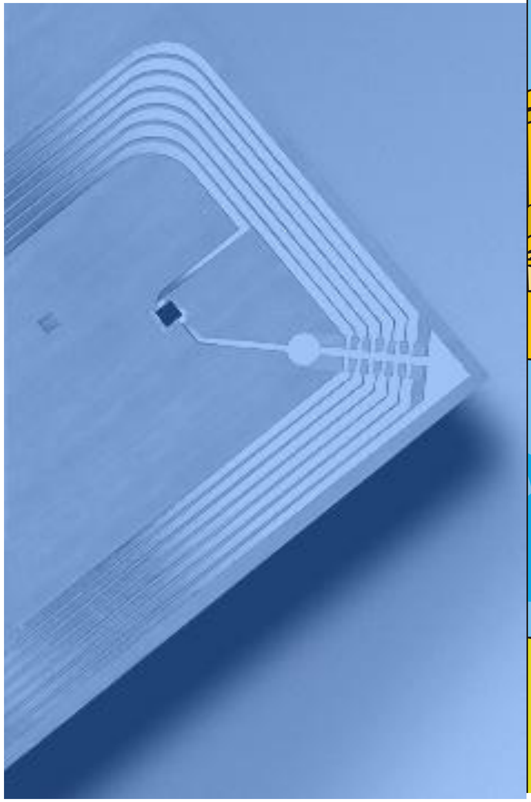
RFID and IOT: An overview



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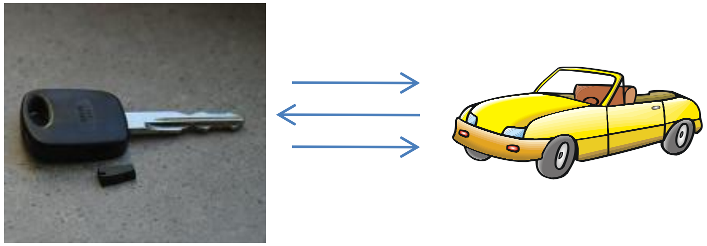
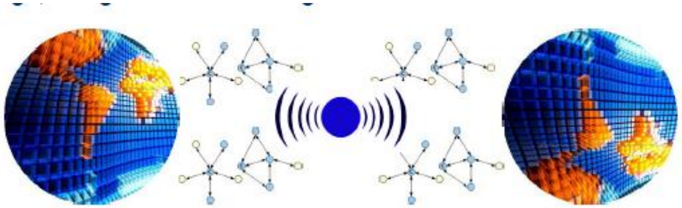
Simula Research Laboratory
University of Oslo

Sep. 2010

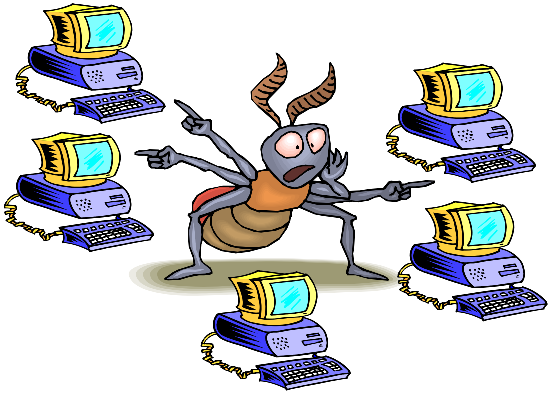
This talk presents an overview of RFID, its applications, IOT, RFID anti-collision protocols and the security issues



RFID Overview, Applications and Anti-collision Protocols



Internet of Things



Security Issues

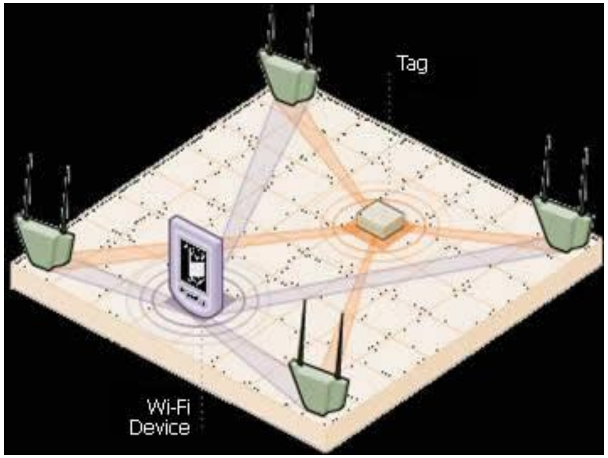
RFID technologies have revolutionized the asset tracking industry

RFID (Radio Frequency Identification) devices are wireless microchips used for tagging objects for automated identification

RFID can identify objects wirelessly without line-of-sight

RFID systems consist of a reading device called a reader, and one or more tags

The reader is a powerful device with ample memory and computational resources



Tags vary significantly in their computational capabilities

Passive tags have limited computational capacity, no ability to sense the channel, detect collisions, and communicate with each other

They respond only at reader commands

Semi-passive tags have an on-board power source that can be used to energize their microchip

Active tags can sense the channel and detect collisions

Passive tags

Semi-passive tags

Active tags

RFID devices may take different forms

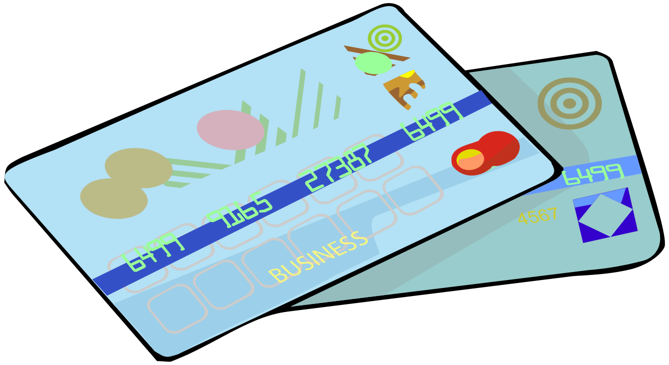
***RFID systems operate in the Industry, Scientific and Medical (ISM) frequency band that ranges from 100 KHz to 5.8 GHz**

The application of RFID spans several areas

RFID technologies have revolutionized the asset tracking industry, with applications ranging from automated checkout to monitoring the medication intakes of elderlies

RFID is being used in proximity and credit cards

RFID is used in Proximity Cards

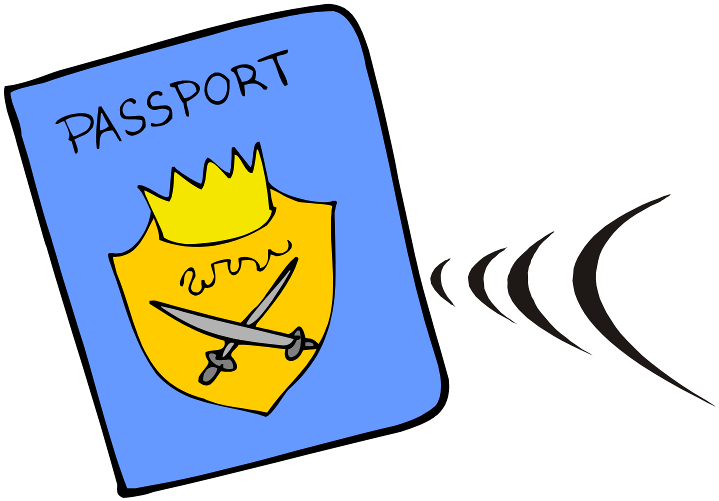


RFID is now offered in all major credit cards in US

RFID has been extensively used for *automobile Ignition Keys*

The applications of RFID has a much wider scope

Many countries are issuing RFID enabled passports



Also in use are the PASS cards and enhanced drivers' licenses with EPC (Electronic Product Code)

RFID can also be used for tracking Cattle

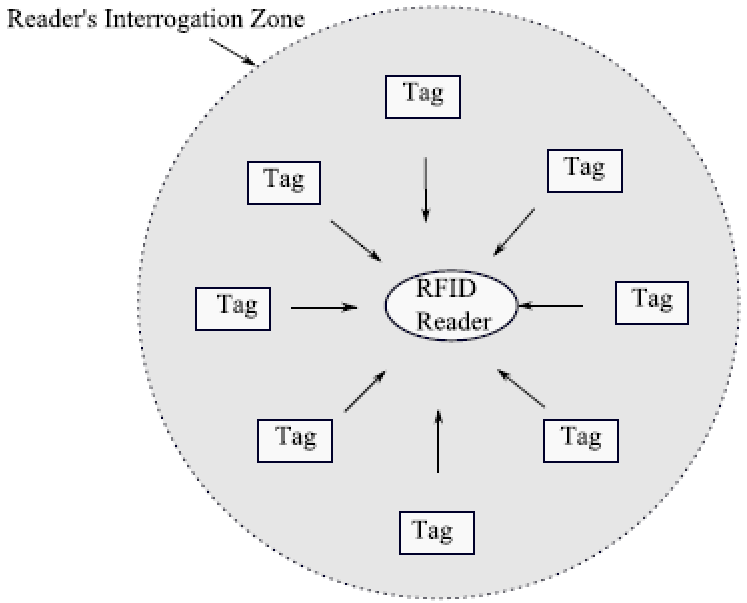
RFID Anti-Collision Protocols

Collision due to simultaneous tag responses is one of the key issues in RFID systems

Tag collision results in wastage of bandwidth, energy, and increases identification delays.

RFID readers must use an anti-collision protocol to

minimize collisions and hence help reduce identification delays



The tag collision problem

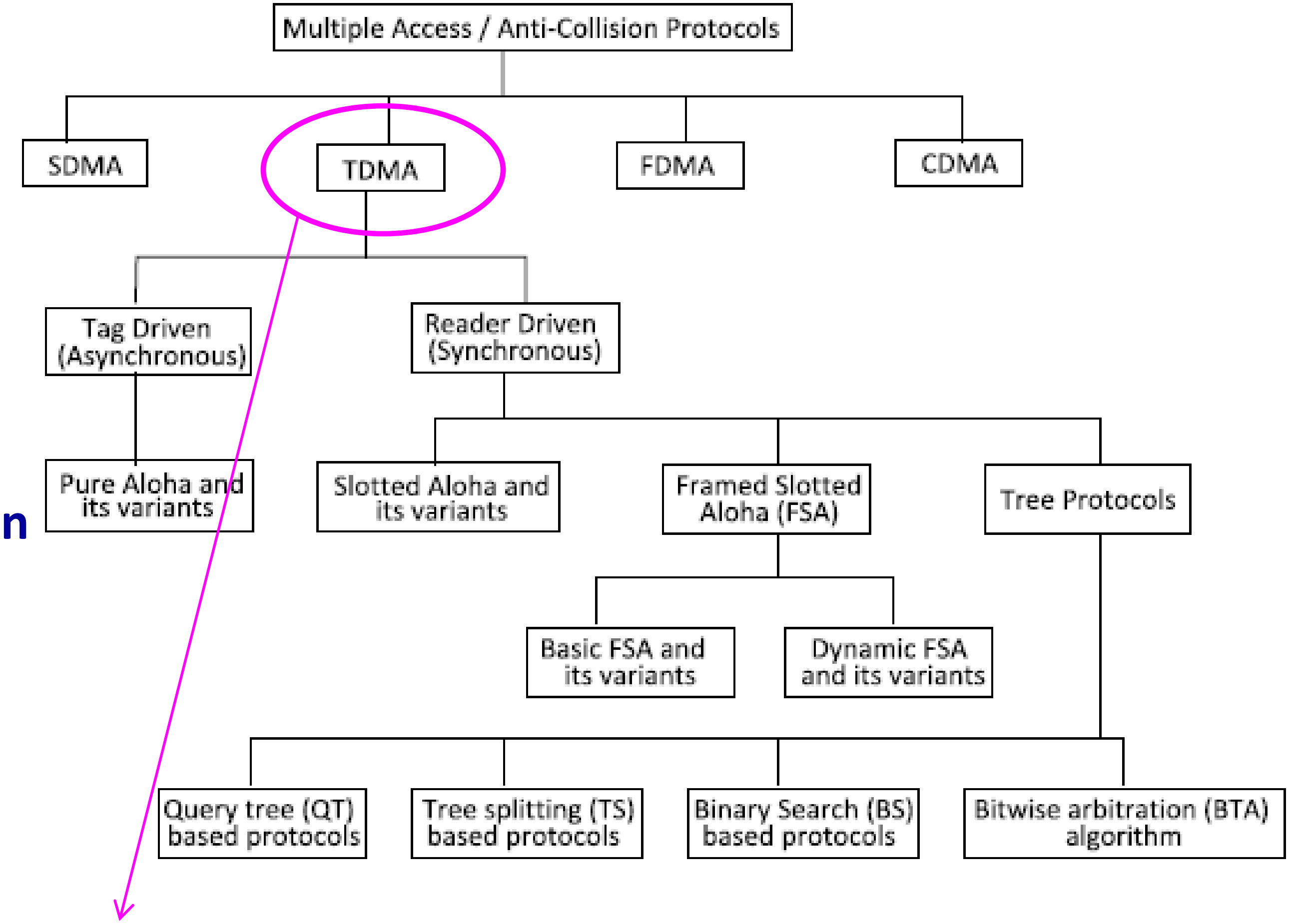
Classification of Existing Anti-collision protocols

SDMA : Space Division Multiple Access

TDMA : Time Division Multiple Access

FDMA : Frequency Division Multiple Access

CDMA : Code Division Multiple Access



Multiple Access / Anti-Collision Protocols

SDMA

TDMA

FDMA

CDMA

Tag Driven (Asynchronous)

Reader Driven (Synchronous)

Pure Aloha and its variants

Slotted Aloha and its variants

Framed Slotted Aloha (FSA)

Tree Protocols

Basic FSA and its variants

Dynamic FSA and its variants

Query tree (QT) based protocols

Tree splitting (TS) based protocols

Binary Search (BS) based protocols

Bitwise arbitration (BTA) algorithm

TDMA protocols constitute the largest group of anti-collision protocols

RFID anti-collision protocols are often categorized as Aloha based protocols and tree based protocols

Aloha based tag reading protocols

- Pure Aloha (PA)

  PA with Muting, PA with Slow Down, PA with Fast Mode, Pure Aloha with Fast Mode and Muting, *PA with Fast Mode and Slow Down*

- Slotted Aloha (SA)

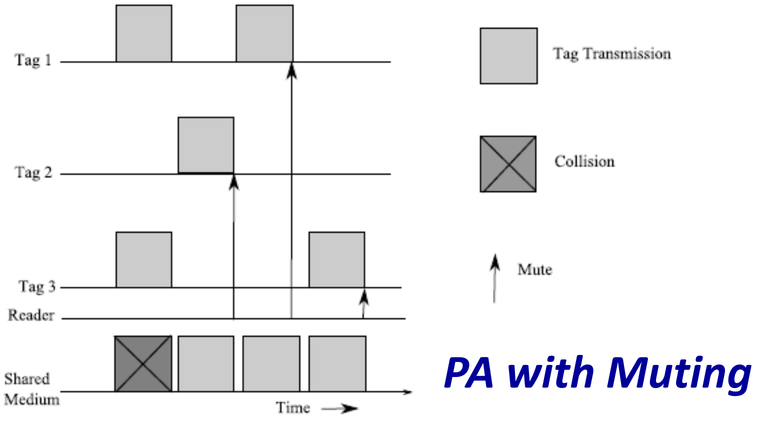
  SA with Muting/Slow Down
  SA with Early End and Muting
  SA with Slow Down and Early End

- Framed Slotted Aloha (FSA)

  Basic framed slotted Aloha (BFSA)
  Dynamic framed slotted Aloha (DFSA)
  Enhanced Dynamic framed slotted Aloha (EDFSA)

In pure Aloha based RFID systems, a tag responds with its ID randomly after being energized by a reader

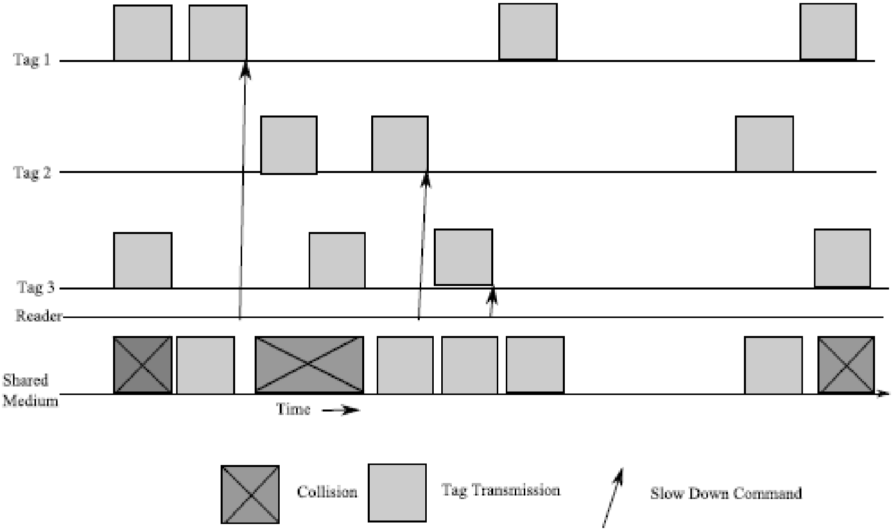
Pure Aloha Variants



PA with Muting

PA with Muting
The number of tags in a reader's interrogation zone is muted after each successful tag response

PA with Slow Down
A tag is **instructed to slow down to reduce its rate of transmissions after each successful tag response**

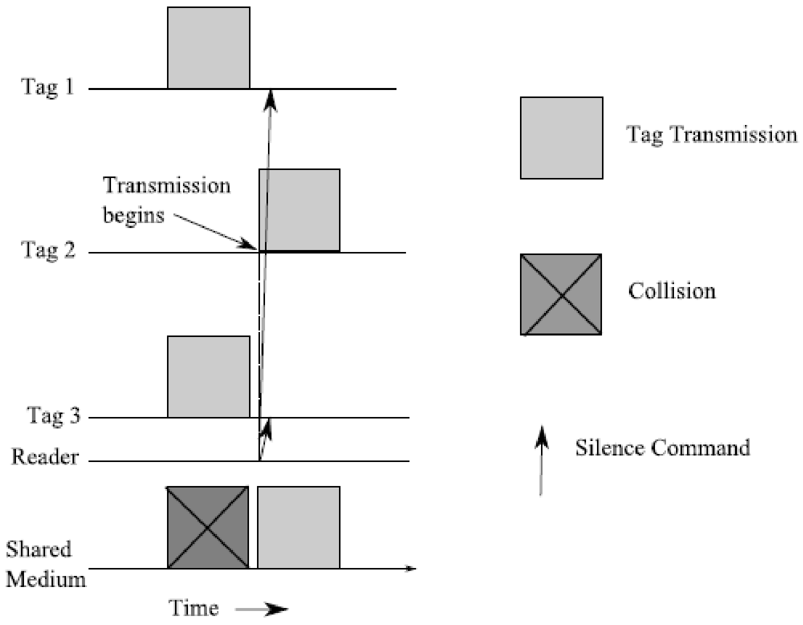


PA with Slow down

Pure Aloha Variants

PA with Fast Mode

A "silence" command is sent by the **reader once it has detected the start of a tag transmission**



Pure Aloha with Fast Mode and Muting

…..

***PA with Fast Mode and Slow Down* …..**

PA with Fast Mode

In Slotted Aloha (SA) based RFID systems, tags transmit their ID in synchronous time slots

The collision occurs at slots boundary only, hence there are no partial collisions

Variants of Slotted Aloha

- ***SA with Muting/Slow Down***
- ***SA with Early End and Muting***
- ***SA with Slow Down and Early End***

Slotted Aloha variants

SA with Muting/Slow Down

The principle operation is **similar to PA with muting/slow down, but operates in a slotted manner**

SA with Early End

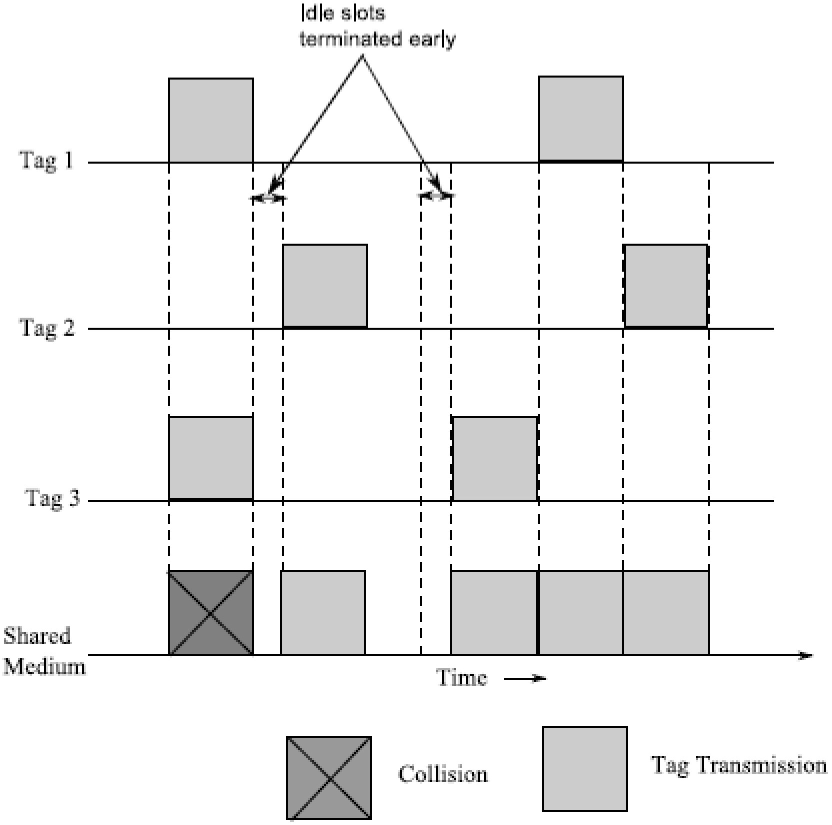
***If no transmission is detected at the* beginning of a slot, the reader closes the slot early**

SA with Early End and Muting

This combines early end with the muting feature

SA with Slow Down and Early End

***This combines slow* down with the early end feature**



SA with Early End

Frame Slotted Aloha protocols mandate that each tag responds only once per frame

In PA and SA based systems, a tag with a high response rate will frequently collide with potentially valid responses from other tags

Basic Frame Slotted Aloha (BFSA)
The frame size is fixed throughout the reading process

BFSA has four variants

BFSA-non muting
A tag is required to transmit its ID in each read round

BFSA-muting
Tags are silenced after identification

BFSA-non-muting-early-end and **BFSA-muting-early end**
The reader closes a slot early if no response is detected at the beginning of a slot

Dynamic Frame Slotted Aloha protocols vary the frame sizes to adapt to the number of tags

DFSA operates in multiple rounds, and it can also incorporate the early-end feature

In each read round, the reader uses a tag estimation function to vary its frame size

DFSA variants based on the tag estimation functions

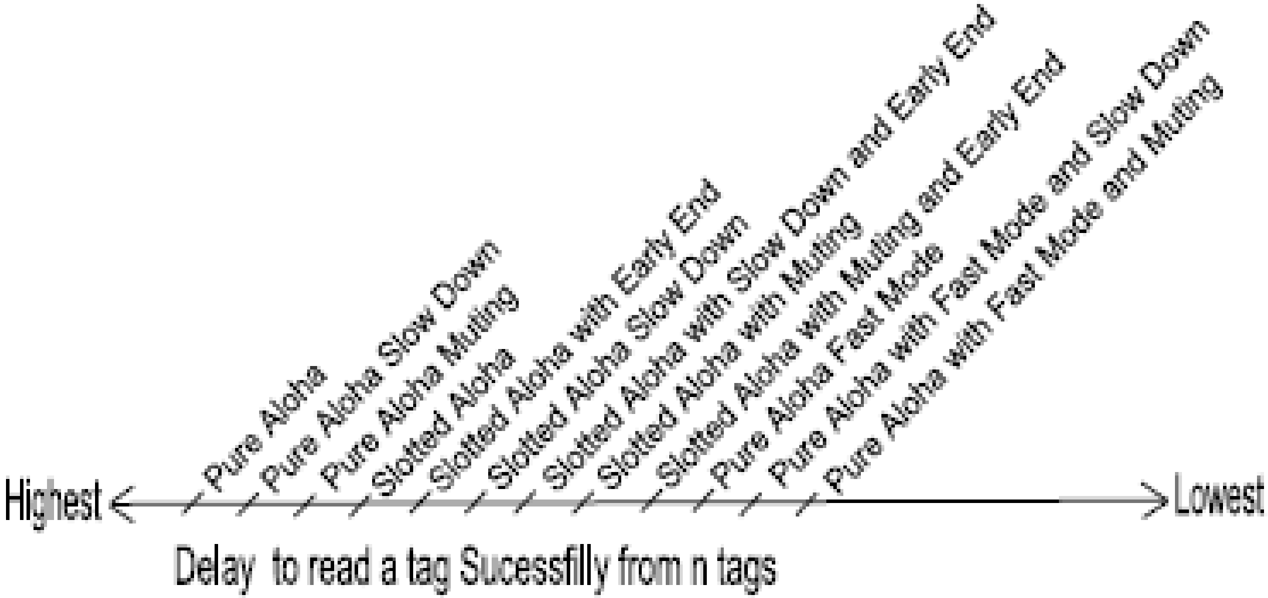
a.Vogt [18][19]
b. Zhen et al. [16]
c.Cha et al. [17]
d. Khandelwal et al. [20]
e. Floerkemeier [21][22]
f. Kodialam et al. [25]
g. Chen et al. [23]
h. Q protocol [24]

EDFSA was proposed to overcome the limitation of the maximum frame size available in DFSA

_A_ limitation of DFSA variants is that the frame size is bounded to a maximum value of 256 or 512

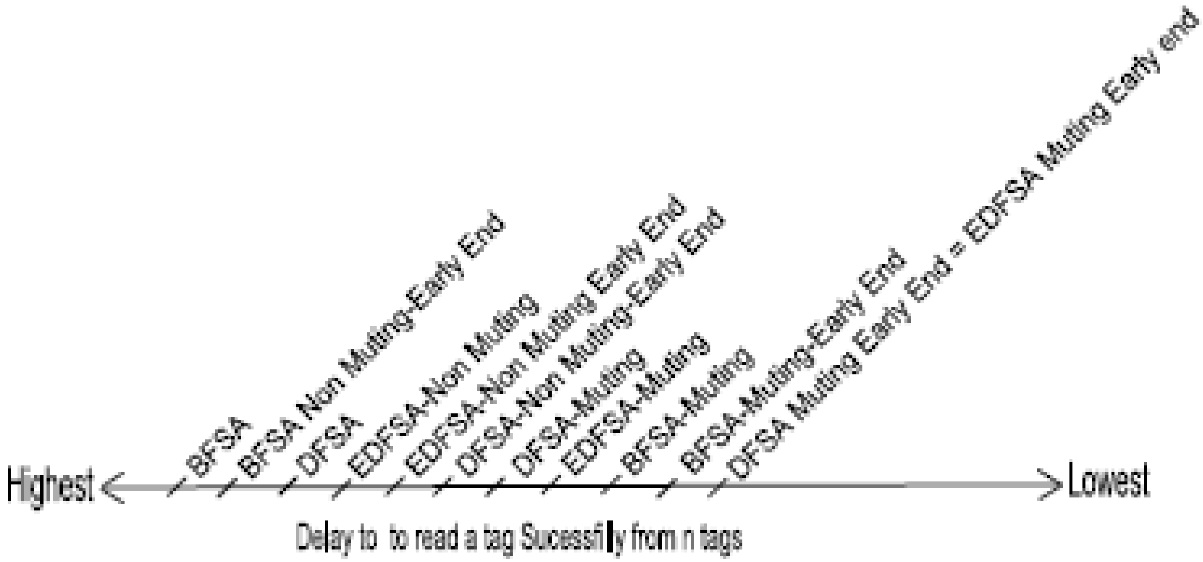
To solve this problem, Lee et. al [26] proposed EDFSA in which tags are divided into _M groups if the tag population is larger than the_ maximum frame size available

The reading delay of pure/slotted Aloha variants shows the following pattern


Highest
Pure Aloha
Pure Aloha Slow Down
Pure Aloha Muting
Slotted Aloha
Slotted Aloha with Early End
Slotted Aloha Slow Down
Slotted Aloha with Slow Down and Early End
Slotted Aloha with Muting
Slotted Aloha with Muting and Early End
Pure Aloha Fast Mode
Pure Aloha with Fast Mode and Slow Down
Pure Aloha with Fast Mode and Muting
Lowest
Delay to read a tag Sucessfilly from n tags

Reading delay of pure/slotted Aloha variants

The reading delay of framed Aloha variants shows the following pattern


Highest
BFSA
BFSA Non Muting-Early End
DFSA
EDFSA-Non Muting
EDFSA-Non Muting Early End
DFSA-Non Muting-Early End
DFSA-Muting
EDFSA-Muting
BFSA-Muting
BFSA-Muting-Early End
DFSA Muting Early End = EDFSA Muting Early end
Lowest
Delay to to read a tag Sucessfilly from n tags

Reading delay of Framed Aloha variants

The most suitable protocol depends largely upon the application

If low cost and complexity is desired, then pure Aloha variants are suitable

DFSA variants are ideal if high speed, accuracy, and efficiency are of concern

Tree based protocols are able to single out and read every tag, provided each tag has a unique ID

All tree based protocols require tags to have muting capability, as tags are silenced after identification

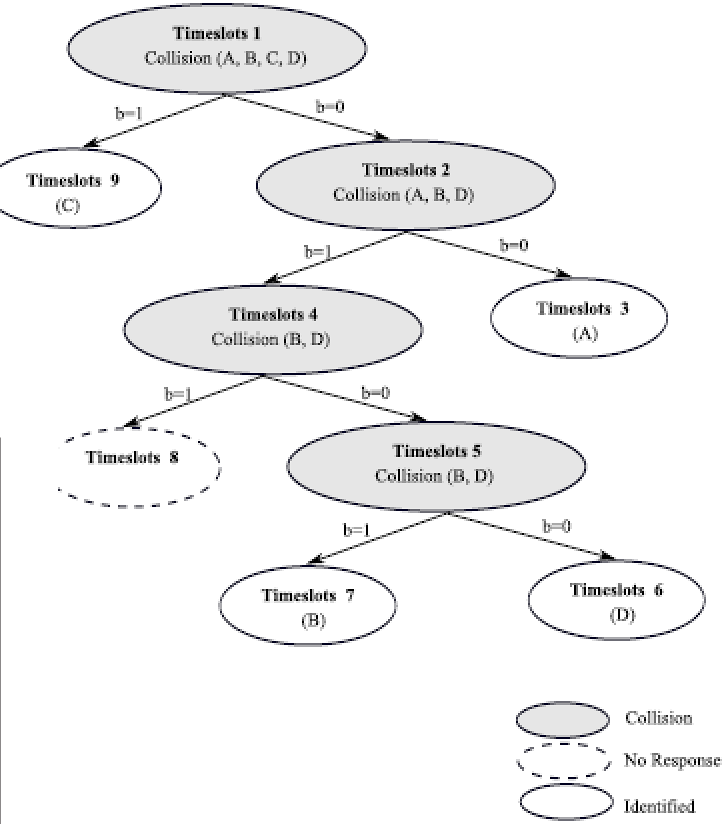
Categories of tree based algorithms

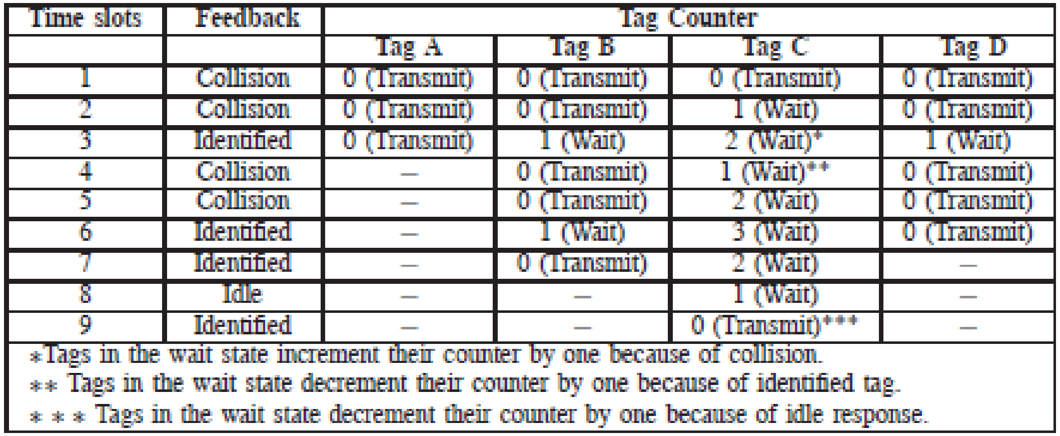
- Tree splitting (TS)
- Query tree (QT)
- Binary search (BS)
- Bitwise arbitration (BTA)

TS protocols operate by splitting responding tags into multiple subsets using a random number generator

Tree Splitting Algorithms

Basic Tree Splitting (BTS)





Time slots	Feedback	Tag Counter			
		Tag A	Tag B	Tag C	Tag D
1	Collision	0 (Transmit)	0 (Transmit)	0 (Transmit)	0 (Transmit)
2	Collision	0 (Transmit)	0 (Transmit)	1 (Wait)	0 (Transmit)
3	Identified	0 (Transmit)	1 (Wait)	2 (Wait)*	1 (Wait)
4	Collision	–	0 (Transmit)	1 (Wait)**	0 (Transmit)
5	Collision	–	0 (Transmit)	2 (Wait)	0 (Transmit)
6	Identified	–	1 (Wait)	3 (Wait)	0 (Transmit)
7	Identified	–	0 (Transmit)	2 (Wait)	–
8	Idle	–	–	1 (Wait)	–
9	Identified	–	–	0 (Transmit)***	–

*Tags in the wait state increment their counter by one because of collision.

** Tags in the wait state decrement their counter by one because of identified tag.

* * * Tags in the wait state decrement their counter by one because of idle response.

Tag's counter in the BTS algorithm

The reader uses nine timeslots to identify all four tags

Tree Splitting Algorithms

Adaptive Binary Tree Splitting

ABTS **achieves fast identification by reducing collisions and idle slots**

Tags have two counters,
Progressed Slot Counter (PSC) and Allocated Slot Counter (ASC)

A tag is allowed to transmit when its ASC and PSC are equal.

Query Tree Algorithms

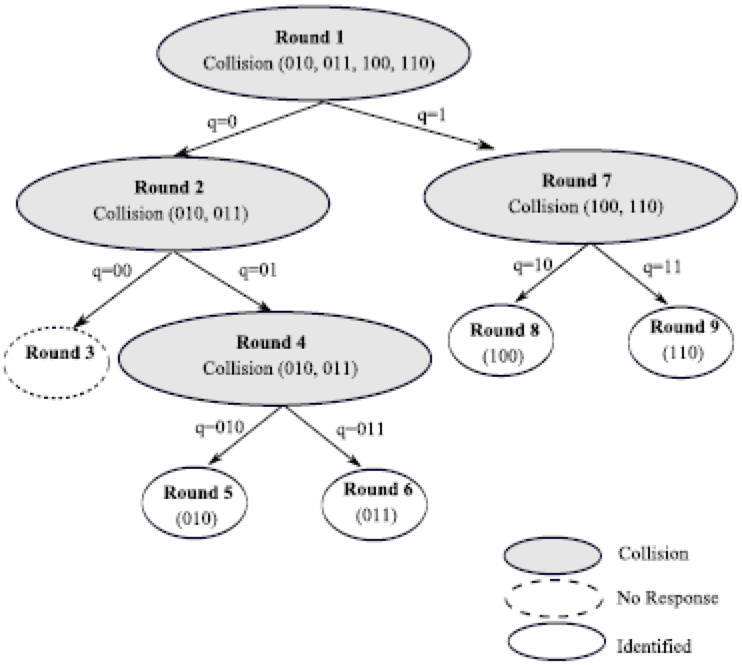
In TS variants, tags require a random number generator and a counter to track their tree position, thus making them costly and computationally complex

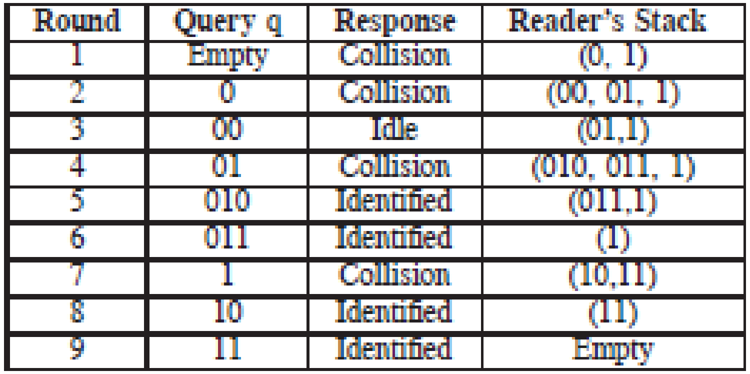
Query tree algorithms overcome these problems by storing tree construction information at the reader, and tags only need to have a prefix matching circuit

Variants of Query Tree Algorithm

- *Query Tree: Law et al. [27]*
- *Adaptive Query Tree (AQT) : Myung et al. [28][29]*
- *Improved QT (*IQT*): Zhou et al. [30]*
- *QT based reservation (QTR): Choi et al. [31]*
- *Randomized Hashing Query Tree (RH-QT): Bonuccelli et* al. [32]
- *Intelligent Query Tree (IQT): [33]*

Example of QT Algorithm





Round	Query q	Response	Reader's Stack
1	Empty	Collision	(0, 1)
2	0	Collision	(00, 01, 1)
3	00	Idle	(01,1)
4	01	Collision	(010, 011, 1)
5	010	Identified	(011,1)
6	011	Identified	(1)
7	1	Collision	(10,11)
8	10	Identified	(11)
9	11	Identified	Empty

Reader's stack for QT Algorithm

Extensions to QT Protocol

Shortcoming

It reduces QT's identification delay by removing redundant queries

Aggressive enhancement

Queries are appended with multiple bits, instead of a single bit

Categorization

***The reader has* prior knowledge of tag IDs, thereby allowing the reader to group tags according to predefined prefixes**

QT-sl (Query-tree short-long) protocol

***The reader* separates tag responses into short and long queries**

…..

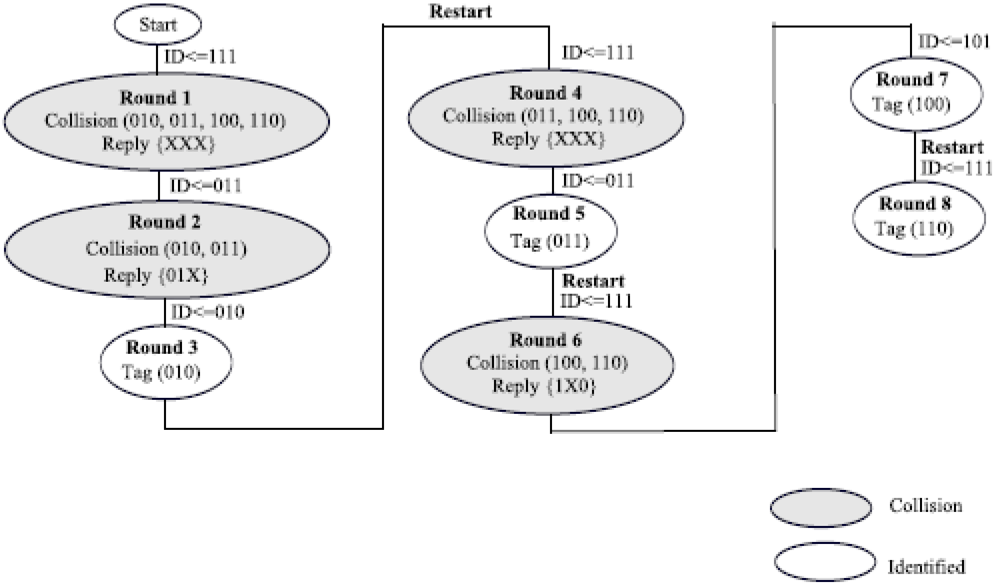
***QT-im (Query-tree incremental-matching) protocol. This* algorithm**

Binary Search algorithm

The reader transmites a serial number to tags to compare with their ID

Those tags with ID equal to or lower than the serial number respond

The reader then monitors tags reply bit by bit and once a collision occurs, the reader splits tags into subsets based on collided bits



The BS algorithm

Variants of BS Algorithm

Enhanced - BS algorithm (EBSA)
EBSA does not restart the reading process after a tag is identified

Dynamic BS algorithm (DBSA)
The reader and tags do not use the entire length of serial number and tags ID during the identification process

Bitwise Arbitration Algorithms

BTA algorithms operate by requesting tags to respond bit by bit from the MSB to the LSB of their ID

Bit replies are synchronized, meaning multiple tags responses of the same bit value result in no collision

A collision is observed only if two tags respond with different bit values

Moreover, the reader has to specify the bit position it wants to read

Variants of BTA

ID-Binary Tree Stack (ID-BTS)
Bit-by-bit (BBT)
Modified bit by bit binary tree (MBBT)
Enhanced bit by bit binary tree (EBBT)
Bit query (BQ)

Comparison of Tree Protocols

Those protocols using BTA require tags to respond bit by bit, hence are the most complex in terms of reader and tag hardware requirements

QT protocols promise the simplest tag design

Hybrid protocols are a new branch of tag reading protocols that combine the advantages of tree and Aloha protocols

Most hybrid protocols combine the QT protocol with an Aloha variant

QT helps a reader to separate tags into smaller groups, thereby reducing contention

Each group can then be read using a tree or an Aloha variant

Hybrid Protocols

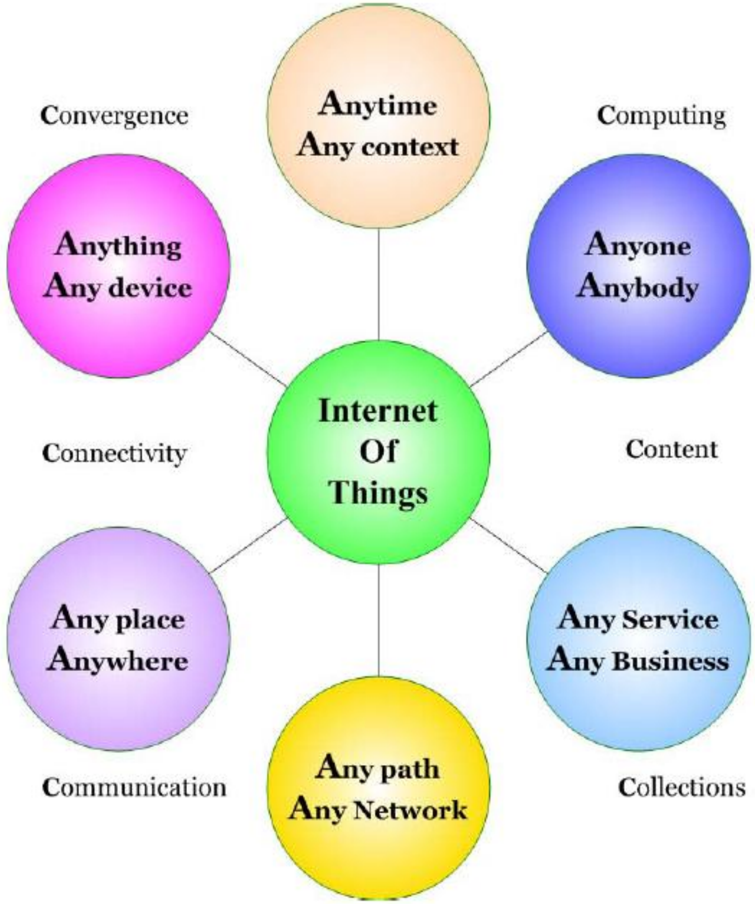
- *Tree Slotted Aloha (TSA)*
- *Hybrid Query Tree (HQT) Protocol*
- *HQT variant*
  - **Framed Query Tree algorithm**
  - **Query Tree ALOHA algorithm**
- *Hybrid Randomized Protocol*
  - **Multi Slotted (MS) scheme**
  - *MS with Selective Sleep (MSS)*
  - *MS with Assigned Slot (MAS)*
- *Hash-Tree Protocol*

……….

The Internet of Things (IoT) allows people and things to be CONNECTED

The IoT allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/network and Any service

This implies context where there is seamless interconnection between people and things and/or between things



Internet of Things

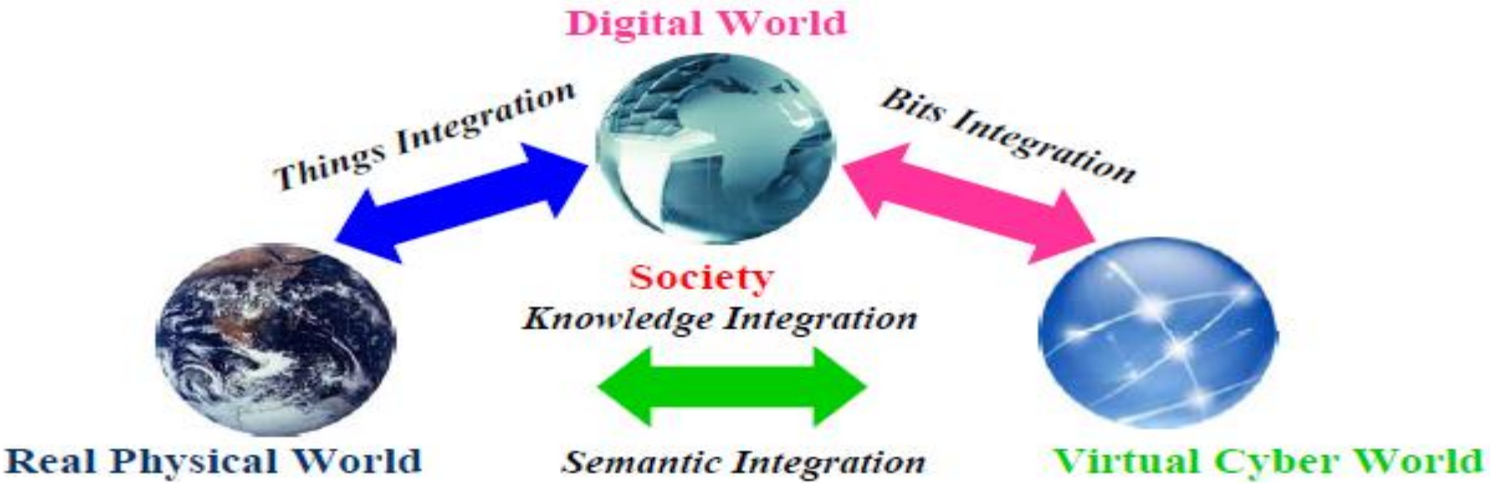
Source: Internet of Things – Strategic Research Roadmap, CERP-IoT, 2010

Internet of Things is an integrated part of Future Internet

IoT is a dynamic global network infrastructure with self configuring capabilities based on standard and interoperable communication protocols

In the IoT, physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces

The physical and virtual "things" are seamlessly integrated into the information network

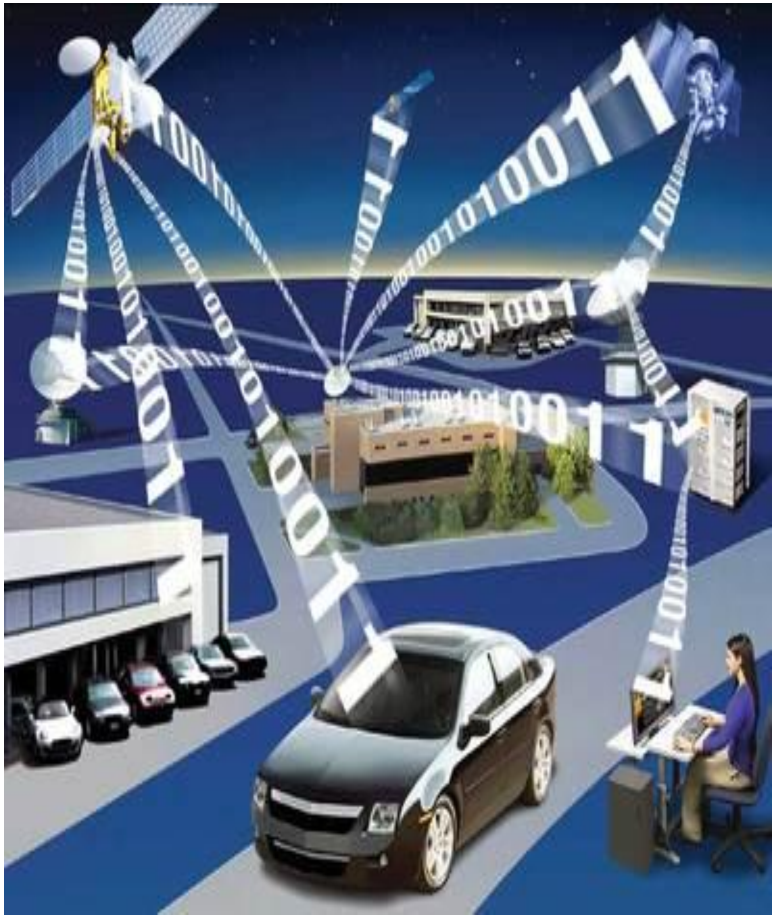


Source: Internet of Things – Strategic Research Roadmap, CERP-IoT, 2010

In the IoT, things are expected to become active participants in business, information and social processes

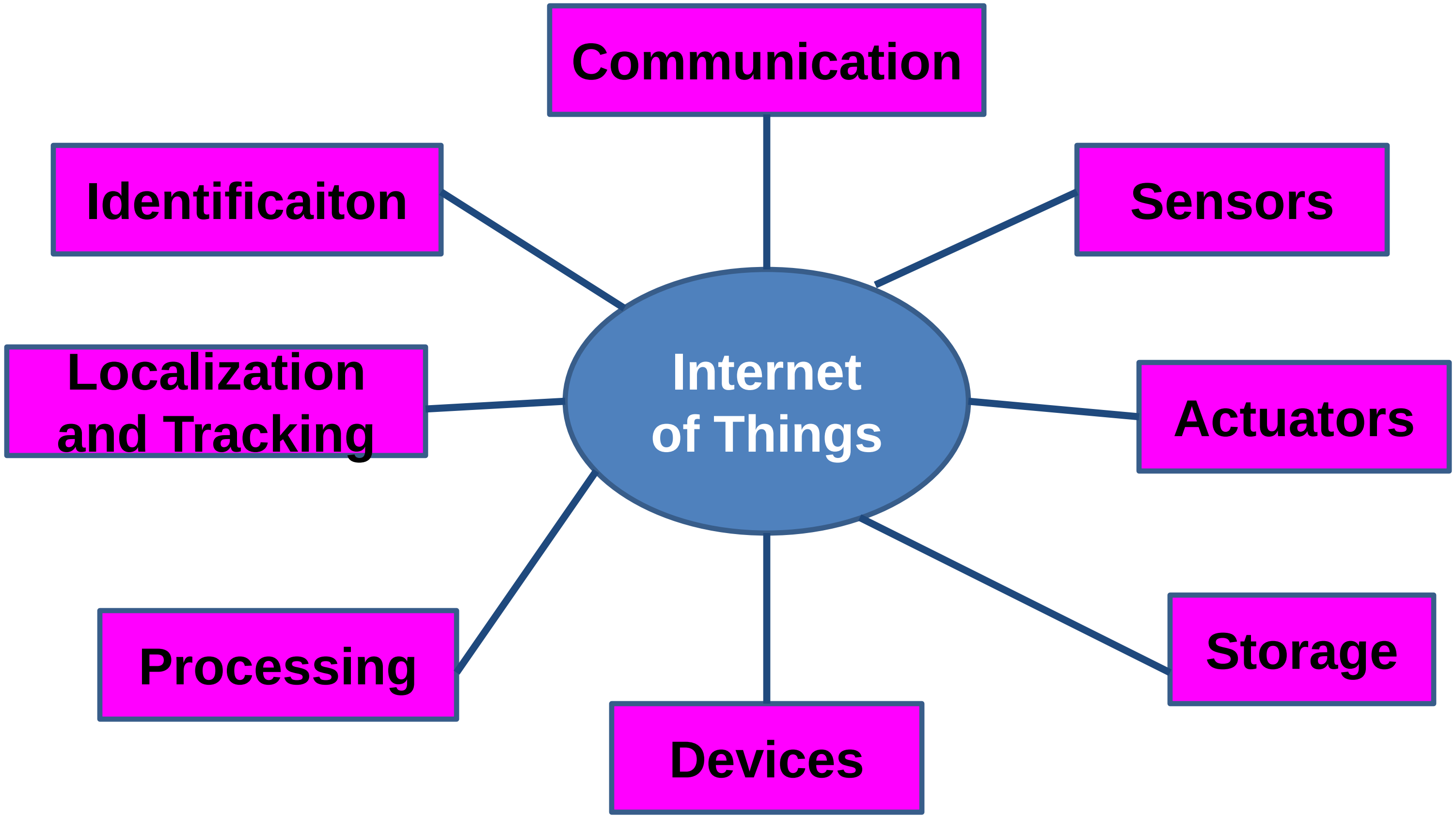
In IoT, things are enabled to interact and communicate among themselves and with the environment by exchanging data and information “sensed” about the environment

Things should react autonomously to the “real/physical world” events with or without direct human intervention



Source: Internet of Things – Strategic Research Roadmap, CERP-IoT, 2010

IoT is consists of the following components

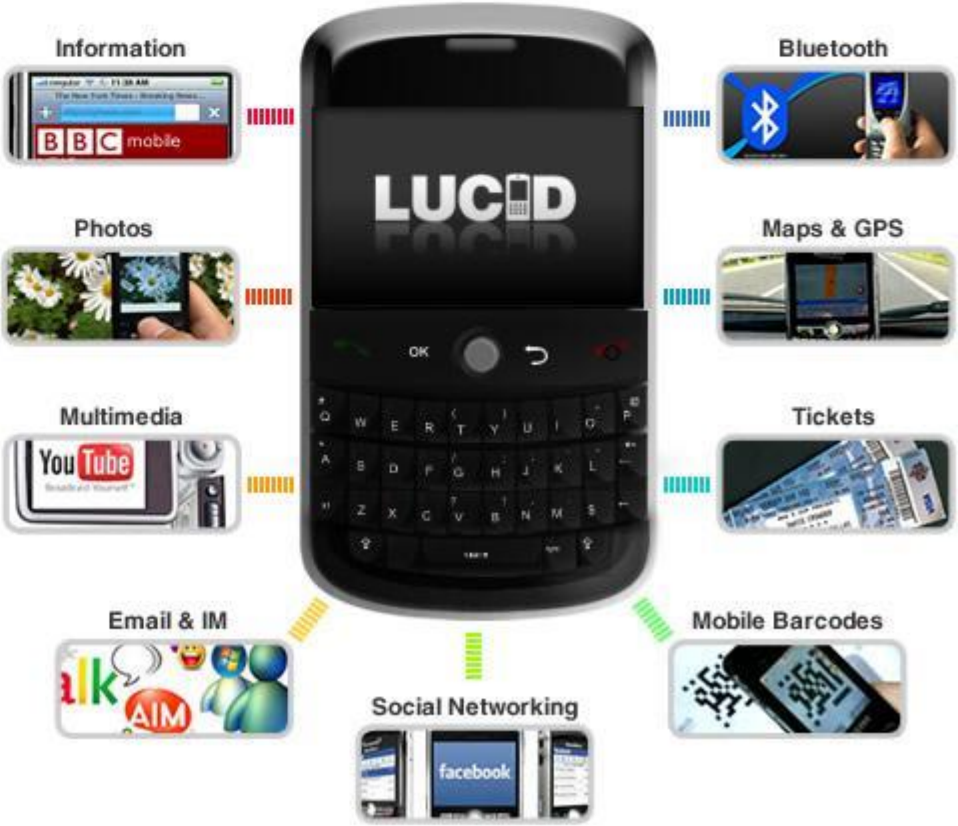


Source: Internet of Things – Strategic Research Roadmap, CERP-IoT, 2010

IoT is envisioned as a network of a billion people interacting with a million e-businesses, with a trillion intelligent devices interconnected

By 2015 there will be 1 trillion sensors linking the physical and digital worlds merging to become an "Internet of Things"

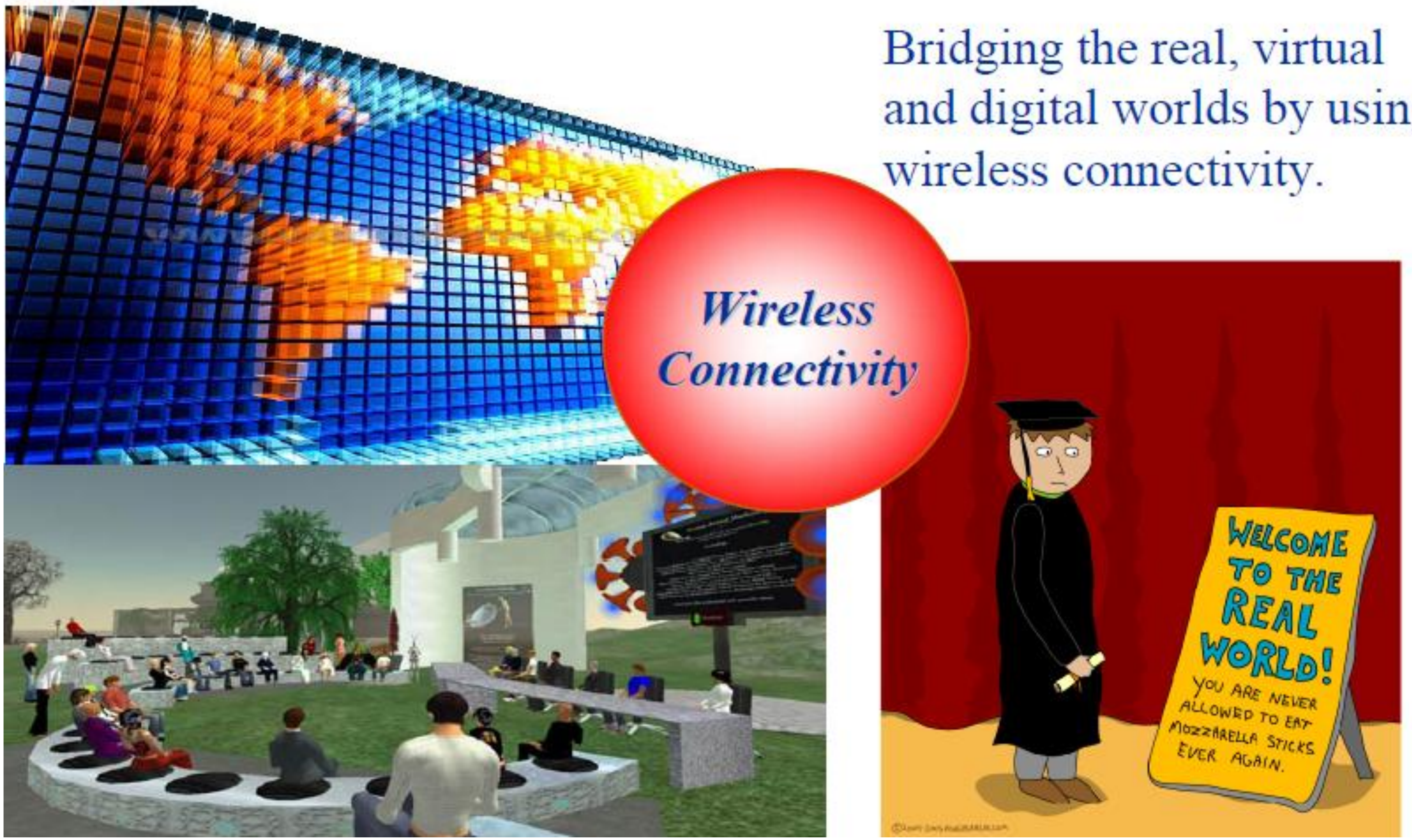
List of applications is limited only by our imagination



Source: Internet of Things – Strategic Research Roadmap, CERP-IoT, 2010

The emerging applications of smart wireless systems is limited only by our imagination

Real Virtual and Digital Worlds

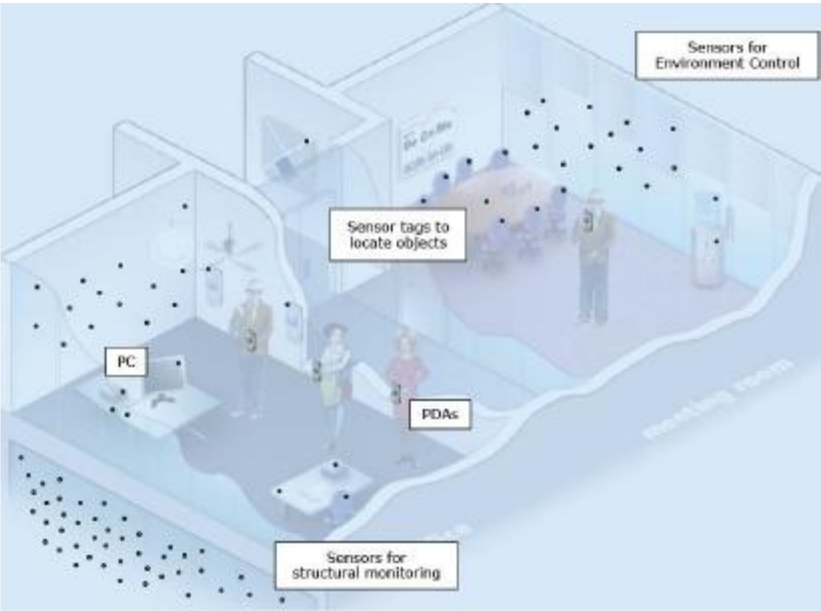

Wireless
Connectivity
WELCOME TO THE REAL WORLD!
YOU ARE NEVER ALLOWED TO EAT MOZZARELLA STICKS EVER AGAIN.

Bridging the real, virtual and digital worlds by using wireless connectivity.

Source: Virtual Reality System: University of Tokyo

RFID in the Office and Buildings

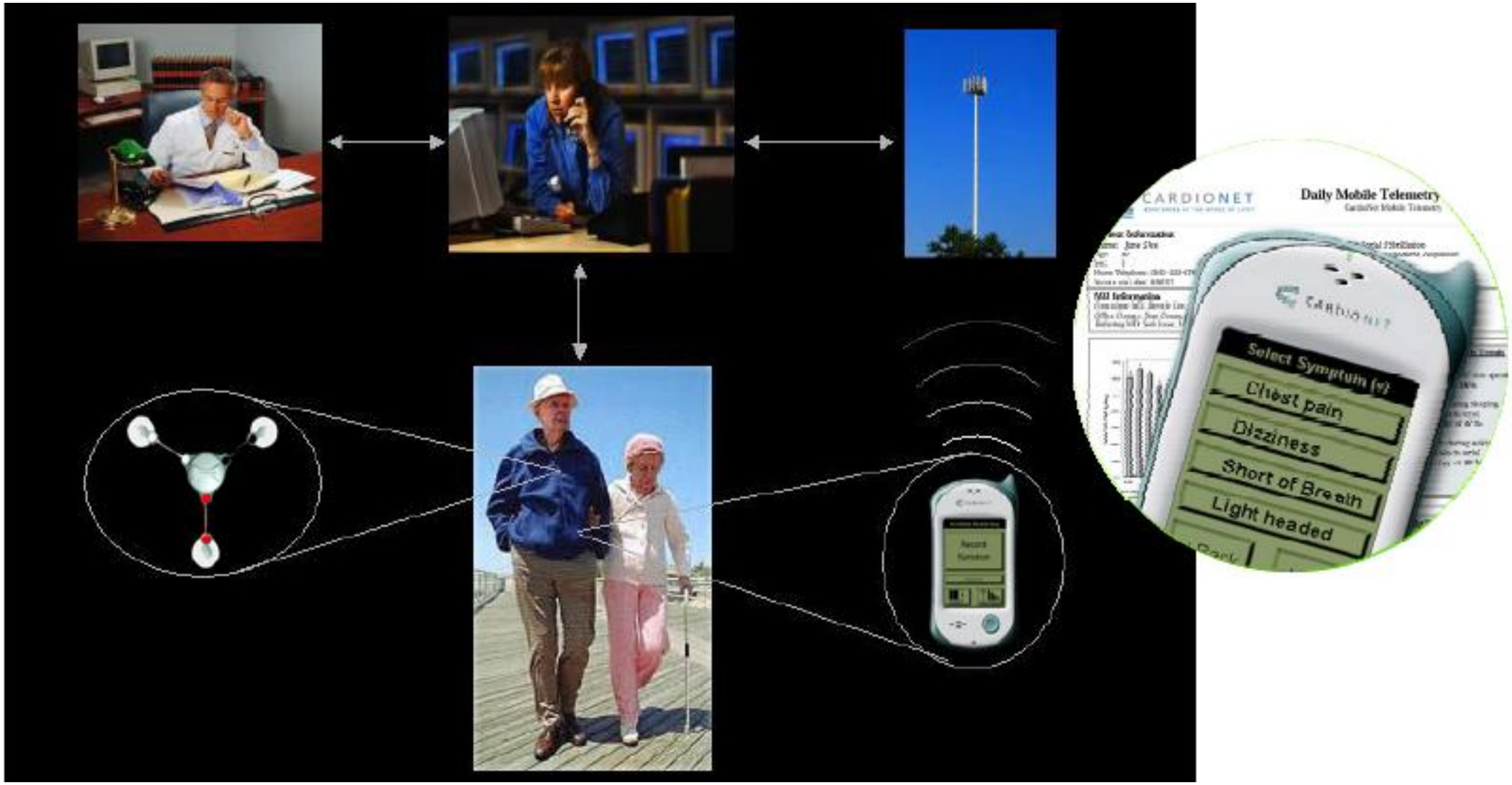
- Sensor data collection
- Exploit moving nodes
- Exploit network coding for efficiency


Sensors for Environment Control
Sensor tags to locate objects
PC
PDAs
meeting room
Sensors for structural monitoring

- Intelligent buildings
- RFID integration

Real virtual and digital healthcare

- Mobile cardiac telemetry monitoring platform
- 24/7/365 patient freedom to go anywhere at anytime



RFID for Intervehicular Communication

RFID for communication between V2V, V2I, I2V

<u>Vehicle Identification System</u>

- To determine if a vehicle registration has expired
- To monitor traffic and vehicle speed in construction zones or other pertinent areas
- Ticketing parking

http://www.compexinc.com/

WSN RFID in Oil and Gas Industry

- Wireless instrumentation for
  - Installations in remote and hostile areas
  - Temporary installations
  - Ease of scalability
  - Redundant data collection for production optimization

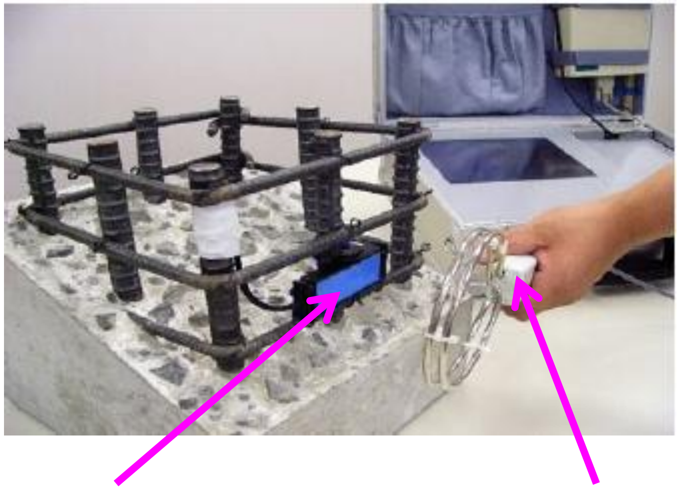
- RFID and WSN for
  - Personnel
  - Equipment
  - Containers
  - Drilling tools
  - Monitoring
  - Maintenance

Source: StatoilHydro

Roads Bridges and RFID

The strain sensing system uses 13.56MHz passive-type sensor-integrated RFID

The system measures the changes and deformation caused by various types of deterioration and loading on the structure, without using a battery



RFID tag

sensor

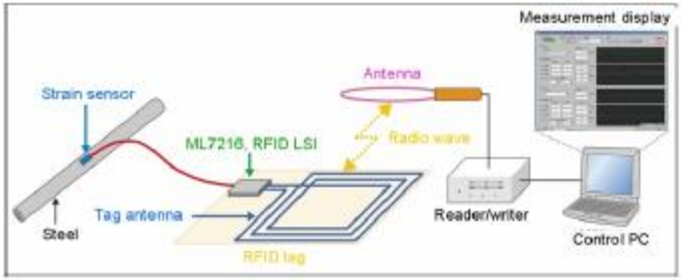
Source: Oki Electric Industry Co., Ltd.

Roads Bridges and RFID

Embedded RFID sensor is integrated within the concrete

Measurements are possible at a strain resolution level of about 10X10-6

Using a thermistor, the system simultaneously measures temperature and can account for deformation caused by temperature



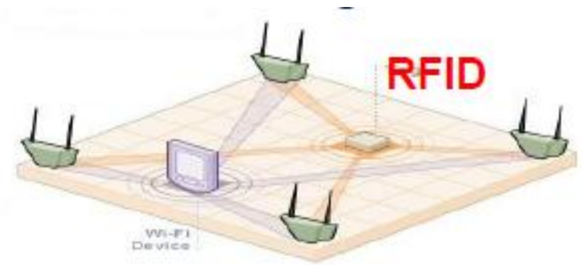
Efficient maintenance and management of roads, bridges and public housing

Concrete and steel structures monitoring due to everyday traffic, wind and earth pressure and earthquakes

Source: Oki Electric Industry Co., Ltd.

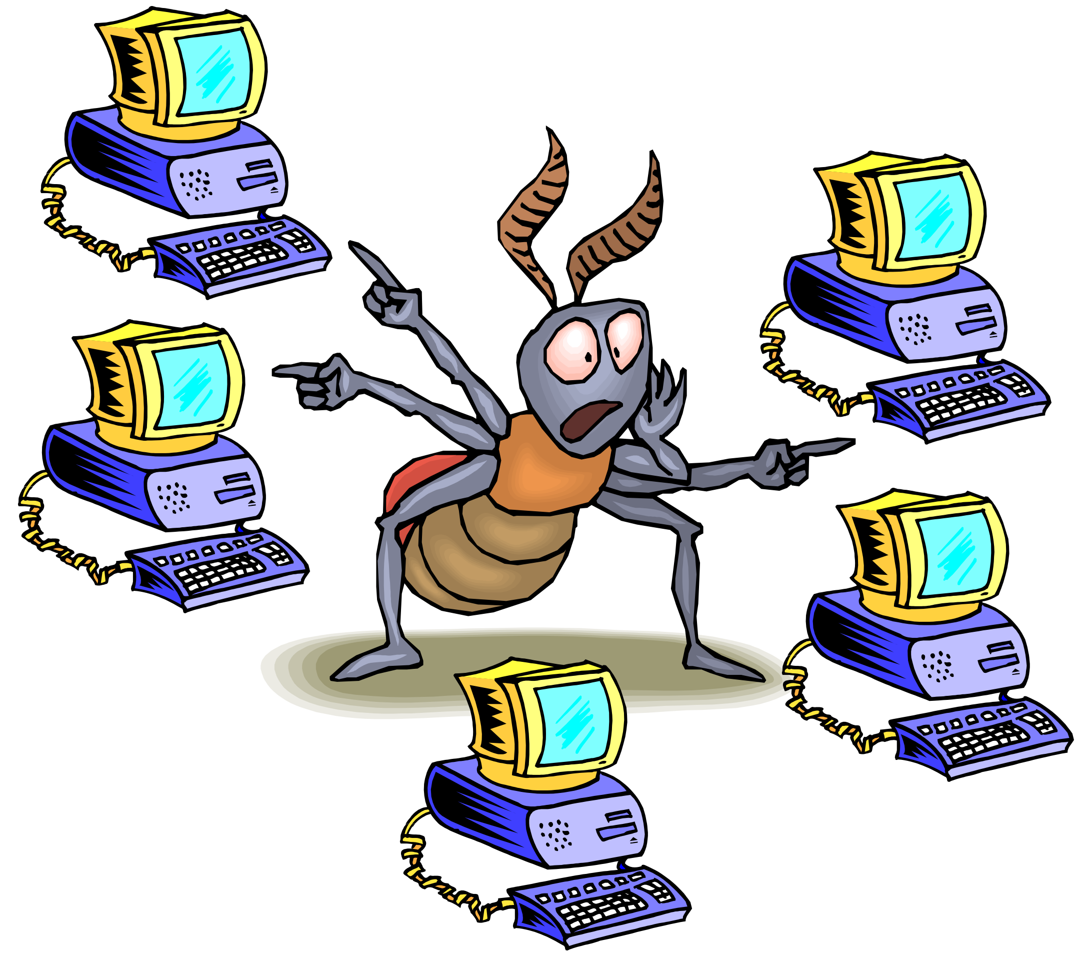
Intelligent long range active RFID systems are being used in real time location systems

They can identify, locate and track assets at a distance of up to 100m



They can deliver superior real time visibility in dynamic, demanding environments

RFID Security Issues



The problems of authentication and privacy are fundamental to RFID security

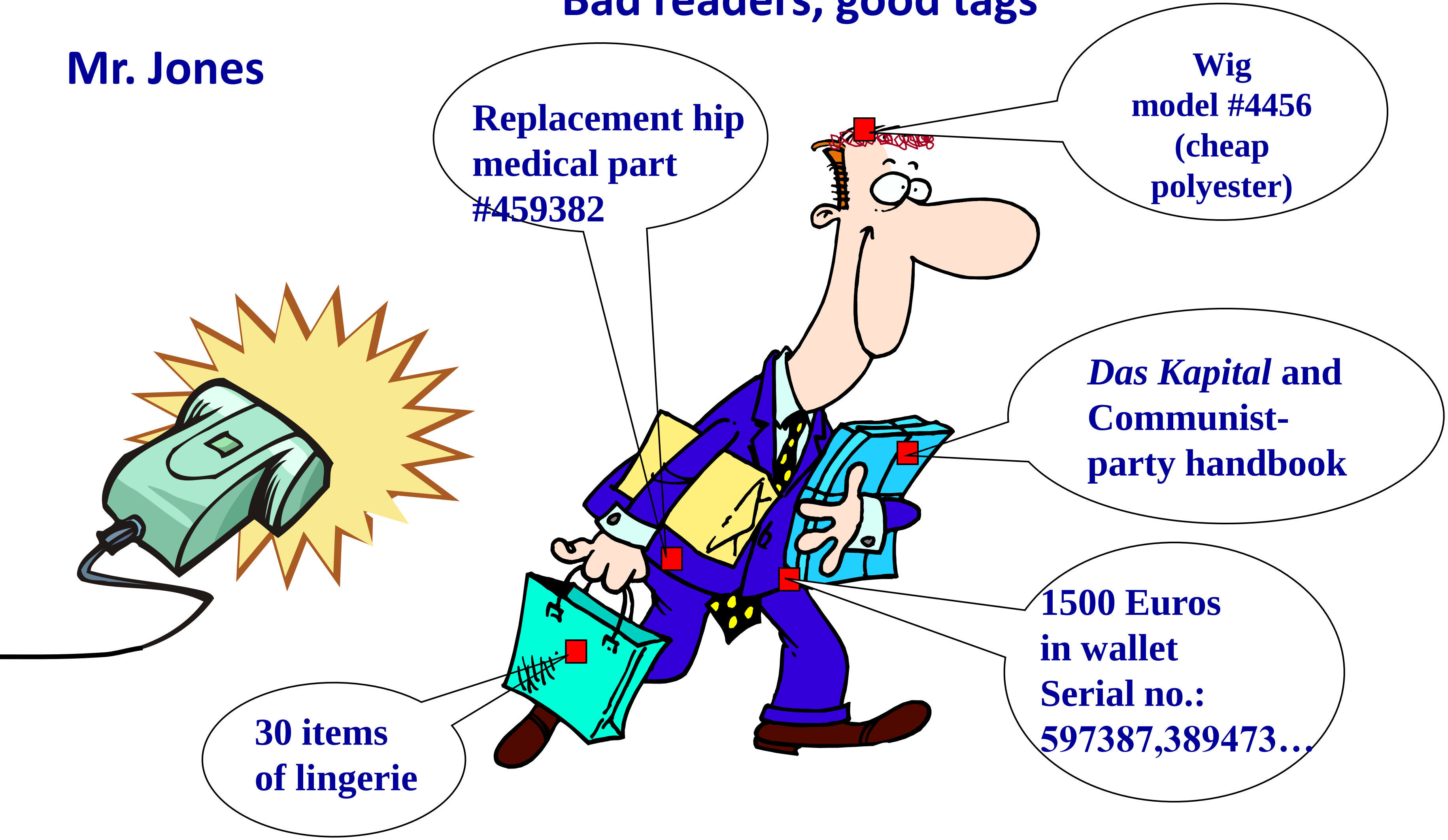
RFID is poised to become one of the sensory organs of our computing networks

The integrity of the data collected by RFID systems and appropriate curbs on the technology’s X-ray power are essential

The Consumer Privacy Problem

Bad readers, good tags

Mr. Jones



Replacement hip medical part #459382

Wig model #4456 (cheap polyester)

Das Kapital and Communist-party handbook

1500 Euros in wallet Serial no.: 597387,389473…

30 items of lingerie

Source RSA Laboratories

The authentication problem

Good readers, bad tags

Mr. Jones

Counterfeit!

Replacement hip

medical part #459382

Mr. Jones’s car!

Mad-cow hamburger lunch

1500 Euros in wallet

Serial numbers: 597387,389473…

Counterfeit!

RFID can possibly be used for more efficient mugging

"Just in case you want to know, she's got 700 Euro and a Rolex…"

RFID is a technology with great promise, but it invites numerous security and privacy issues

Deployed naively, embedding of RFID tags in consumer items can present a serious danger to privacy and security of consumers and enterprises in the future

<u>Technical Approaches to Enhancing RFID Privacy</u>

- **Cryptography**
- **Pseudonym rotation**
- **The "Blocker" Tag**

  Polite Blocking
- **Personal Simulator or Proxy for RFID etc…..**

List of Recent Survey Papers and Tutorials: RFID Anti Collision Protocols, RFID Security, IoT, Applications

RFID Anti-Collision Protocols

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[2] Thomas F. La Porta, Gaia Maselli, and Chiara Petrioli, "Anti-collision protocols for single-reader rfid systems: temporal analysis and optimization", IEEE Transaction on Mobile Computing

RFID Security and Applications

[3] A. Juels and S. Weis, Defining Strong Privacy for RFID, Extended abstract in PerTec ’07

[4] S. Garfinkel, B. Rosenberg, ”RFID: Applications, Security, and Privacy”, http://www.amazon.com/RFID-Applications-Security-Simson-Garfinkel/dp/0321290968

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[5] A. Juels, “The Vision of Secure RFID”, Proceedings of the IEEE. Aug., 2007

[6] T. S. Heydt-Benjamin, D. V. Bailey, K. Fu, A. Juels, and T. O'Hare, ”Vulnerabilities in First Generation RFID enabled Credit Cards”, Financial Cryptography 2007.

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Internet of Things

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[15] Internet of Things, Strategic Research Roadmap
http://www.sintef.org/upload/IKT/9022/CERP-IoT%20SRA_IoT_v11_pdf.pdf

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Primers and current RFID news:
www.rfidjournal.com
RSA Labs RFID Web site:

www.rsasecurity.com/go/rfid
www.rfid-security.com (unofficial)

JHU/RSA RFID Web site:
www.rfidanalysis.org

New survey (and all papers described here) at
www.ari-juels.com

For a list of papers on RFID Security
http://www.rsa.com/rsalabs/node.asp?id=2115
http://www.rfid-cusp.org

In summary, an overview of RFID, IoT has been presented with their applications and the associated security issues

Questions?