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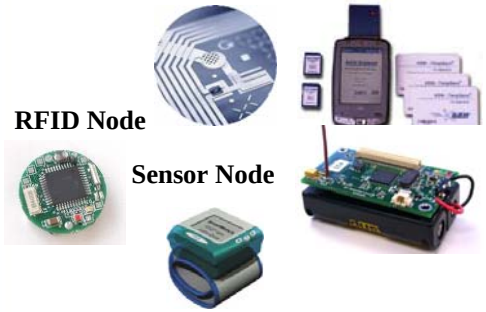


Smart Sensors on Wireless Cars
WSN Approach
February 5th 2009
Trento - Italy

Ubiquitous Wireless Sensor Networks and future "Internet of Things

Dr. O. Vermesan
SINTEF, Norway

Ubiquitous Sensor Network

- Any place, any thing using wireless tags/nodes-**Ubiquitous**
- Sensing ID and environmental information-**Sensor**
- Real time monitoring and control using a-**Network**

RFID Node

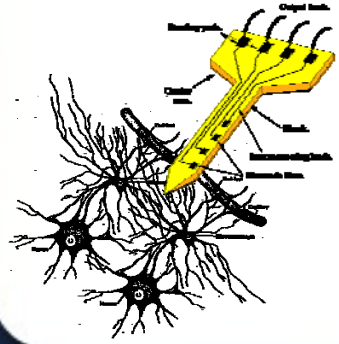
On-Body

Sensor Node

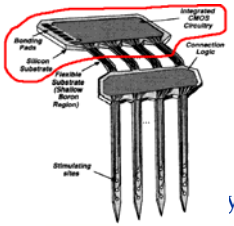
Ad-hoc Sensor

Adaptive Wireless

In-body

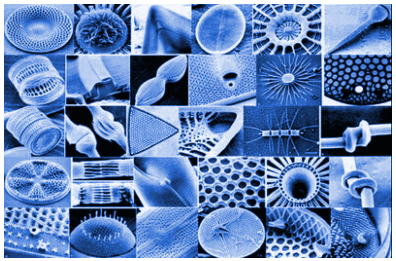


Neuro-stimulators



ynamicArm

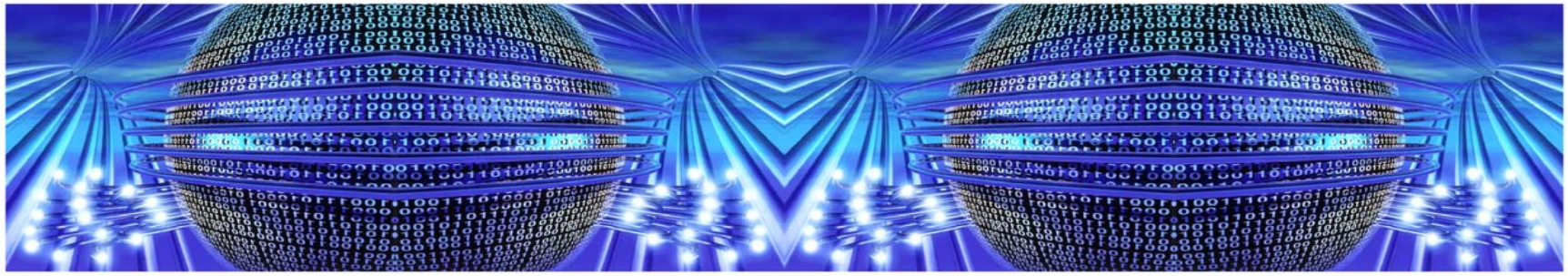
MEMS Sensors



In-Home

Internet of Things (IoT)

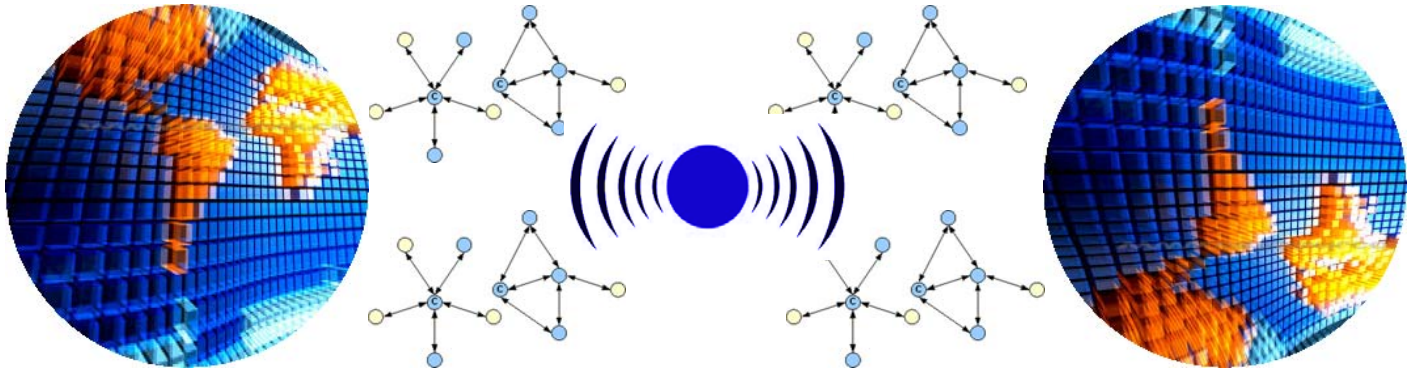
- A world-wide network of uniquely addressable interconnected objects, based on standard communication.
- Wireless identifiable devices are able to seamlessly interact and communicate with the environment and with other devices.



- IoT is referred together with terms like Ambient Intelligence, Ubiquitous Computing, Pervasive Computing, or Pervasive Networks and Semantic Web.

Internet of Things (IoT)

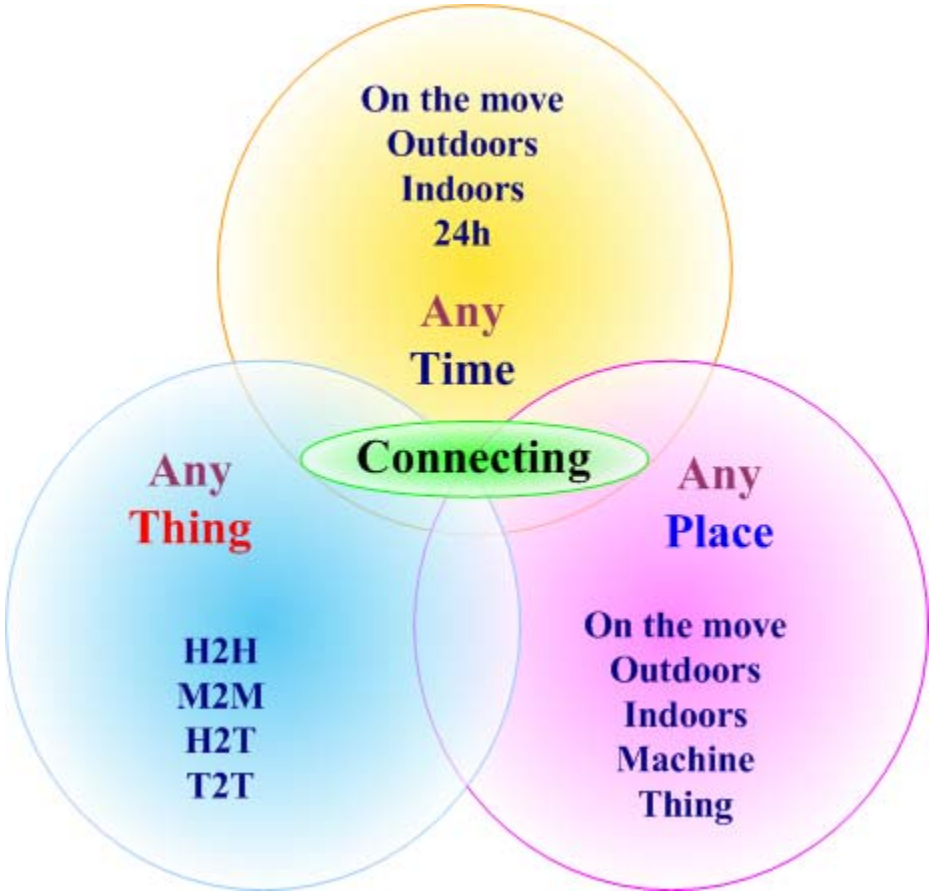
- Connectivity for ***anything***, ***anytime***, ***any place***, ***anyone***.



- Connect objects and devices to large databases and networks using simple, and cost effective systems of item identification so data about things can be collected and processed.
- Ability to detect changes in the physical and environmental status of things, using sensor technologies.
- Devolving information processing capabilities to the edges of the network using embedded intelligence in the things.
- Miniaturization and use of nanotechnology so smaller and smaller things will have the ability to interact and connect.

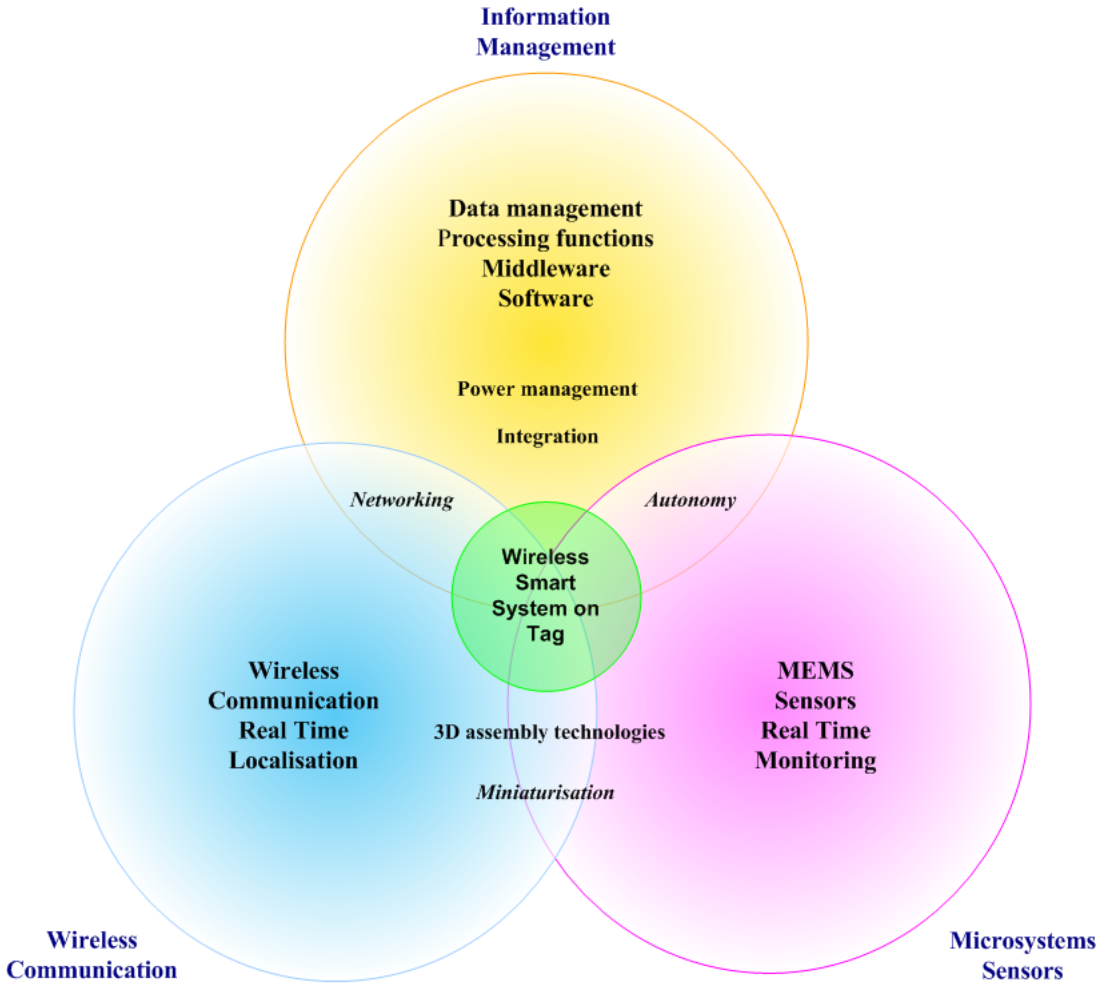
Internet of Things (IoT)

- Connectivity for ***anything***, ***anytime***, ***any place***, ***anyone***.



Smart Systems on Tags

- Sense
- Actuate
- Identify
- Interact
- Interface
- Communicate



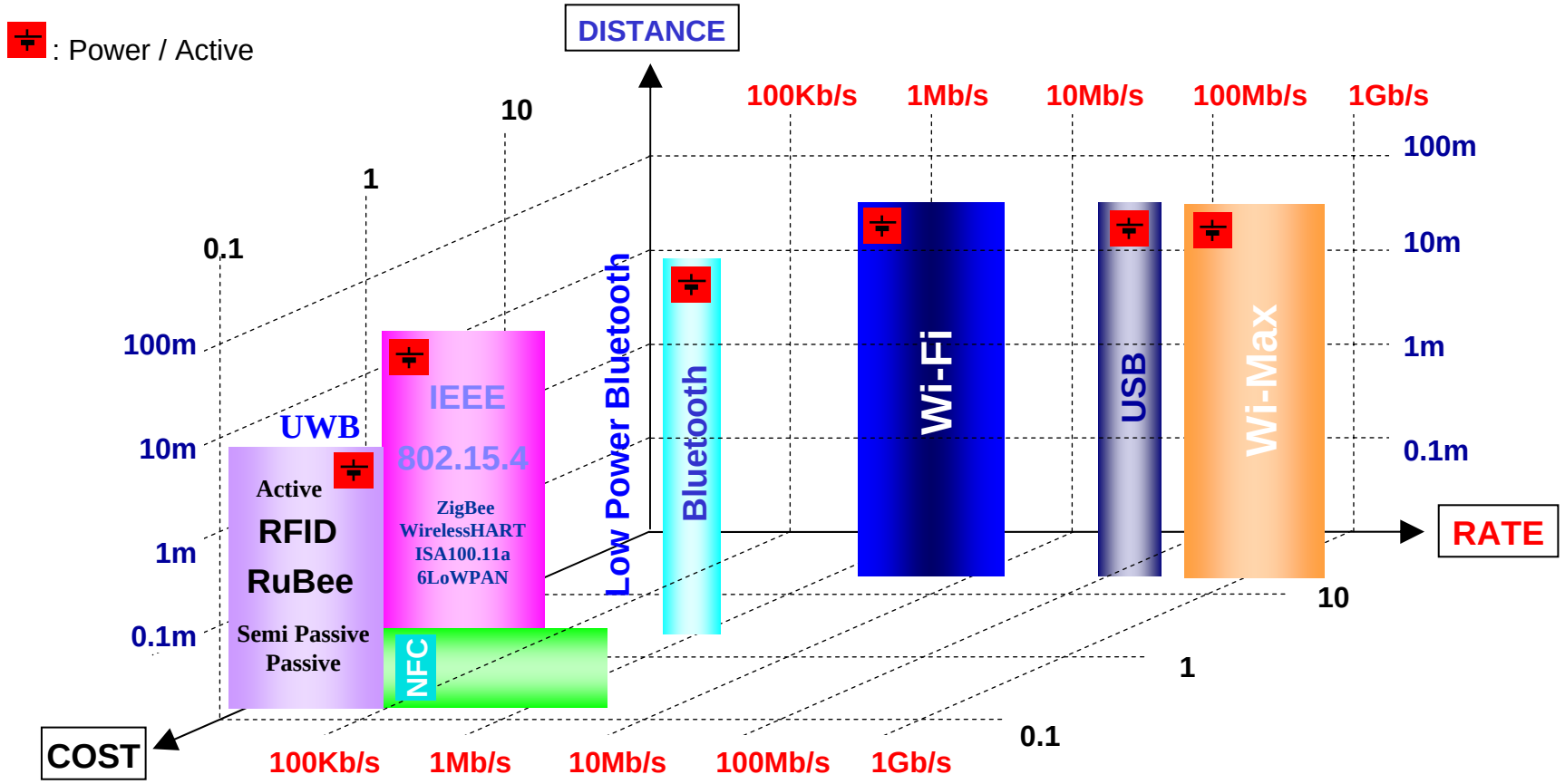
Wireless Systems Characteristics

- Wireless
  - Limited bandwidth, high latency
  - Variable link quality and link asymmetry due to noise, interference, disconnections
  - Easier snooping
    - Signal and protocol processing
- Mobility
  - Determine variability in system design parameters:
  - Connectivity, bandwidth, security domains, location awareness
    - Protocol processing
- Portability
  - Limited capacities (battery, CPU, I/O, storage, dimensions)
    - Energy efficient signal and protocol processing

Source: Momenta

Source: Momenta neck-worn PC

Communication Technologies



Communication Technologies

M2M/T2T

RFID (424kb/s, 7m, 13.56MHZ, 866-960MHZ)
RFID (433MHz, 2.45GHz)

ZigBee* (250kb/s, 10m, 2.47GHz)
ZibBee*–a (20kb/s, 75m, 900 MHz)

RuBee
RuBee

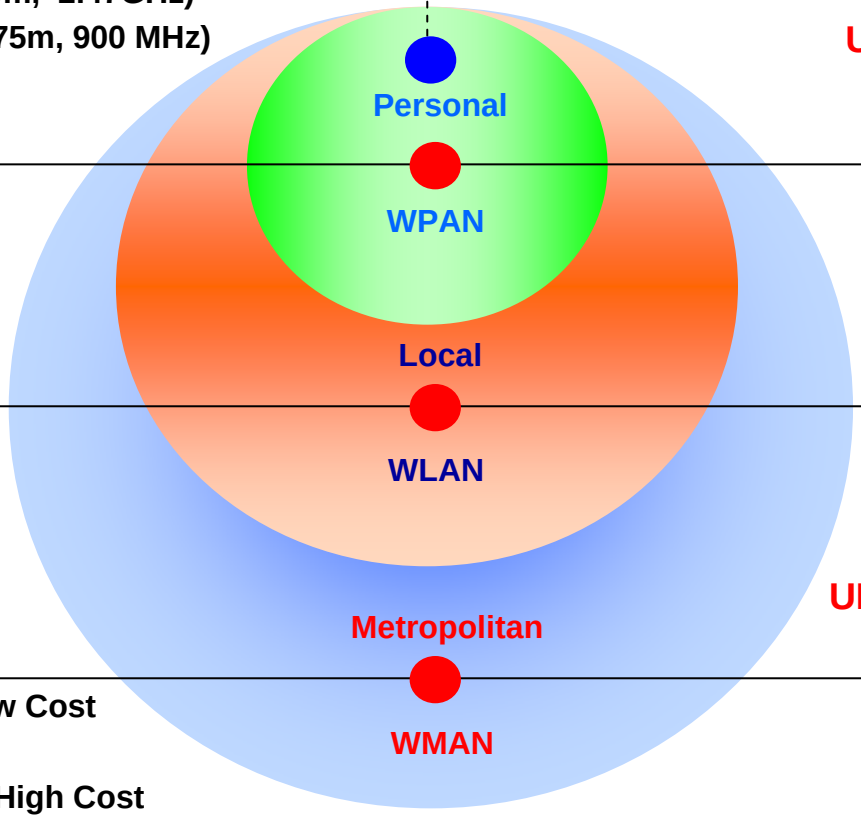
WirelessHart
ISA 100

H2M/H2H

Bluetooth (750kb/s, 10m, 2.47GHz)

Low Power Bluetooth

UWB (50Mb/s, 30m, Wide Range)



Wi-FI (50-320Mb/s, 100m, 2.4-5.8GHz)

Wi-Max (70Mb/s, 50Km, 2-11GHz)

UMTS, CDMA (2Mb/s), **EDGE, MBWA**

Passive – Low Cost

Active – Mid/High Cost

Wireless Technologies - RFID

	Frequency Band	Frequency Range	Wavelength	RFID Frequency	Standard
LF	Low Frequency	30kHz to 300kHz	10km to 1km	30-50kHz 125/134kHz 131/450kHz	USID ISO 18000-2 IEEE P1902.1/ RuBee
MF	Medium Frequency	300kHz to 3MHz	1km to 100m		
HF	High Frequency	3MHz to 30MHz	100m to 10m	6.78MHz 7.4-8.8MHz 13.56MHz 27MHz	ISO 18000-3 ISO/IEC 15693 ISO/IEC 14443/NFC ISO/IEC 10536
VHF	Very High Frequency	30MHz to 300MHz	10m to 1m	125MHz	
UHF	Ultra High Frequency	300MHz to 3GHz	1m to 10cm	433MHz 840-956MHz 2.45GHz	ISO 18000-7 18000-6 Type A, B. C EPC C1G2 IEEE 802.11 ISO 18000-4 IEEE 802.15 WPAN IEEE 802.15 WPAN Low Rate IEEE 802.15 RFID
SHF	Super High Frequency	3GHz to 30GHz	10cm to 1cm	3.1-10,6GHz 5.8GHz 24.125GHz	IEEE 802.15 WPAN UWB ISO 18000-5
EHF	Extremely High Frequency	30GHz to 300GHz	1cm to 1mm		MMID

Wireless Technologies - WSN

- IEEE 802.15.4
- ZigBee
- *Wireless*HART
- ISA100.11a
- 6LoWPAN
- Low Power Bluetooth
- RFID

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Wireless Technologies - Comparisons

	ZigBee	Bluetooth	UWB	Wi-Fi	Proprietary
Standard	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.15.3a (TBR)	IEEE 802.11 a, b, g, n	Proprietary
Industry Groups	ZigBeeT Alliance	Bluetooth SIG	UWB Forum & WiMedia Alliance	Wi-Fi Alliance	N/A
Topology	Mesh, Star, Tree	Star	Star	Star	P2P, Star, Mesh
RF Frequency	868/915MHz 2.4GHz	2.4GHz	3.1-10.6GHz	2.4GHz 5.8GHz	433/868/900MHz 2.4GHz
Data Rate	250Kbps	723Kbps	110Mbps-1.6Gbps	11-105Mbps	10-250Kbps
Range	10-70 m	10m	4-20m	10-100m	10-70m
Power	Very Low	Low	Low	High	Very Low-Low
Battery Operation Life	Alkaline (m-y)	Rechargeable (d-w)	Rechargeable (h-d)	Rechargeable (h)	Alkaline (m-y)
Nodes	65000	8	128	32	100-1000

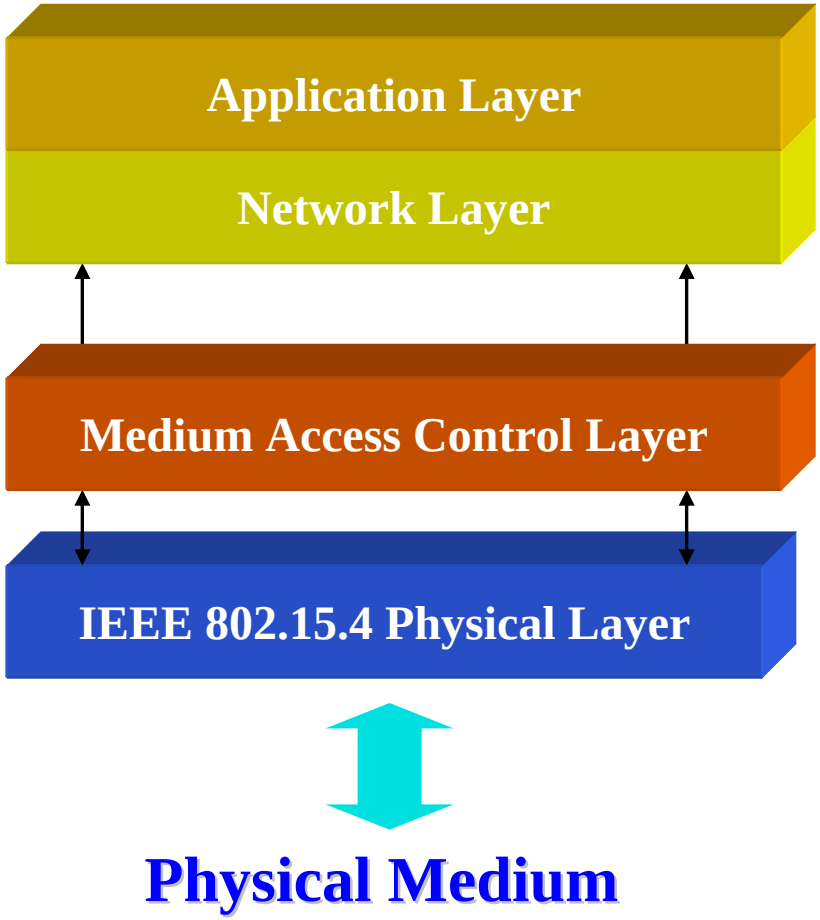
Wireless Technologies - Comparisons

Feature	ZigBee	SP100	WirelessHART
Market	Consumer and Commercial	Industrial	Industrial
Applications	Smart Energy, Building Automation	Process Control Factory Automation	Industrial Control
802.15.4	2003	2006	2006
Battery Operation Life	++++	+++	++
Device Type	FFD, RFD	FFD, RFD	FFD
Topology	Mesh, Tree	Mesh, Tree	Mesh
Channel Hopping/Agility	Agility - Specifications 2007	Hopping	Hopping
Sleeping Routers	No. TBA in future specifications	Yes	Yes
Latency	4ms	10ms	10ms
Preferred Channels-Channel Blacklist	Preferred channel	Blacklist	Blacklist
Encryption	AES128	AES128	AES128
Key Exchange	Profile	Yes	Yes
Cost	Low	Medium	High
Message Priority (QOS)	No	Yes	Yes
Certification Program	Yes	Yes	Yes

Wireless Technologies - Comparisons

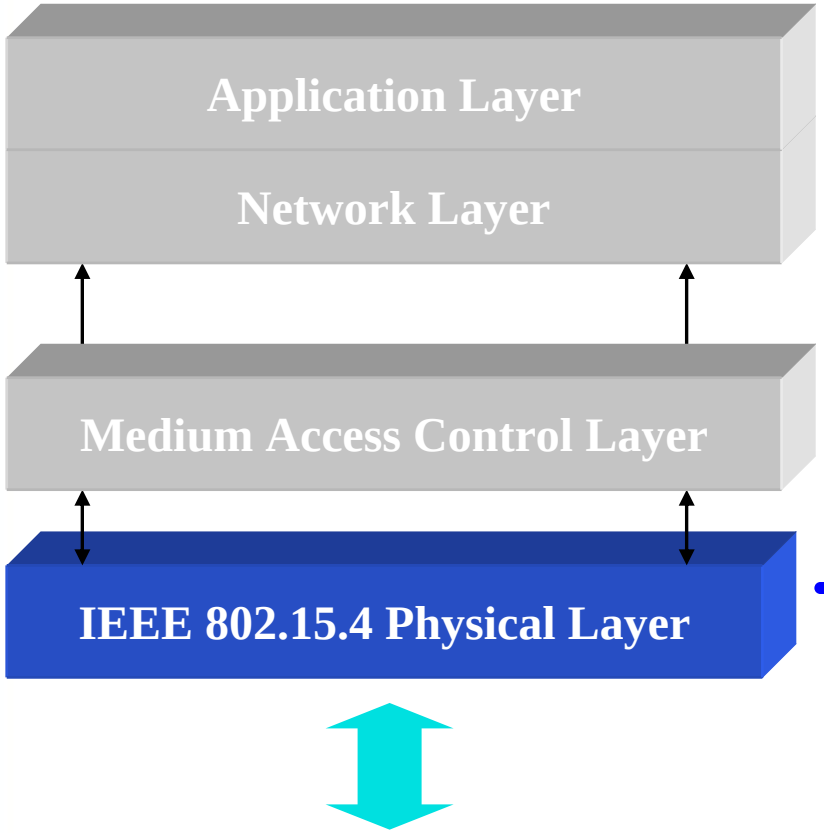
Protocol	PROS	CONS
ZigBee	General market appeal Lots of backing in Smart Energy space Products in market today	Not cost effective for high volume consumers Complex Not Industrial Grade
SP100.11a	Deterministic Immune to Multipath Sleeping Routers CSMA and TDMA tunable Multiple Fieldbus support Pv6 Support	Costly components required Object Structure in the Application Layers adds structure which might be viewed by developers as restrictive
WirelessHART	Deterministic Immune to Multipath Sleeping Routers Existing wired devices in market	Costly components required TDMA mode only

Wireless Sensor Networks Stack



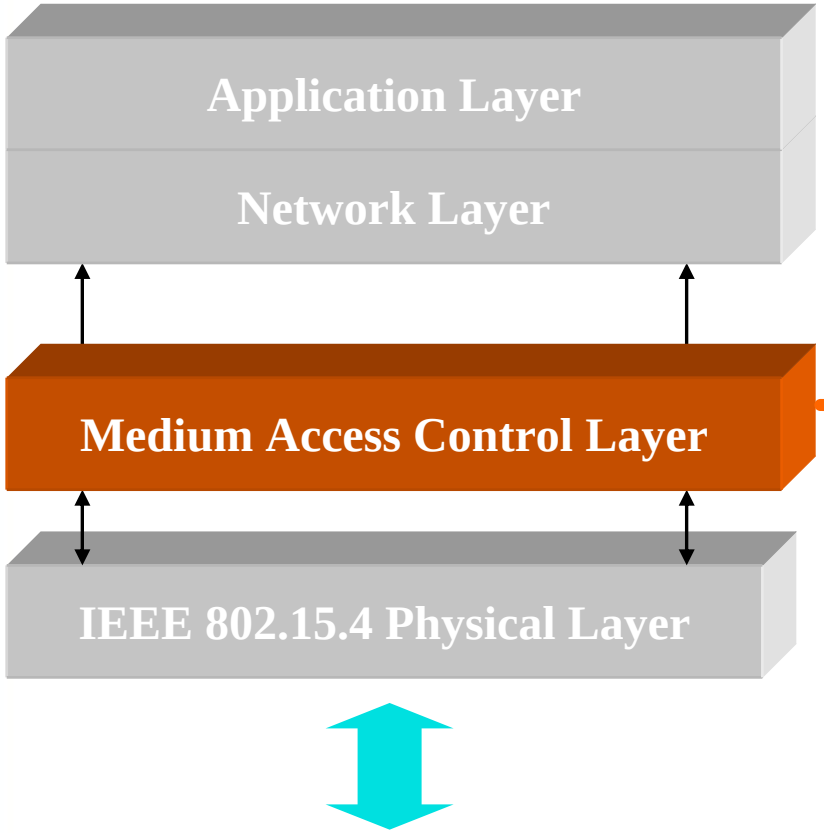
- Stack
  - Layered, abstract description for network protocol design
- Layer
  - Collection of related functions
  - Provides services to the layer above it
  - Receives service from the layer below it.

Stack Configuration



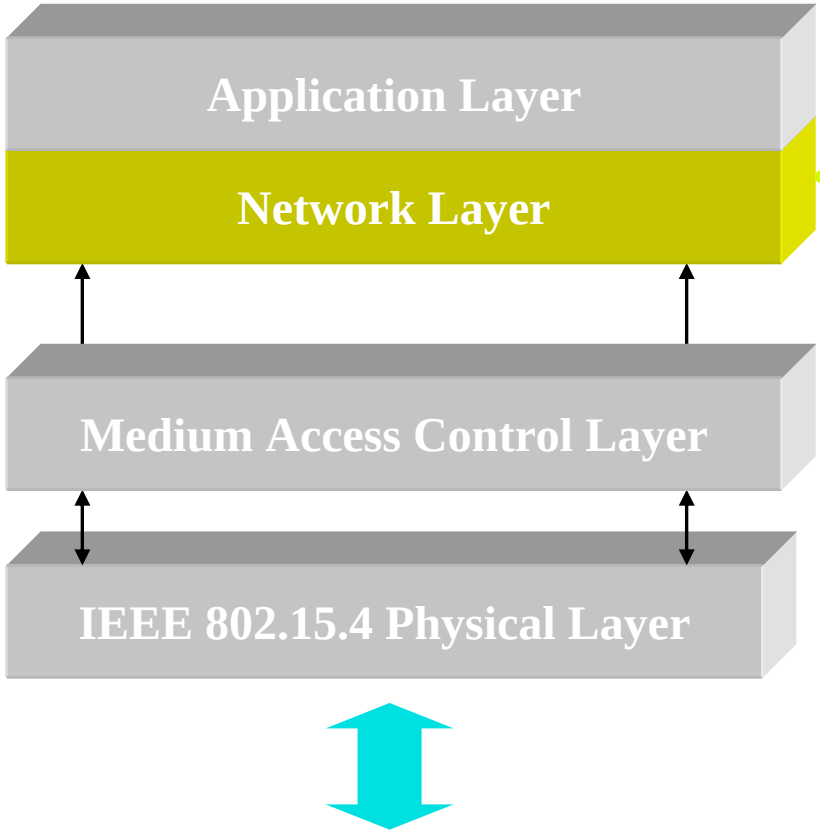
- Physical Layer
  - Controls the physical RF transceiver
  - Performs frequency and channel selection
  - Provides means for transmitting raw data bits (not packets)

Stack Configuration



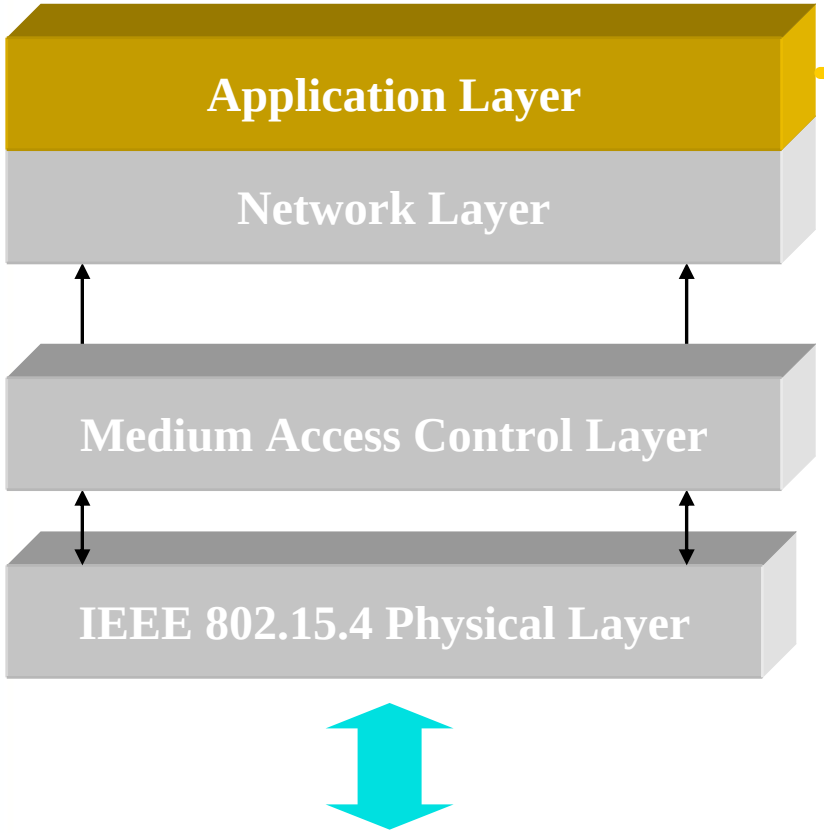
- Medium Access Control (MAC) Layer
  - Handles access to the physical radio channel
  - Manages radio synchronization
  - Provides reliable link between two peer MAC entities

Stack Configuration



- Network Layer
  - Responsible for joining and leaving the network
  - Routes frames to their destination
  - Discovers and maintains routing tables

Stack Configuration



- Application Layer
  - Provides services to user-defined *application processes,* not to *end-users*
  - Handles fragmentation and reassembly of data packets
  - Defines the role of the device within the network
    - Coordinator, router or end-device

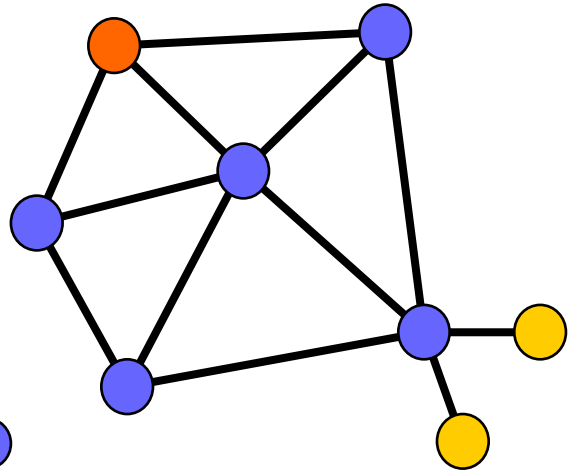
IEEE 802.15.4

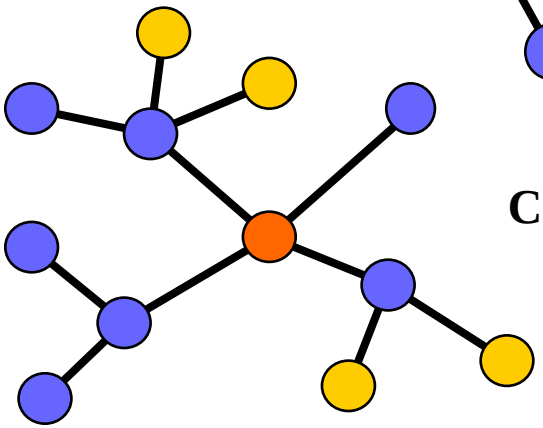
- Defines Physical (PHY) and Medium Access Control (MAC) layer
  - The Network and Application layers outside the scope of the standard
- Available frequencies
  - 868/915 MHz (20-40kbit/s)
  - 2.4 GHz (250kbit/s)
- Low power consumption
- Reliable MAC layer
  - Error checking
  - ACK based retransmissions

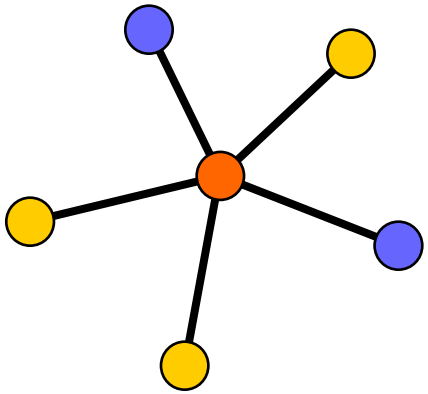
BAND		COVERAGE	DATA RATE	CHANNEL NUMBERS
2,4 GHz	ISM	Worldwide	250 kbps	11-26
868 MHz		Europe	20 kbps	0
915 MHz	ISM	Americas	40 kbps	1-10

IEEE 802.15.4

- Full Function Device
  - PAN Coordinator
  - Router
  - Sensor
- Reduced Function Device
  - Sensor







PAN coordinator
Full Function Device
Reduced Function Device

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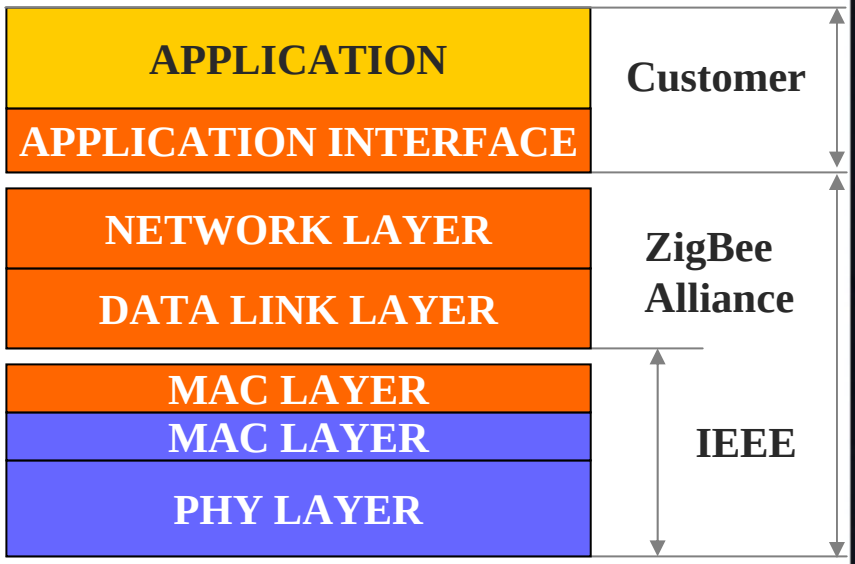
ZigBee

ZigBee™ Alliance
Wireless Control That Simply Works

- Defines Network and Application layer for IEEE 802.15.4 WSN
- Typical Applications
  - Consumer
  - Wireless keyboard/mouse and remote controls
  - Home Automation
  - Light-switch
  - Temperature monitoring automatic heating control
- Weaknesses
  - Static channels
  - Susceptible to background noise and RF interference
  - Not robust enough for industrial applications in harsh RF environments
- ZigBee PRO
  - ZigBee version aimed at the industrial market
  - ”Frequency agility” – may change channels when faced with noise/interference



*Wireless*HART

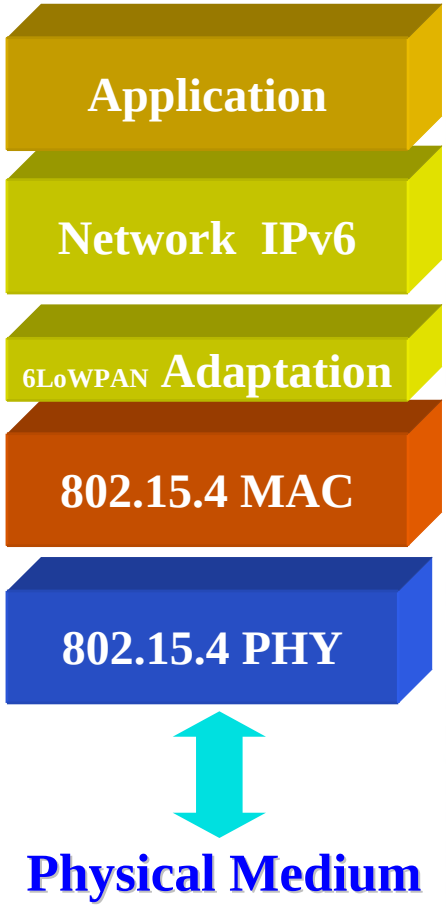
- Part of HART Field communication Specification, Revision 7.0
  - Released Sept. 2007
  - Allows for wireless transmission of HART messages
- Based on IEEE 802.15.4 PHY with modified MAC Layer
- Full mesh network topology
- Adaptive frequency hopping
- Time-division multiple access (TDMA)

ISA100.11a

- ISA100
  - Family of wireless standards for industrial automation
  - WSN, WLAN, WiMAX
- ISA100.11a
  - Wireless non-critical monitoring and control applications
  - Uses IEEE 802.15.4 PHY and modified MAC
  - Frequency hopping
  - Star-mesh network
  - Capable of transferring multiple wired protocols
    - 4-20ma, Ethernet, HART, FF, Modbus
  - Expected ratified

6LoWPAN

- Provides open-systems based interoperability among low power devices over IEEE 802.15.46. Turns IEEE 802.15.4 into the IP enabled link
- Orthogonal stackable header format
  - Almost no overhead for the ability to interoperate and scale.
  - Coexistence with other network protocols over same link
  - Header dispatch - understand what's coming
- IPv6 address <prefix64 interface id> for nodes in 802.15.4 subnet derived from the link address.
  - PAN ID maps to a unique IPv6 prefix
  - Interface identifier generated from EUID64 or Pan ID and short address
  - Hop Limit is the only incompressible IPv6 header field
- Appropriate for WSN that have resource constraints of low power, low memory, low bandwidth devices.



Low Power Bluetooth - WiBree

- WiBree forum merged with Bluetooth SIG to become part of the *Bluetooth* specification. WiBree rounds out BT technology PAN. Ultra low power BT two implementation options:
  - Stand-alone implementation
  - Dual-mode implementation (extension to Bluetooth radio)

	Stand-alone IC	Dual-mode IC
Data rate	1 Mbps	1 Mbps
Range	5-10m	5-10m
Power	0.1-0.25*BT	0.75-0.80*BT
Cost	0.5-0.6*BT	1.1*BT

Enhances the current BT use cases around personal devices (e.g. mobile phones)
Seamless connectivity with very LP sensor devices

Technology	Bandwidth	Range	Power	Frequency band
Bluetooth 2.0	2.1 Mbit/s	0.01-100m	Low	2.4 GHz
Wibree	1 Mbit/s	10 m	Very Low	2.4 GHz
ZigBee	250, 40, 20 Kbit/s	10 -75 m	Very Low	2400, 915, 868 MHz
WirelessHD	2 -20 Gbit/s	10 m	Very High	60 GHz
Certif. Wireless USB	480 Mbit/s	10 m	Medium	3.1 -10.6 GHz
WirelessUSB	1 Mbit/s -62.5 Kbit/s	10 -50 m	Low	2.4 GHz
Wi-Fi IEEE 802.11n	540 Mbit/s	50 m	High	2.4 GHz or 5.8 GHz
Fixed WiMAX	75 Mbit/s	1 -50 km	Medium	3.5, 5 GHz (in Europe)
Mobile WiMAX	30 Mbit/s	2 -5 km	Medium	3.5, 5 GHz (in Europe)
HSDPA	14.4 -1.8 Mbit/s	0.1-20 km	Medium	1900-1920 & 2010-2025 MHz

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UWB

- High data rates are possible
  - 500+ Mbps achievable at short ranges (i.e., < 3 meters) under current regulations
  - Data rate scales with ever faster CMOS circuits
- Low power compatible with CMOS
  - Suitable for battery-operated devices
- Position and Location capabilities
- Key elements and challenges
  - FLEXIBLE - provide variable spectral filling of the wideband channel and better co-existence
  - SCALABLE - scale performance with technology advancement
  - ADAPTABLE - accommodate potentially different worldwide regulations
  - LOW COST - enable full CMOS integration
  - WORLDWIDE STANDARD – provide a single, common physical layer to meet broad industry requirements
- IEEE 802.15.3a (TBR - to be ratified)

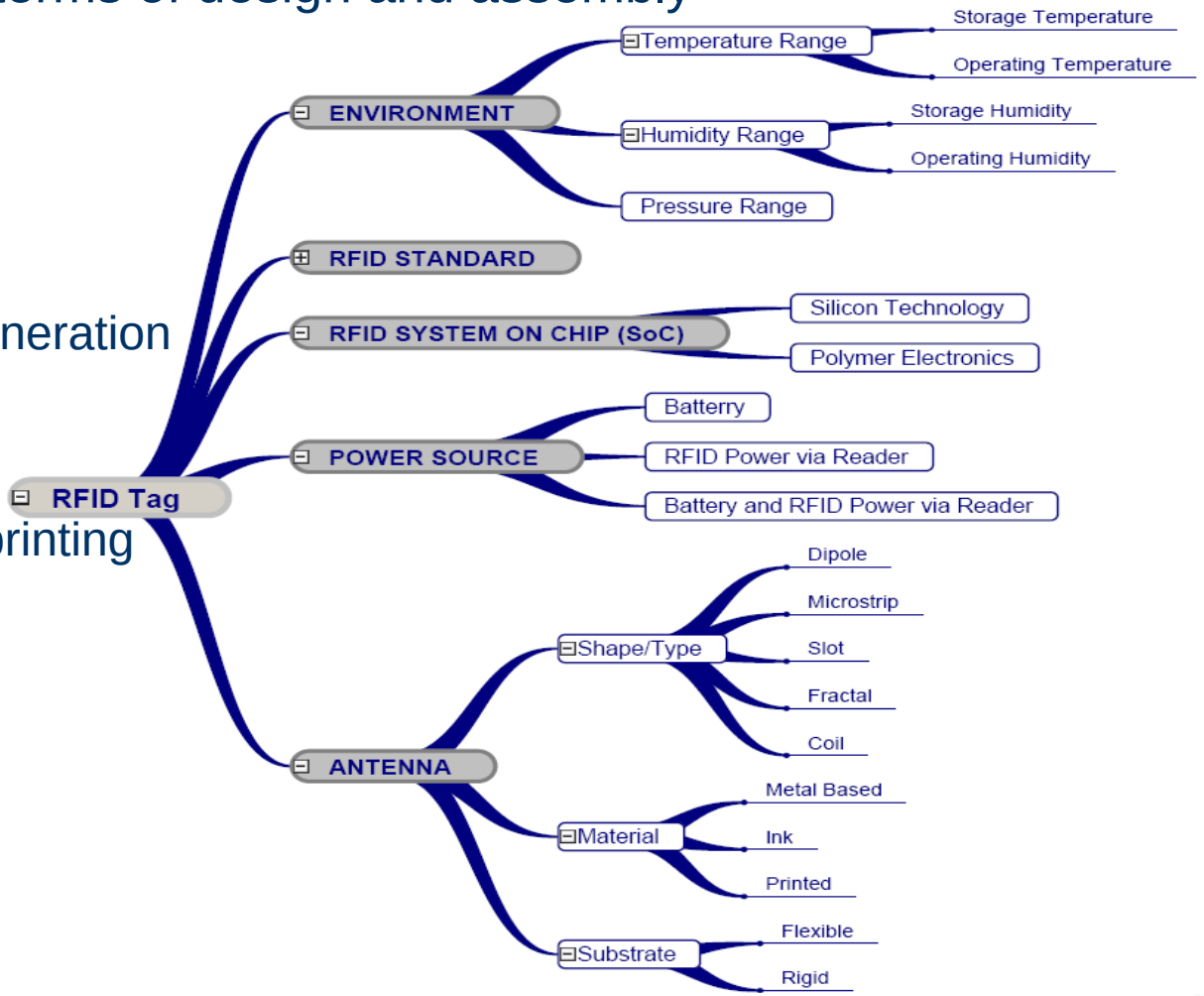
RuBee IEEE P1902.1

- 131 KHz TCP/IP IPv6 Protocol IEEE P1902.1 – Pending
- RuBee is a bi-directional, low power wireless peer to peer protocol (LF) based on magnetic field. Signals are unaffected by steel or water and could be appropriate for placing tags in metal objects.
- User memory capacity required is recommended to be minimum 2048 bits. The ID number of bits recommended is minimum 96bits.

Standard	RuBee P1902.1
Data	5kbs
Battery Operation Life	4000 days
Bandwidth kbps	1 + Clip
Net Size	No Limit
Range m	1-30
Security	High

RFID Tags-Complex Smart Systems

- Many alternatives in terms of design and assembly
- Several components and suppliers
  - ICs (SoC)
  - Sensors
  - Batteries, power generation
  - Energy harvesting
  - Inlays & labels
  - Antenna design & printing



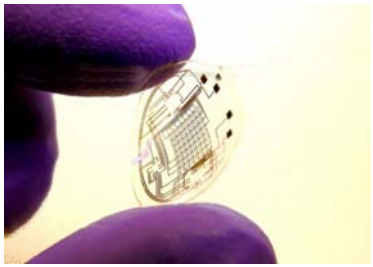
Smart Wireless Systems

- Beyond RF ID - Functionality
  - Multi Antennas
    - On Chip Antenna –OCA
    - Coil on Chip (HF)
    - Printed antennas
    - Embedded antennas
    - Multiple antenna substrates
    - 3D structures
  - Integrated Circuit Micro/Nanoelectronics/Polymer
    - Multi RF Front Ends
      - HF/UHF/MW/Radar
    - Memory – EEPROM/FRAM/Polymer
    - ID 128 bits + other type ID
    - Multi Communication Protocols
    - UWB
    - Digital Processing
    - Security

Source: Toshiba

- Displays
  - Bi-stable
  - Flexible
  - Transparent

Combined flexible contact lens with an imprinted electronic circuit



Source: University of Washington

Source: Siemens

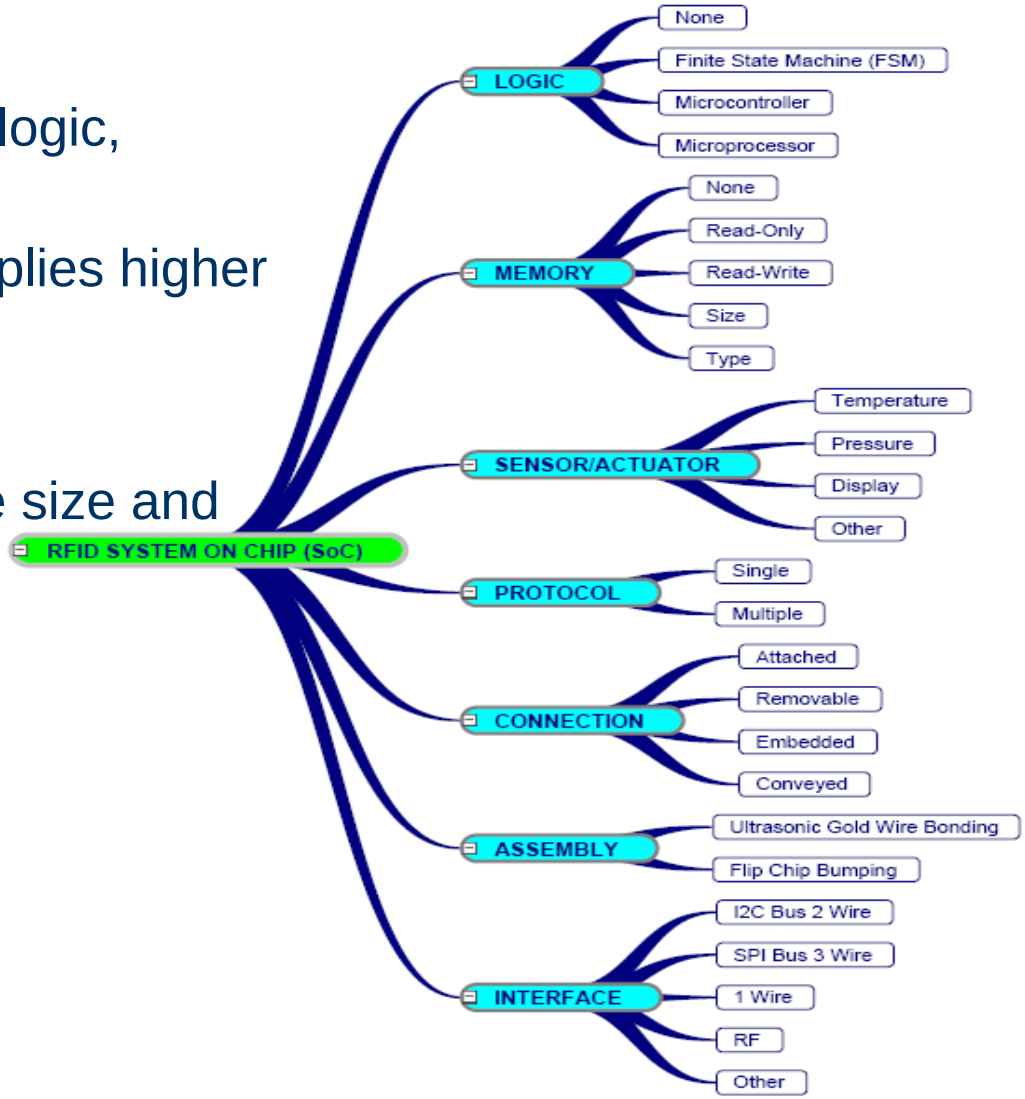
- Sensors/Actuators
  - MEMS/NEMS
  - Sensors on Chip
  - Molecular sensors
- Assembly
- Power Generation
  - RF
  - Solar
  - Harvesting (vibration, temp, etc.)
  - Batteries printed/polymer
  - Fuel cells

Challenges and Constraints

- Semiconductor technology scaling gives rise to three key challenges:
  - Challenge of scalability
    - the need to extend communications and processing to large data, over heterogeneous channels
  - Challenge of adaptation
    - the need to reuse and retarget both hardware and software
  - Challenge of integration
    - the need to more optimally exploit heterogeneous component technologies with respect to cost, performance, energy tradeoffs
- Fundamental technology *constraints*:
  - Energy (limitations of batteries, sensors)
  - Bandwidth (limited speed of semiconductor devices)
  - Non-scalability of analog circuits
  - Scaling of on- and off-chip interconnects

Challenges and Constraints

- On-chip intelligence
  - FSM, micro-programmed logic, microcontroller
  - Wider programmability implies higher power consumption
- Embedded memory
  - Higher capacity higher die size and power consumption
- Embedded sensors
  - Higher design complexity
  - Easier assembly phase
  - Smaller tag cost



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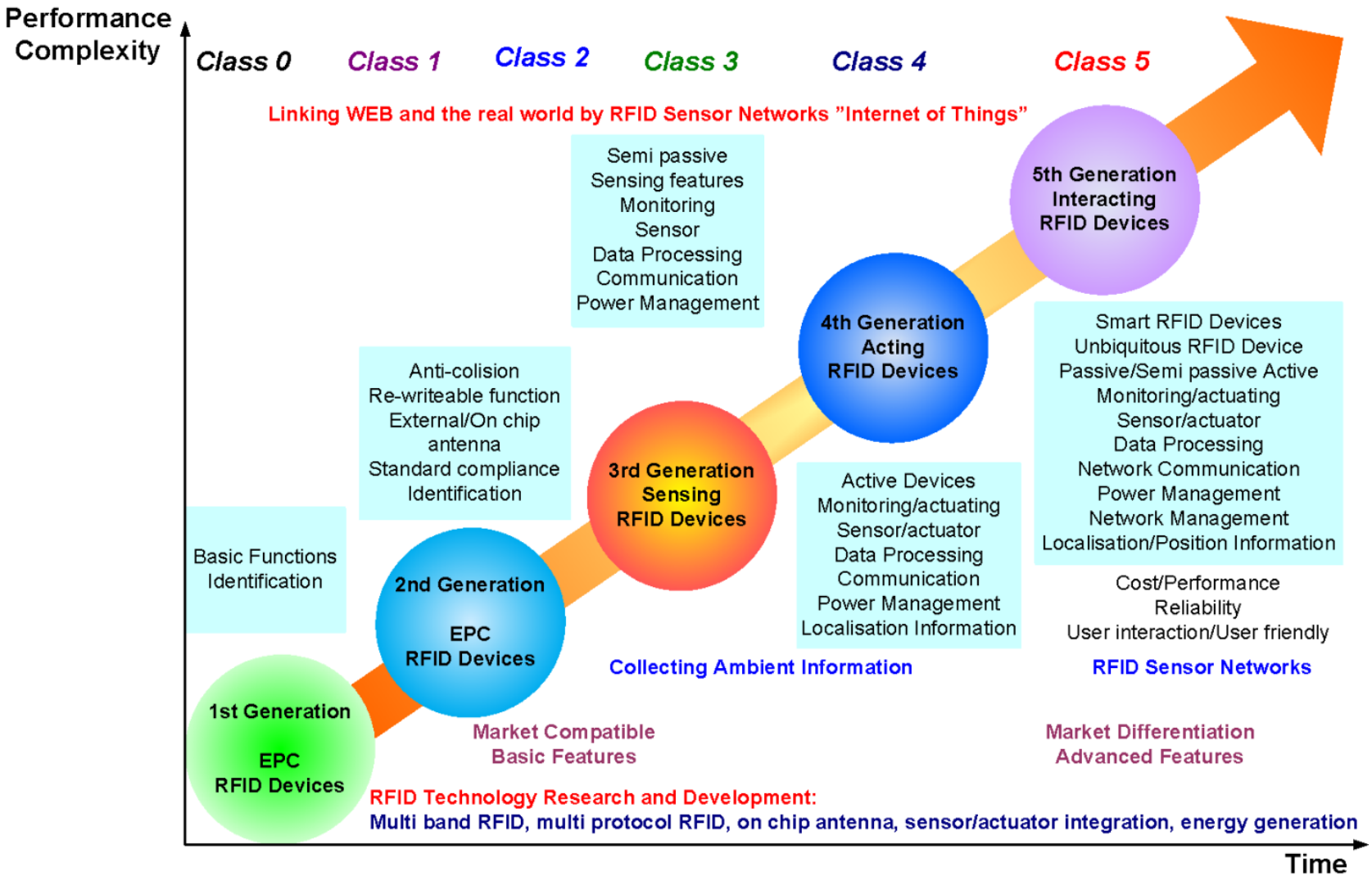
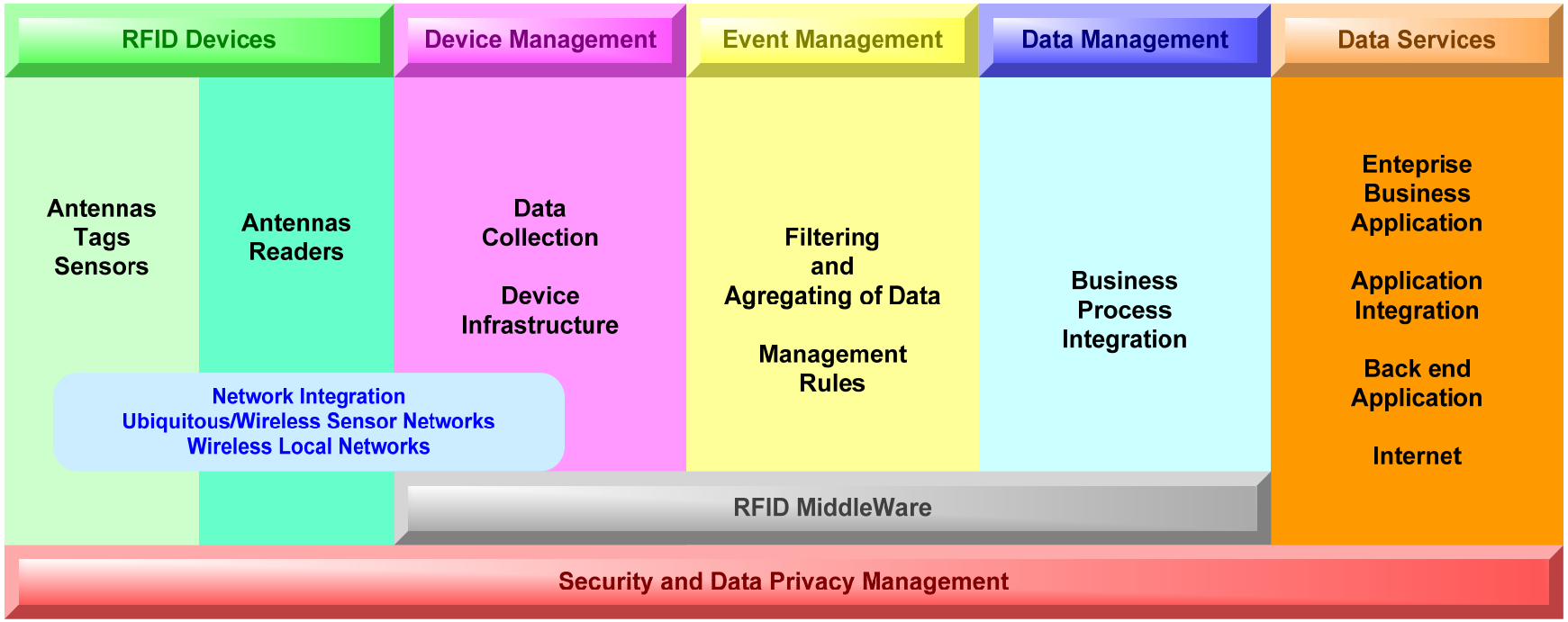
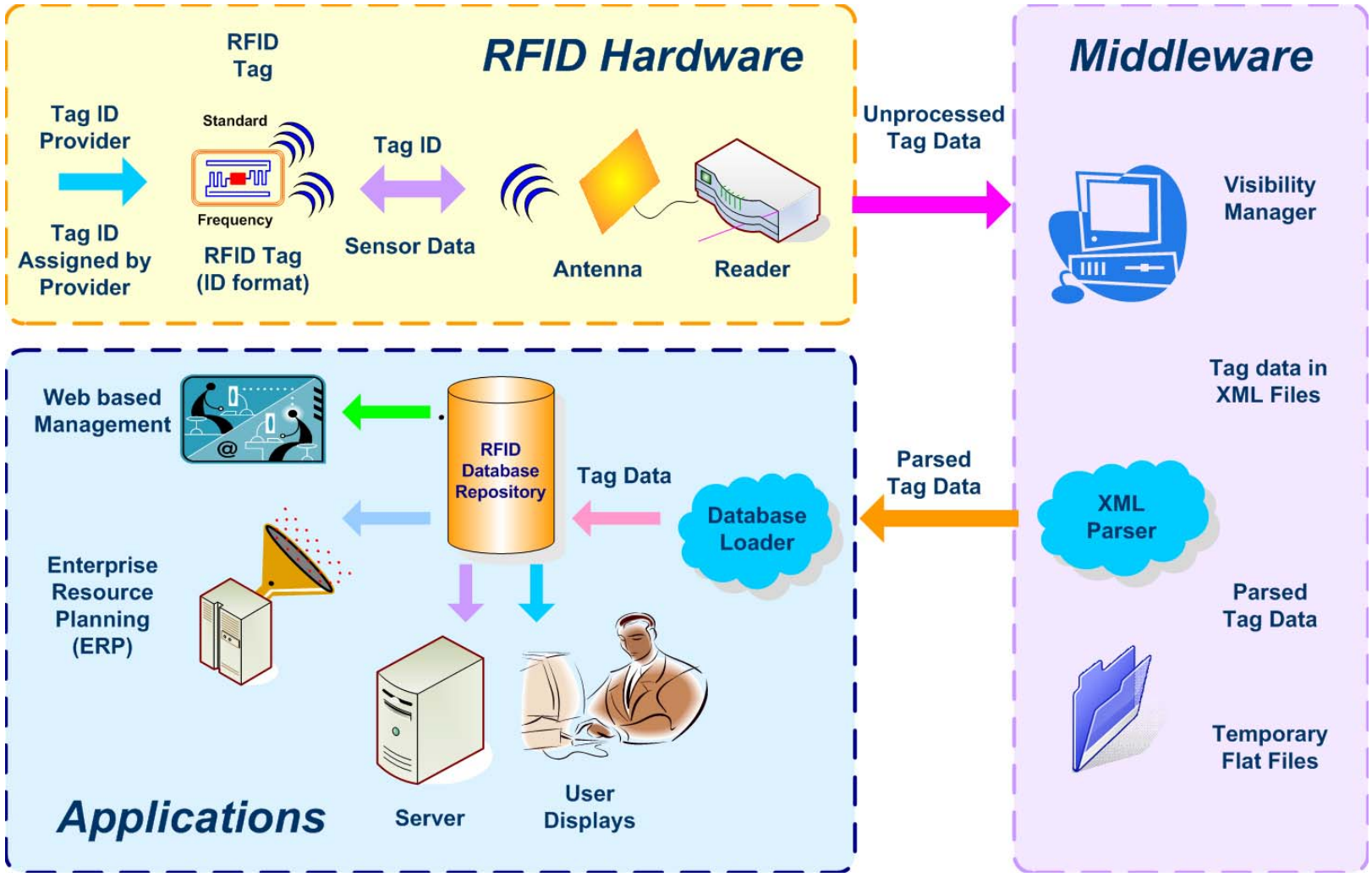
Smart Integrated Systems



Application Integration



Architecture



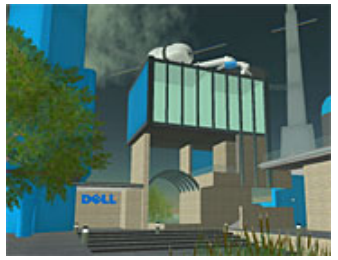
Real virtual and digital worlds

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

Wireless Connectivity

Source: University of Tokyo -Virtual-reality system

Real virtual and digital worlds



- Connecting real, virtual and digital worlds
- The challenge:
  - Linking smart wireless identifiable devices and RFID data with virtual worlds software programs
- Transfer positions of real persons and real things into the virtual world.
- Enable the smart wireless devices to trigger actions in the real world.

“Connecting Consumers Virtual Lives with Their Real World Needs”

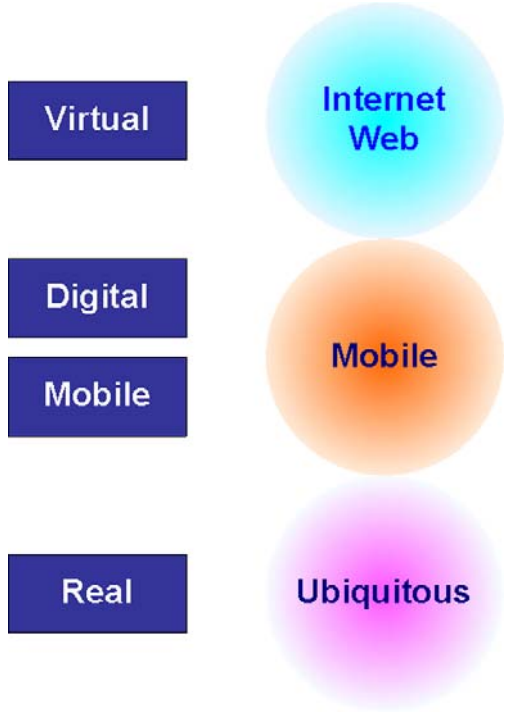
“Connecting virtual reality with real world commerce"

Residents can go to the virtual factory, customize their Dell and purchase, and their PC arrives at their real-life door.

Source: Dell

Real virtual and digital worlds

- Physical world embedded with:
  - RFID, smart wireless identifiable devices, novel materials, processing units.
  - MEMS, NEMS, micro/nano robots, computational particles
  - Wired and wireless networks
- Ubiquitous smart/intelligent things/objects
  - Things capable of computing and communicating
  - Things able to be connected to everything
  - Smart things behaving with certain “intelligence”



Ubiquitous intelligence

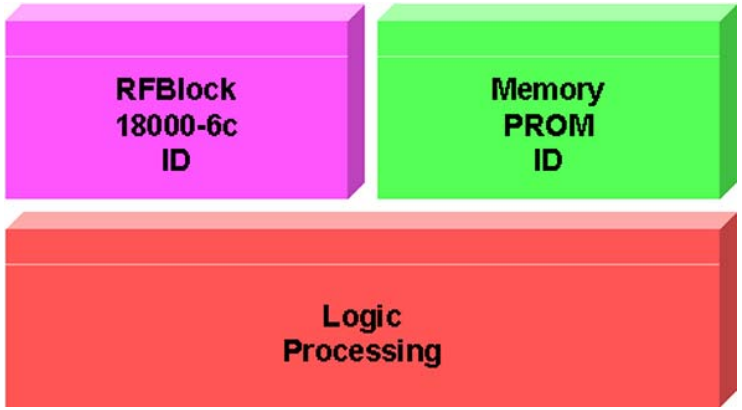
Being a ubiquitous existence
Residing in everyday objects, environments, etc.
Man-made and natural things

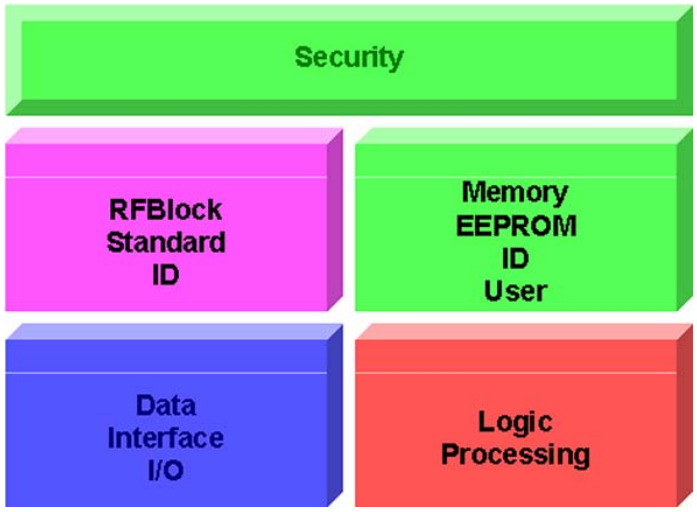
SINTEF

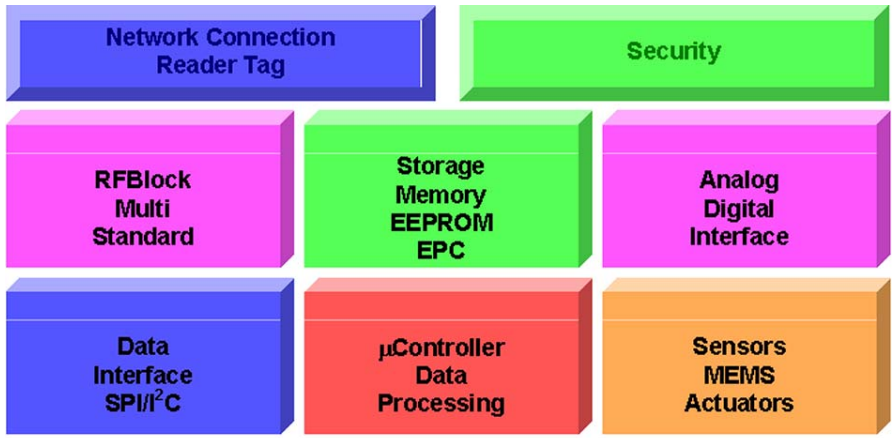
Wireless identifiable devices and RFID

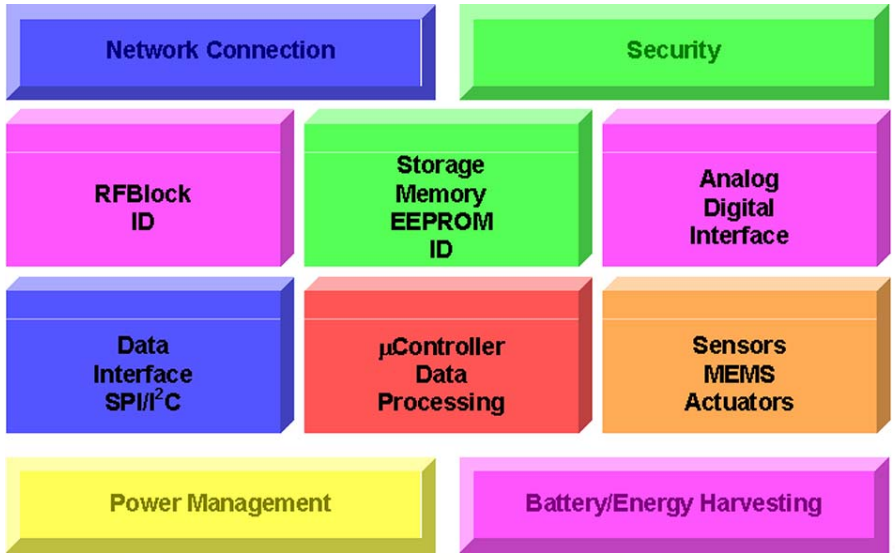
Application Layer	**Data interpretation** Application software, diagnosis
Algorithmic Layer	**Algorithms for data interpretation** Pattern matching, sensor data fusion, classification
Processing Layer	**Digital signal processing** Sensor data calibration, data correction, compression, feedback and control loop
Interfacing Layer	**Interface between sensor and signal processing unit** ADC, DAC, counter, pulse generator
Signal Conditioning Layer	**Signal conditioning** Amplification, buffering, actuator driving, analog electronics
Physical Layer	**Physical sensing or actuating mechanism** Transducer design and physics, device physics inside circuit, MEMS, sensors,
Technology Layer	**Circuits and sensor technology** MEMS, CMOS, nanotechnology, micro-optics

Wireless identifiable devices and RFID

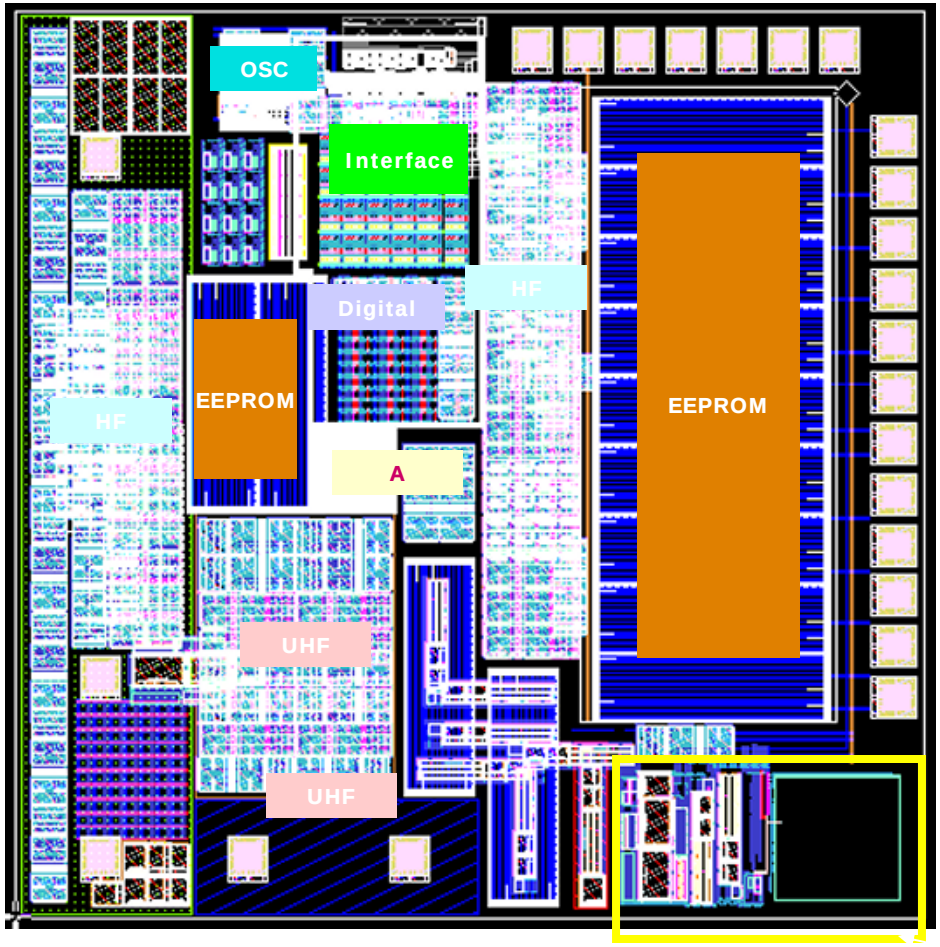








Multi standard and sensing RFID

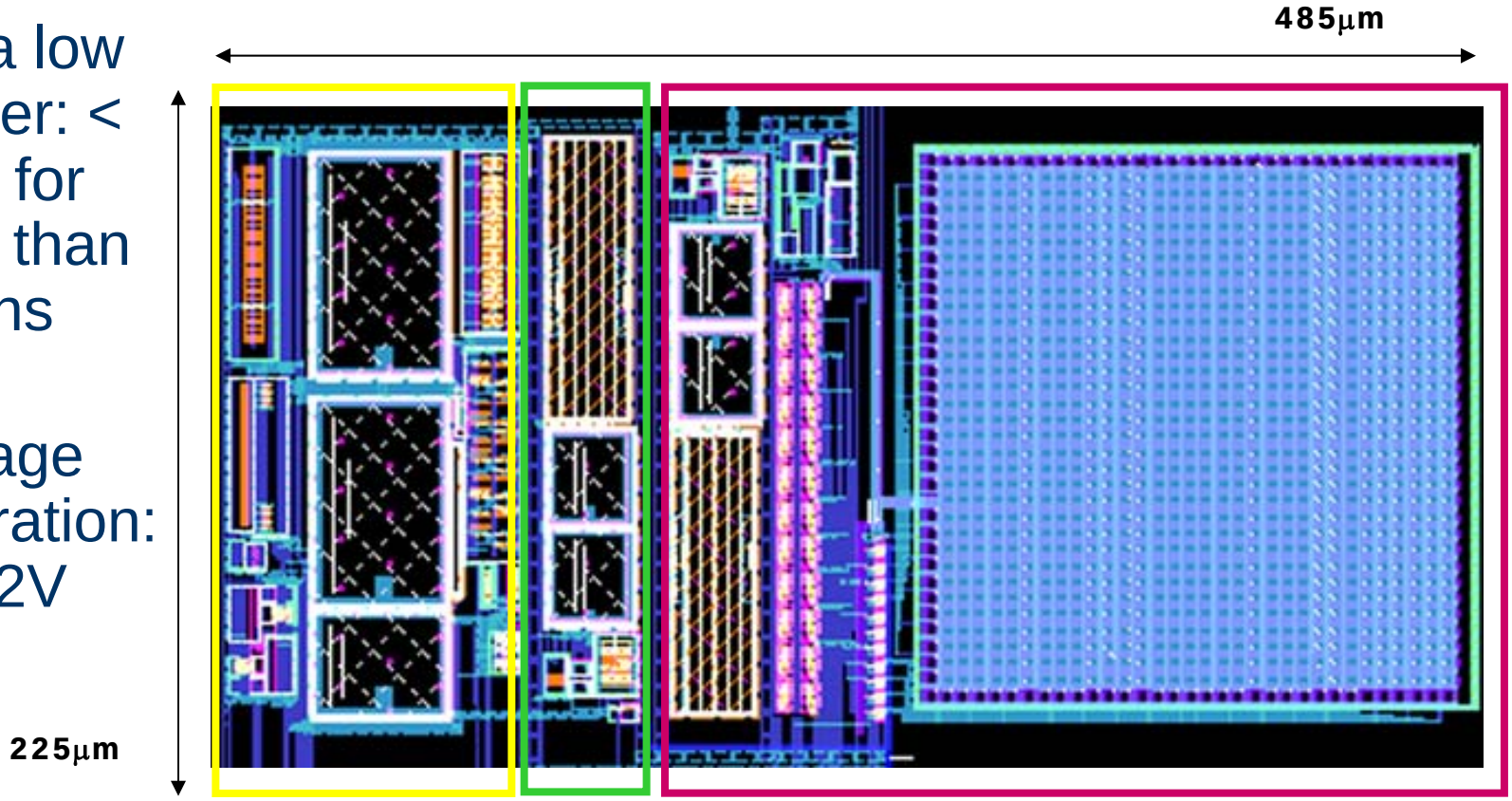


- 2 Standards
- HF/UHF
- Sensing

Mixed Signal Interface

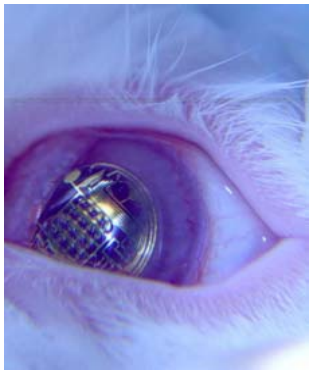
RFID Mixed Signal Sensor Interface

- Ultra low power: < 8μA for less than 400ns
- Low voltage operation: 1-1.2V

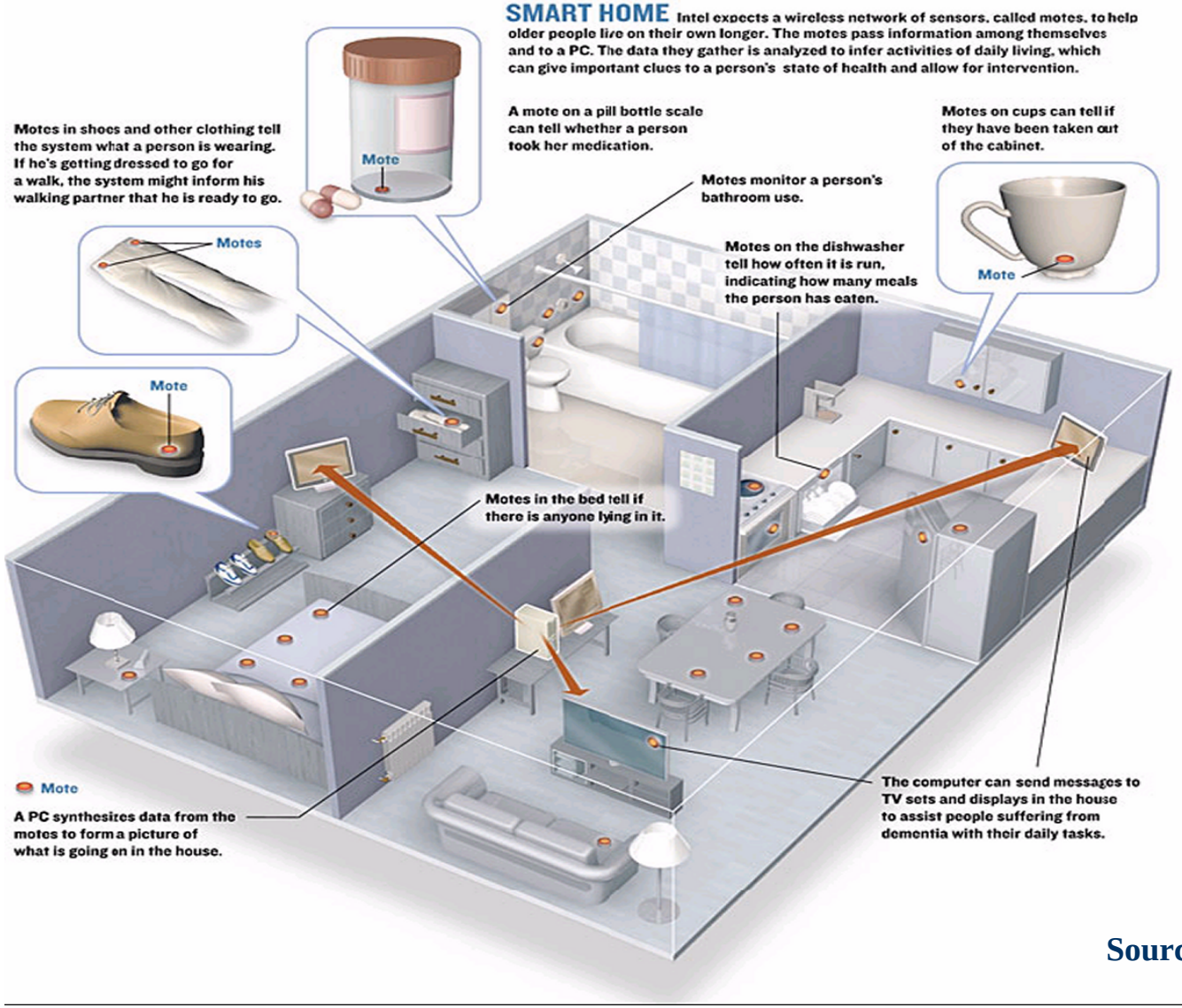


Wireless Smart System Applications

- Automotives
- Aeronautics
- Information and Telecommunication (ITC)
- Medical Technologies
- Logistics and object mobility and management



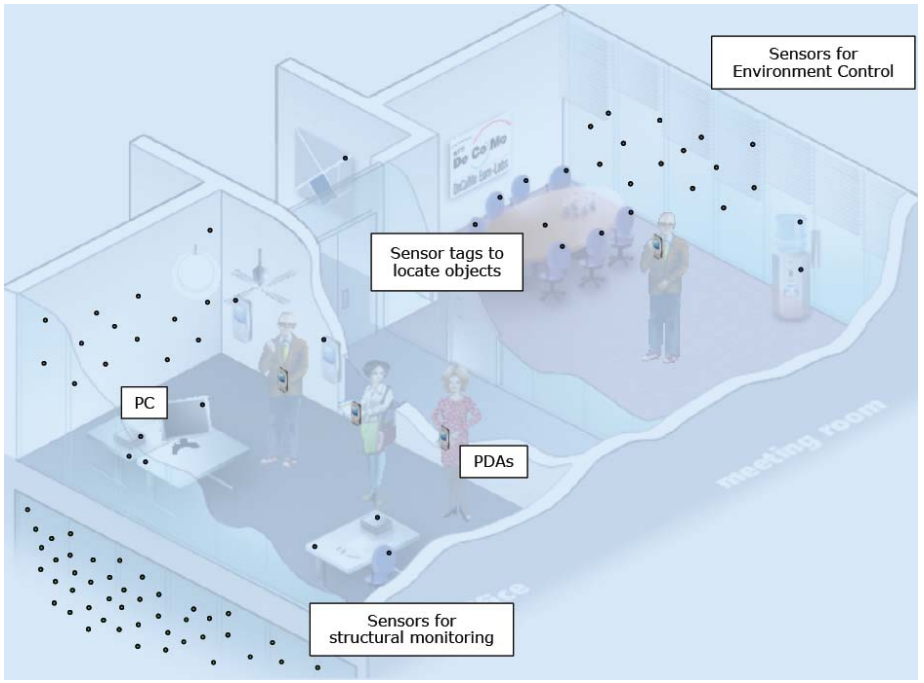
Real virtual and digital home



Source: Intel

RFID in the Office and Buildings

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



- Intelligent Buildings
- RFID Integration

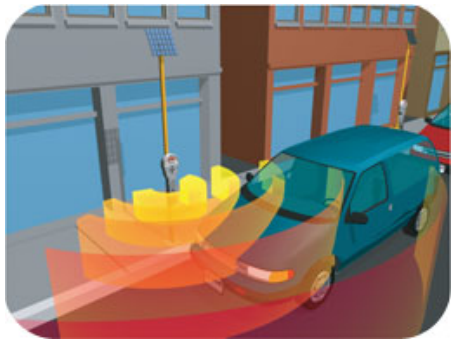
Real virtual and digital car

- RFID derived position among vehicles (V2V)
- RFID for communication between the vehicle and infrastructure (V2I and I2V),
- LANE LEVEL position

http://www.compexinc.com/

Vehicle Identification System

- **Determine if a vehicle registration has expired.**
- **Monitor traffic and vehicle speed in construction zones or other pertinent areas.**
- **Ticketing parking.**



WSN RFID in Oil and Gas Industry

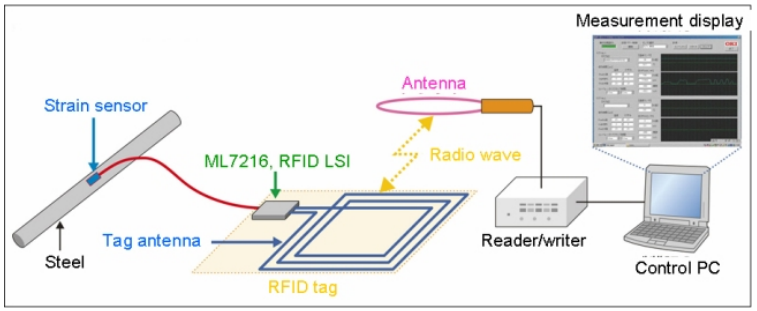
- Wireless instrumentation for
  - Installations in remote and hostile areas
  - Temporary installations
  - Ease of scalability
  - Redundant data collection for production optimization
- RFID and WSN for
  - Personnel
  - Equipment
  - Containers
  - Drilling tools
  - Monitoring
  - Maintenance

Source: StatoilHydro

Roads Bridges and RFID

- Strain Sensing System Using 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.
- Embedded RFID sensor that is integrated within the concrete
- Measurements at a strain resolution level of approximately 10X10-6.
- Using a thermistor, the system simultaneously measures temperature and can account for deformation caused by temperature.

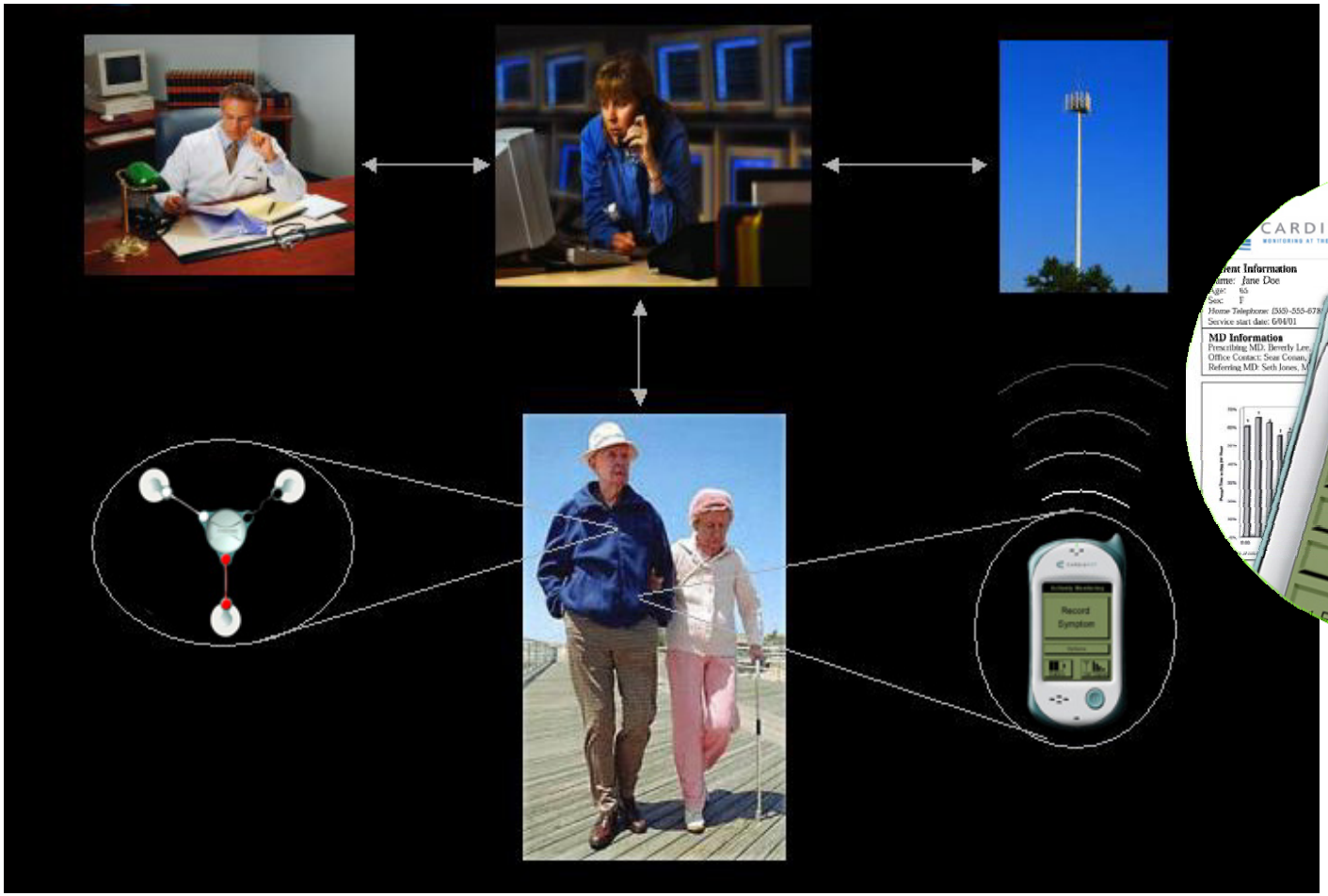
Measures the sensor (white taping area on steel) from RFID tag (in blue) with a portable reader/writer with control PC



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

Real virtual and digital healthcare

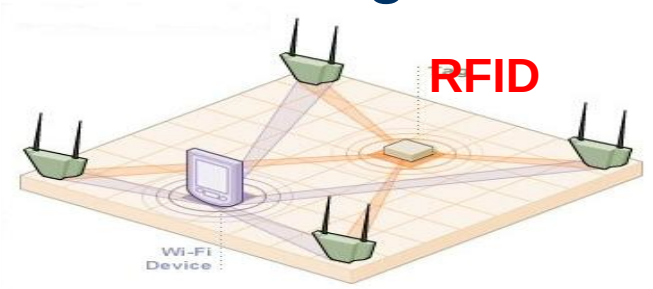
- Mobile cardiac telemetry monitoring platform
- 24/7/365 patient freedom to go anywhere at anytime



Source: CARDIONET

Real Time Location Systems

- Intelligent long range active RFID systems to identify, locate and track assets at a distance of up to 100m and to deliver superior real time visibility in dynamic, demanding environments.
- Long range (100m) RFID tag not with read/write capability, and 360° visibility of wireless regardless of tag orientation.
- Features:
  - Sensor location layout map
  - Planned number of readers and access point antennas
  - Placement of active RFID Tags on the assets.



Distributed RFID and Wireless Smart Sensor Systems

- RFID Sensors
- Wireless communication
- Electronics and Systems Integration
- Information Technologies
- Systems Engineering,
- Maintenance technologies

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