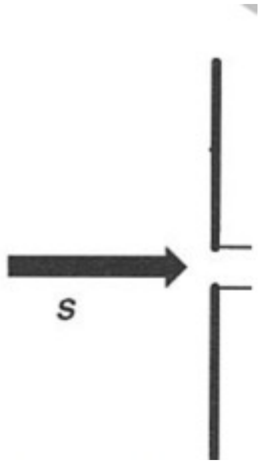
What about higher frequencies?
2.45, 5.8 GHz

Mini Antennas but lower read range

RFID UHF Drill into EM coupling







Swicth on: low impendence (Z_{mod}=0)
Strong backscattering

Swicth off: high impendence (Z_{mod}=inf)
low backscattering

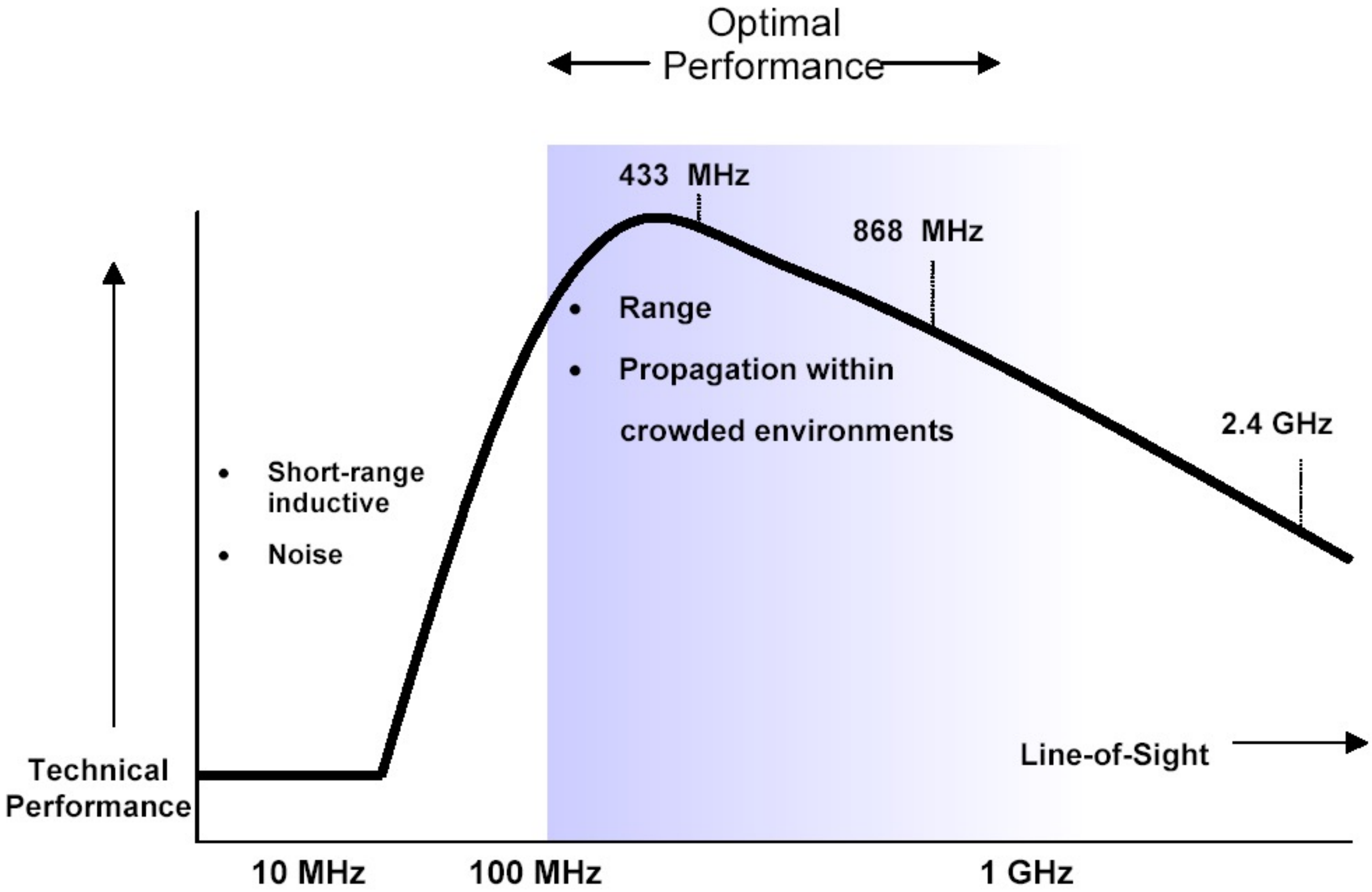
RFID UHF - Qualitative performance overview

High reading range 

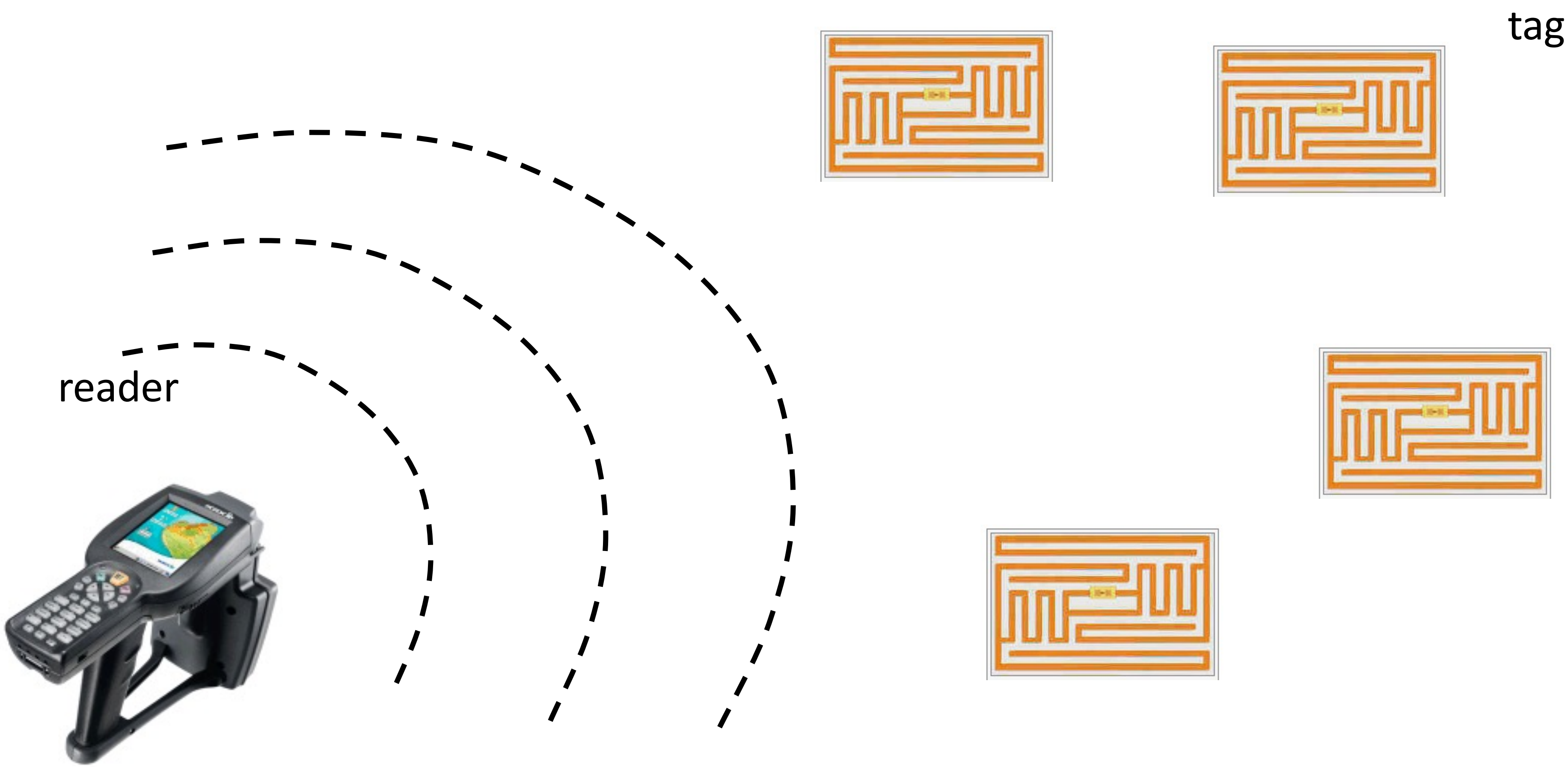
High bit rate 

High impact of the environment 

Which Band to Choose?

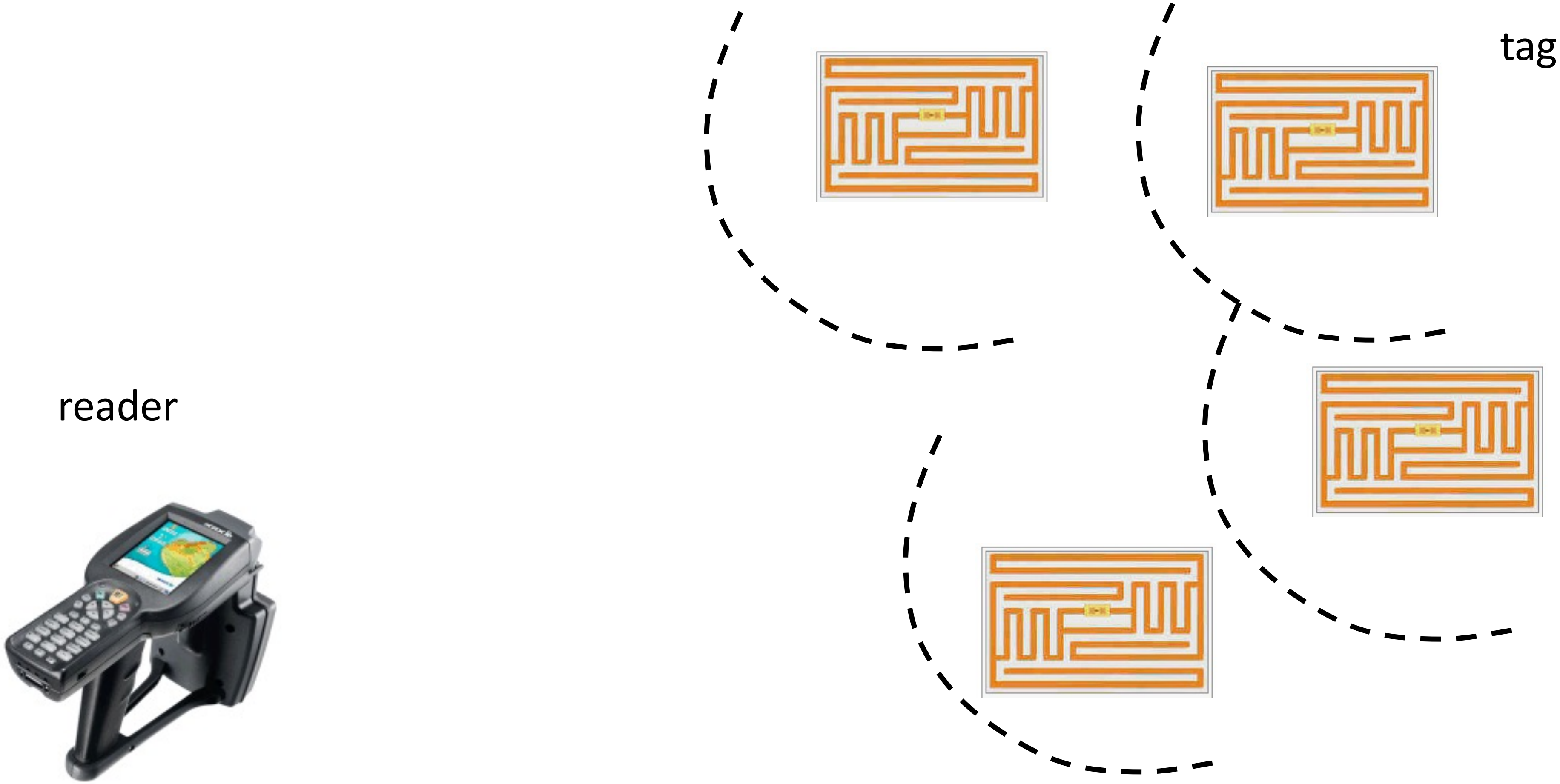


General Problem: Tag Identification/arbitration/singulation



Interrogation

Conflicts in the Responses



Multiple Answers: Arbitration Required

Tag Arbitration Peculiarities

Similar to classical Access Control but:

- Fixed unknown population size
- Tags cannot implement complex protocols (E.g., carrier sense is out)
- Often reader-driven algorithms

Collision Arbitration Mechanisms: A Classification

Vertical Classification

ALOHA-like access mechanism
- Slotted ALOHA
- Dynamic Frame ALOHA

Tree-based access mechanisms
- Binary Tree

Horizontal Classification
- Centralized/Distributed
- Type of Channel Feedback (S,C,0)

Tag Arbitration Efficiency

The efficiency is commonly defined as the tag population size, *N*, over the length of the arbitration period *L(N)*

$$\text{Efficiency} \quad \eta = \frac{N}{L_N}$$

Slotted ALOHA Protocol
(Abramson, 1969)

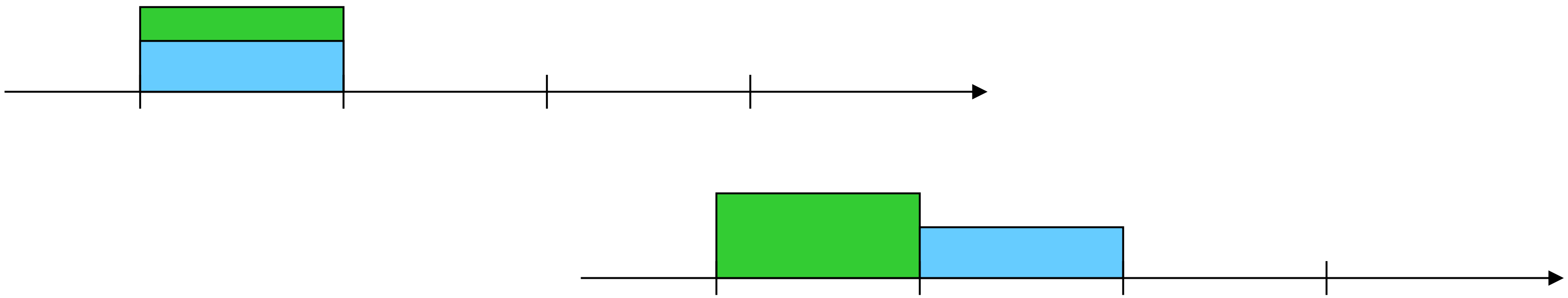
No channel feedback required, only the ACK

Time is slotted

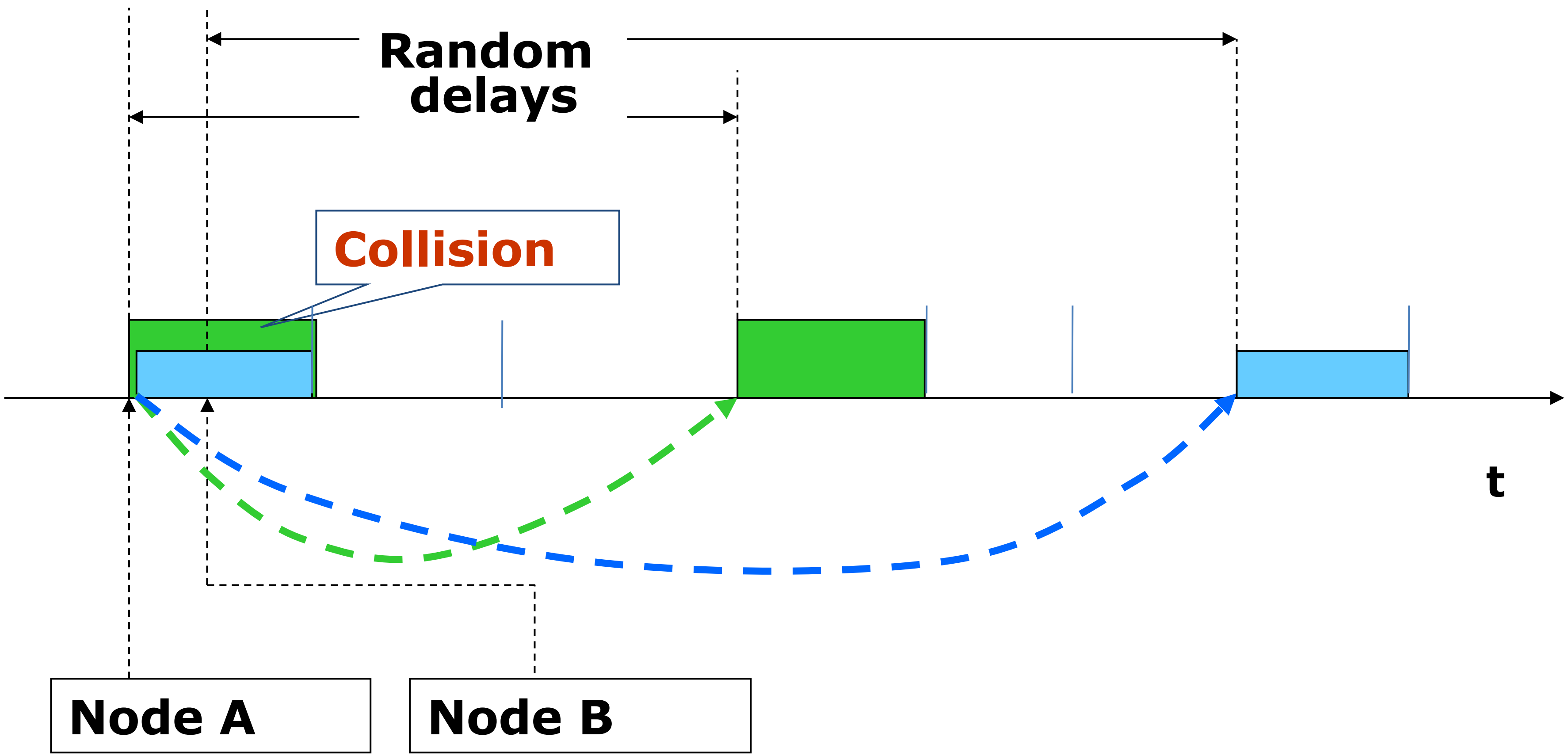
Protocol:

The first packet in the transmission queue is transmitted in the first available slot

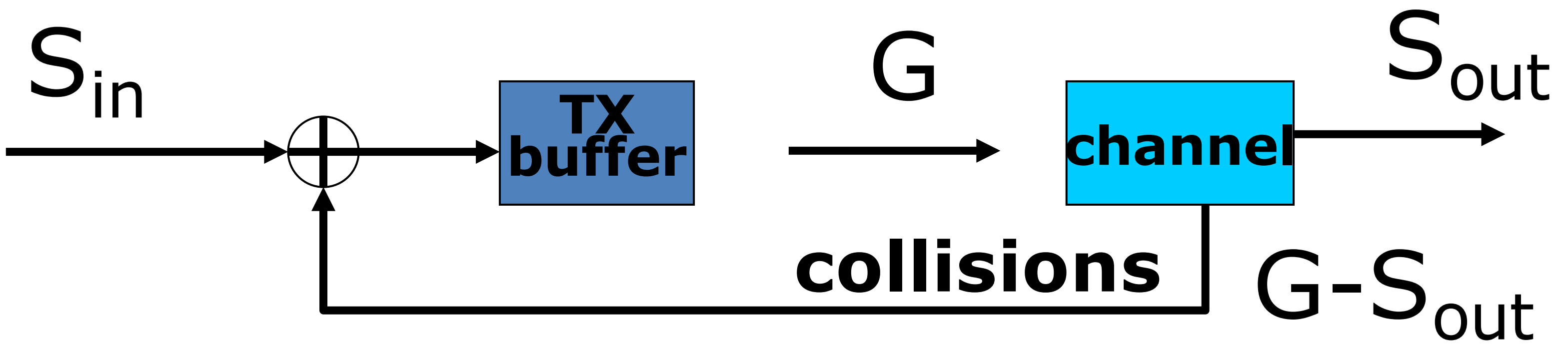
If the ACK does not come, the transmission is re-attempted after a random number of slots X



Slotted ALOHA: retransmissions

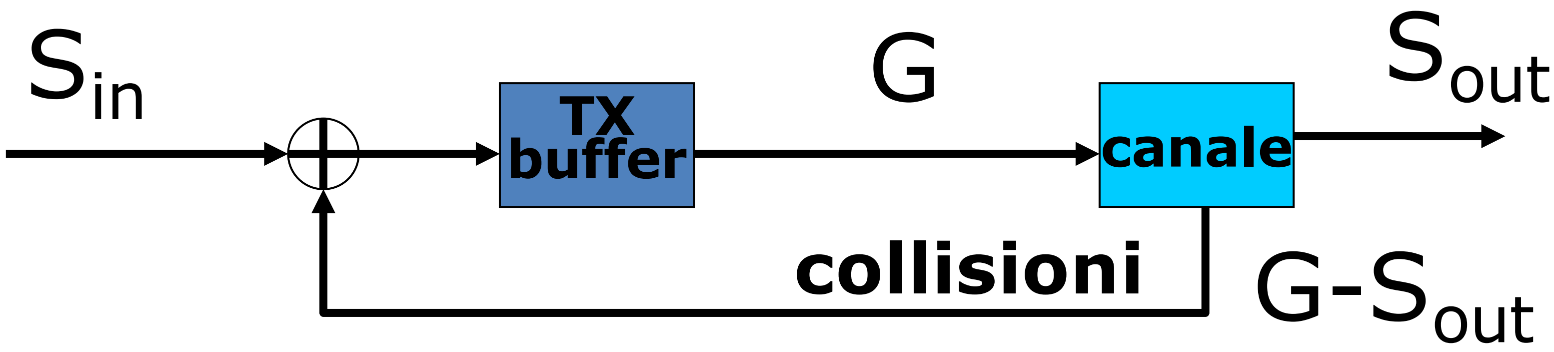


Slotted ALOHA performances



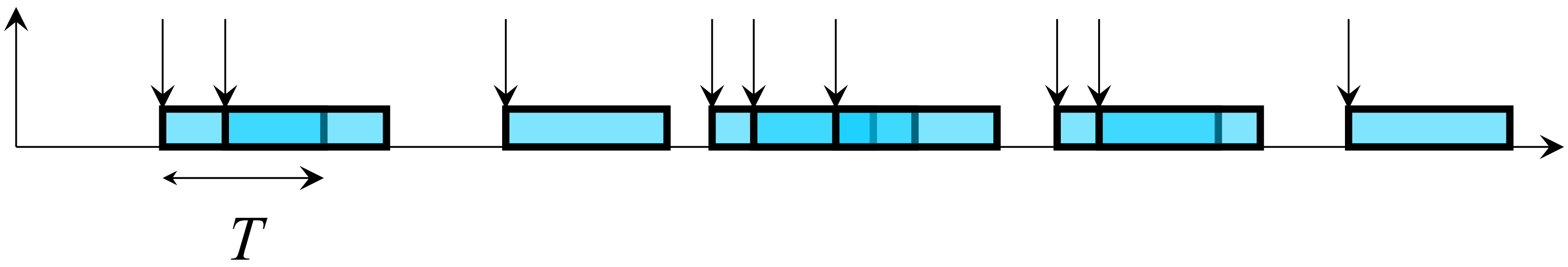
S_{in} incoming traffic
S_{out} outgoing traffic
G traffic on the channel: transmissions + retransmissions
S_{out}<=G

Slotted ALOHA performances



Assumptions:

- Stationarity: $S_{in}=S_{out}$
- Traffic G distributed according to Poisson process
  - Packet arrivals is a poisson point process with parameter λ
  - Transmissions last T
  - $G=T \times \lambda$



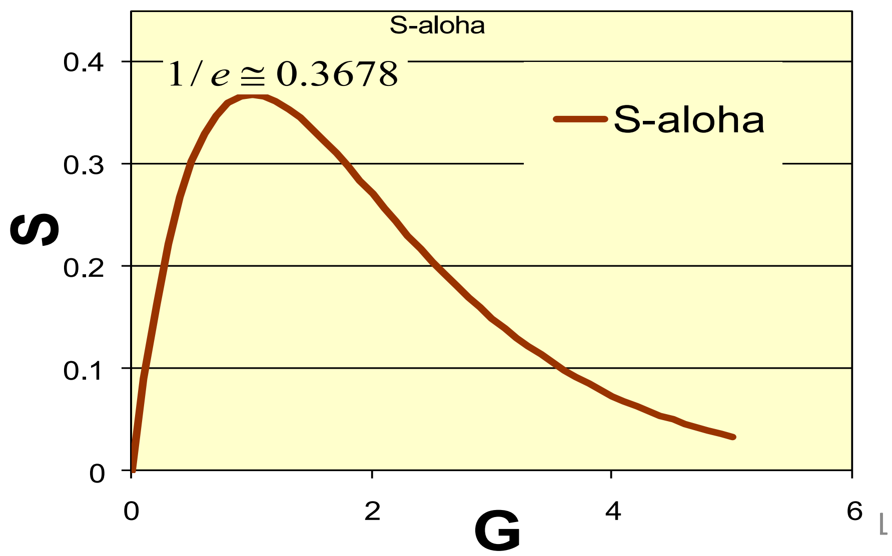
Slotted ALOHA performances

The probability P_s for a packet transmission to be successful is the probability that no other packet arrives in the previous slot.

$$P_s = P[N(t-T,t)=0] = e^{-G}$$

The throughput is:

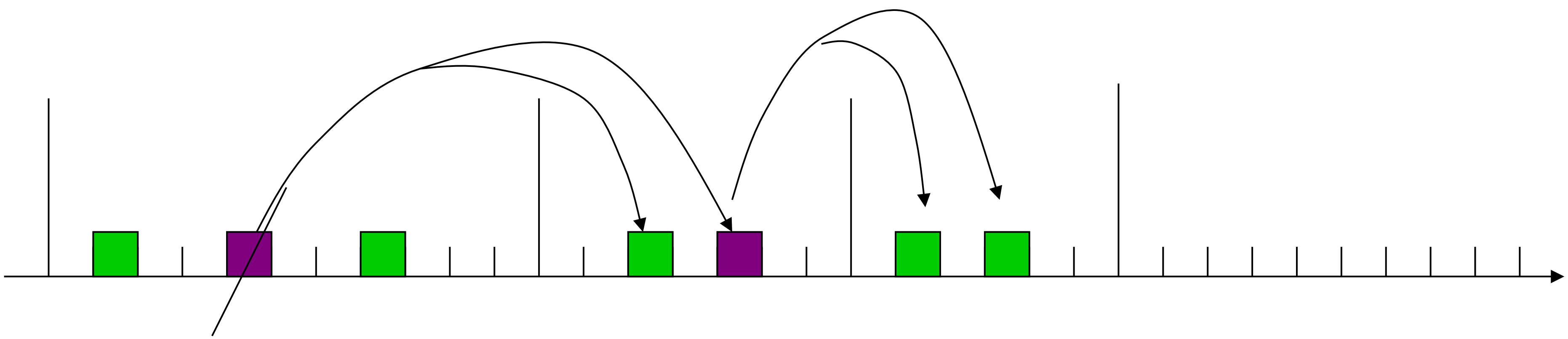
$$S = Ge^{-G}$$



The Frame ALOHA

Extension of the ALOHA protocol where nodes are allowed to transmit once every frame

Frame composed of *r* slots
Every tag chooses a slot in the frame
If transmission is failed, retry at next frame



Frame ALOHA: Single Frame

The average throughput is:

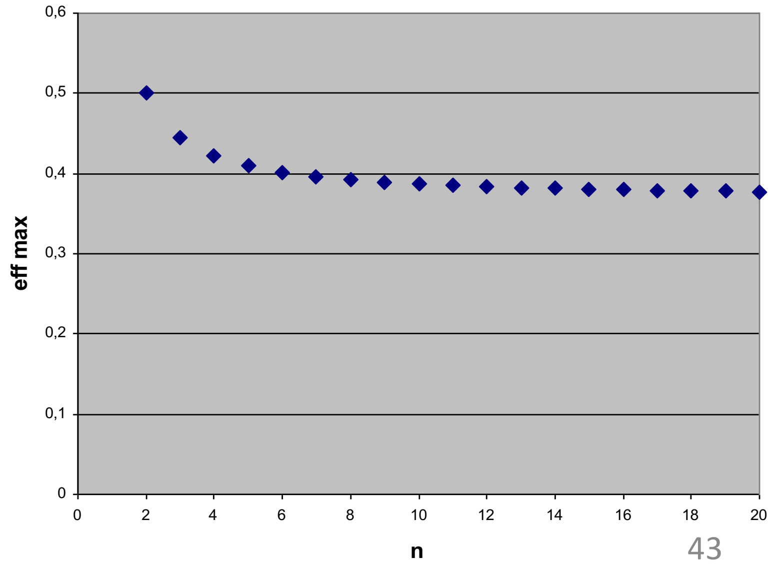
$$E[S] = n\left(1-\frac{1}{r}\right)^{n-1}$$

Thus, the efficiency is:

$$\eta = \frac{E[S]}{r} = n\frac{1}{r}\left(1-\frac{1}{r}\right)^{n-1}$$

Which is maximum for: *r*=*n*

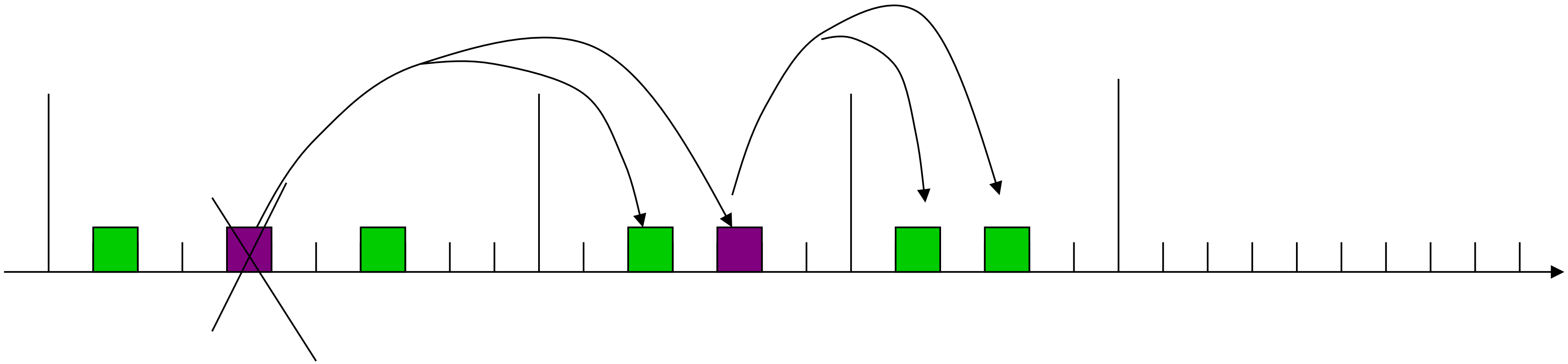
$$\eta_M(n) = \left(1-\frac{1}{n}\right)^{n-1}$$



Frame Aloha: Multiple frames

The FA efficiency depends on the initial tag population (N), the current backlog (n) and the frame size (r).

Current Frame size *r* is dynamically set to the current backlog *n* -> Dynamic Frame Aloha



Frame ALOHA: Multiple Frames

$$\text{Efficiency} \quad \eta = \frac{N}{L_N}$$

The average tag resolution process can be recursively calculated as:

$$L_n = r + \sum_{i=0}^{n-1} P(S=i) L_{n-i}$$

which leads to:

$$L_n = \frac{r + \sum_{i=1}^{n-1} P(S=i) L_{n-i}}{1 - P(S=0)}$$

Example

Find out the efficiency in case N=2, and r=2.

$$L_2 = 2 + \sum_{i=0}^{1} P(S=i) L_{2-i} = 2 + P(S=0) L_2 + P(S=1) L_1$$

$$L_2 = \frac{2 + P(S=1)}{1 - P(S=0)} = 4$$

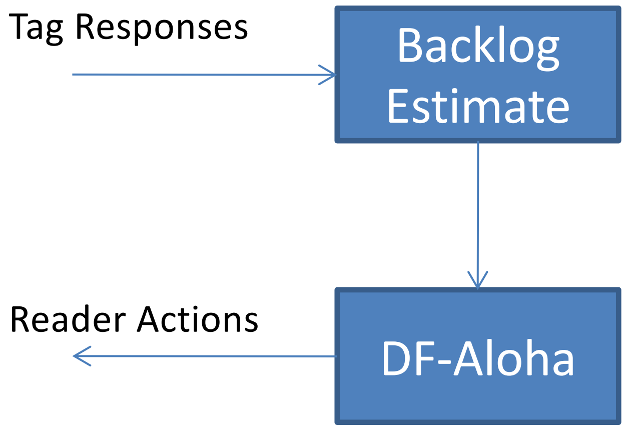
$$\eta = 0.5$$

Problem

Initial population *N* and backlogs *n* are not known

Tag arbitration is actually composed of two modules:

- Backlog Estimation Module: to provide and estimate of the backlog n_{est}
- Collision Resolution: run Frame Aloha with $r = n_{est}$



Schoute’Estimate

Assume that any procedure is able to keep the frame size *r* equal to the current backlog *n*

Under this assumption, the number of terminals transmitting in a slot is approximated by a Poisson process with intensity 1 *[terminal/slot]*

The average number of terminals in a collided slot can be consequently calculated as:

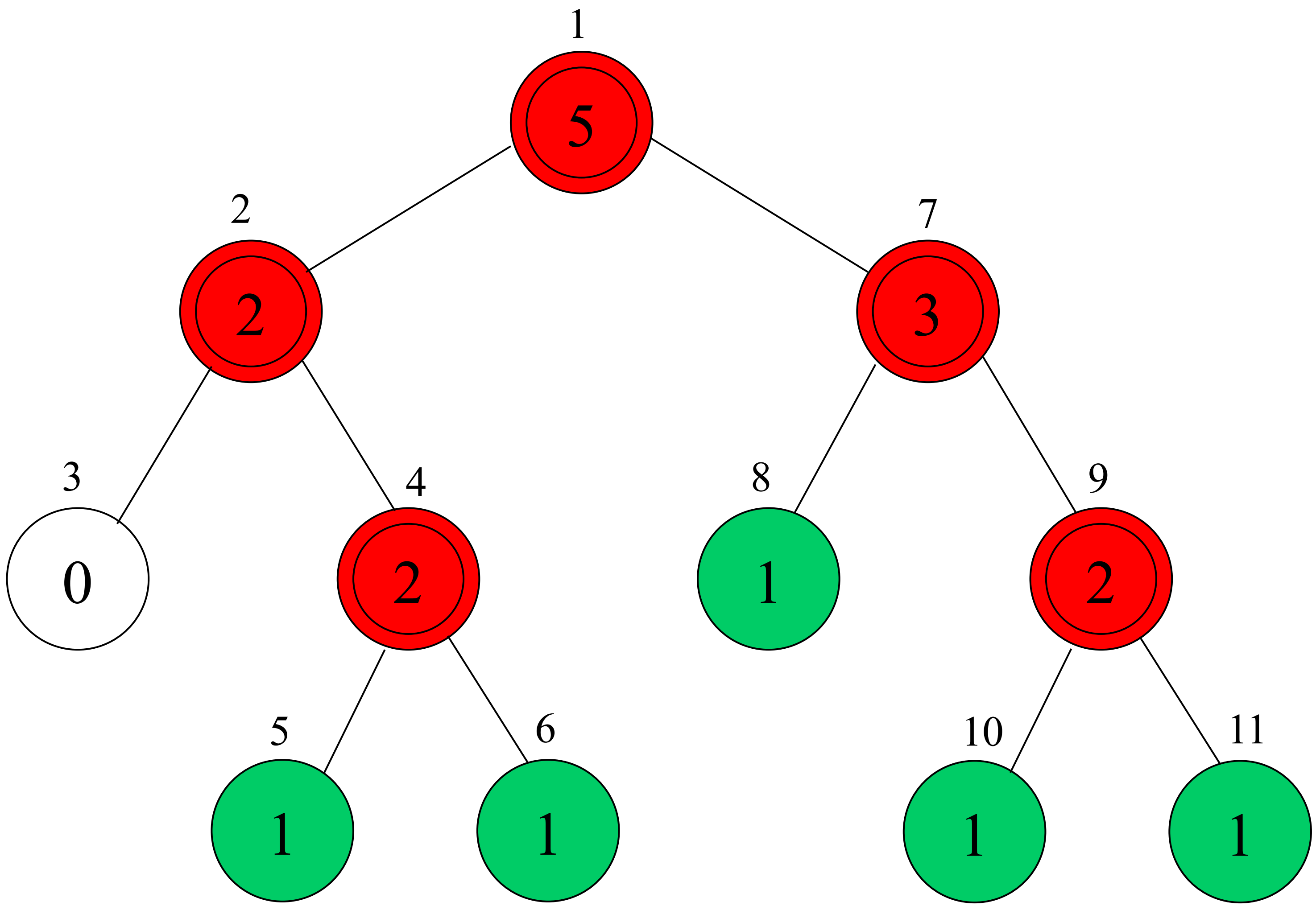
$$H=(1-e^{-1})/(1-2e^{-1})=2.39$$

The backlog is estimated as:

$n_{est}=round(Hc)$, being c the number of collided slots.

The Binary-Tree

Random Numbers are used to partition the set of colliding tags



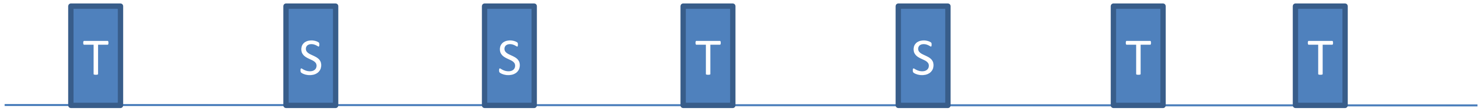
The Binary Tree Implementation

Tags have counters set to 1
The reader broadcasts

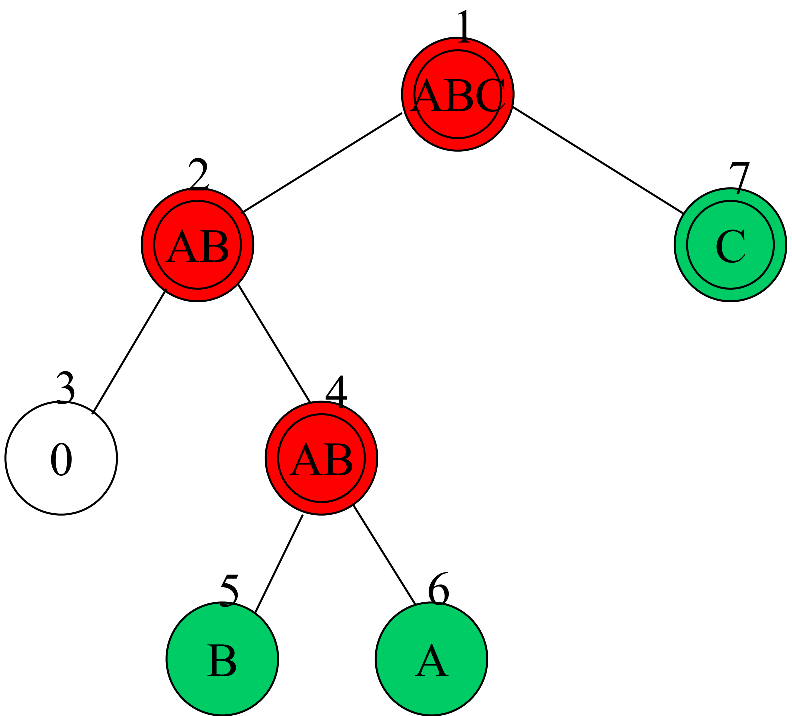
Trigger command: sent at the beginning and after successful/empty slots
tags decrease their counter and transmit if counter is 0

Split commands: sent after collided slots
tags with counter equal to 0 randomly choose a new counter value in [0,1]
Tags with counter greater than 0 increase their counter

The Binary Tree

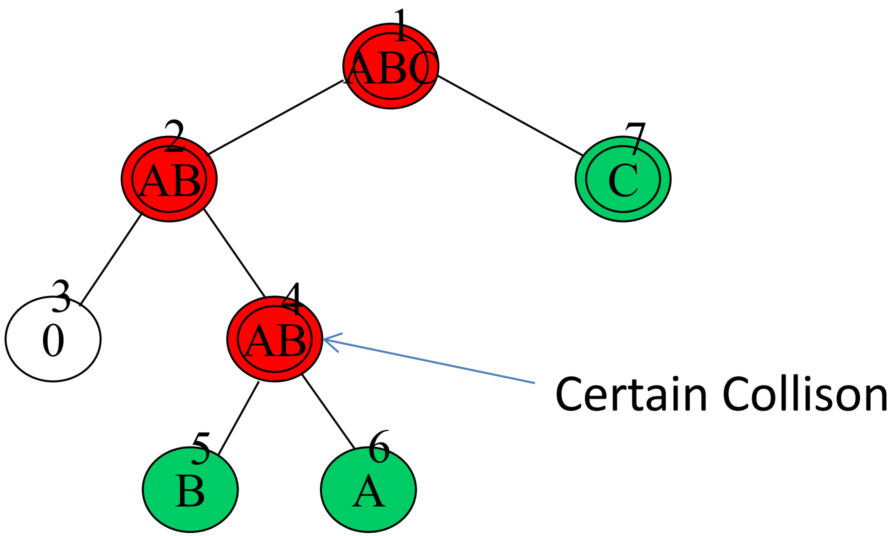


A: 1	1->0	0->0	0->1	1->0	0->1	1->0	Res
B: 1	1->0	0->0	0->1	1->0	0->0	Res	Res
C: 1	1->0	0->1	1->2	2->1	1->2	2->1	1->0 Res



Binary Tree: Optimizations

More refined feedbacks can be used to steer the splitting
Leverage tag population estimates to steer splitting
In some slots collisions are certain, use *Split* command other than *Trigger* one



EPC Global Standard

Tags have a 96 bit ID and a short 16 bit RN

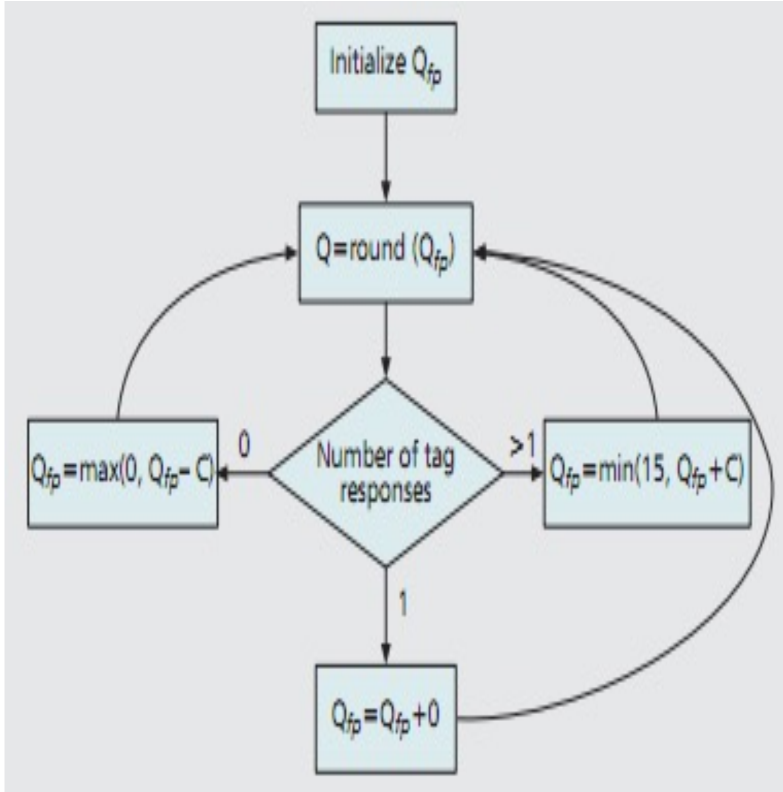
Arbitration procedure:

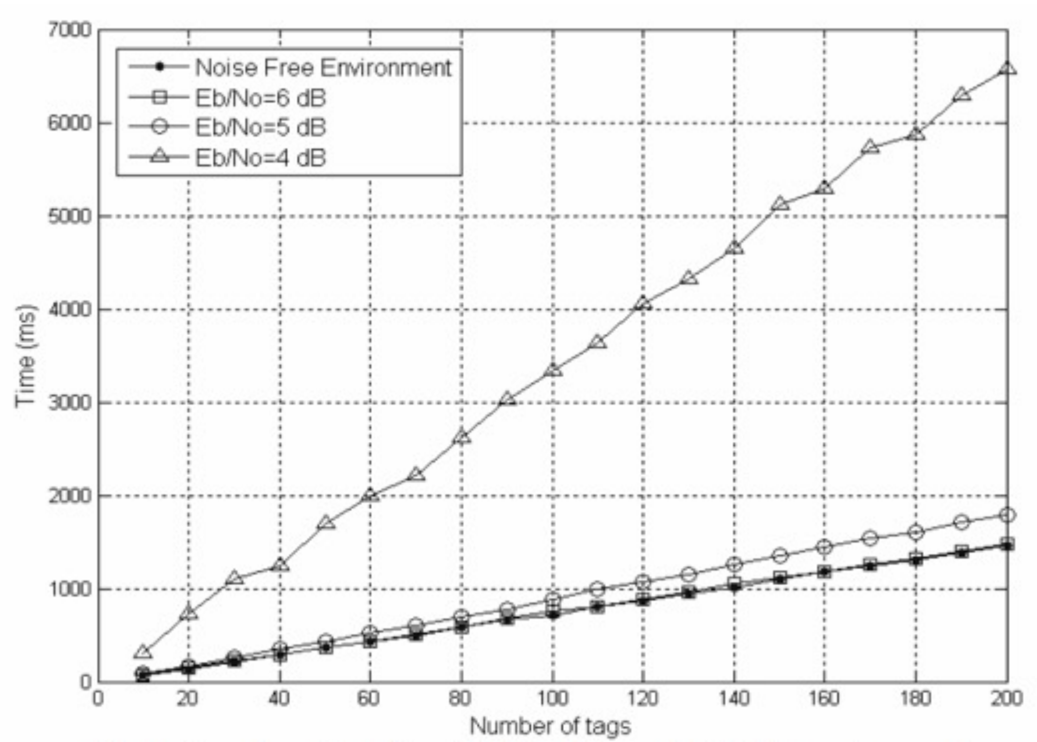
- The Reader broadcasts a *QueryAdjust* notifying parameter Q
- Upon reception of *QueryAdjust*, tags draw a random number in $[0, 2^{Q-1}]$. Those drawing "0" respond with their short address (16 bit)
- If multiple tags reply, or no tags reply, the reader issues a *QueryRep* command which decreases the counter of unsilenced tags and silences for the frame the collided ones
- If one tag replies, the tag is resolved by a direct query to the short address (different commands are defined) and the tag is silenced
- The *QueryAdjust* command can be used before the end of the current frame (frame interruption)

The Q Algorithm

The reader can cancel the running frame at any time slot.
The decision is taken running a slot-by-slot dynamic algorithm to update parameter Q.

Typical used values: initial Q_{fp}=4, C=0.5





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