Open Wireless Architecture (OWA)

- OSI layer 1 & OSI layer 2 define the wireless technology
- For these two layers the 5G mobile network is likely to be based on Open Wireless Architecture (OWA)
- Physical layer + Data link layer = OWA

Network Layer

- All mobile networks will use mobile IP
- Each mobile terminal will be FA (Foreign Agent)
- A mobile can be attached to several mobiles or wireless networks at the same time
- The fixed IPv6 will be implemented in the mobile phones
- Separation of network layer into two sub-layers:

(i) Lower network layer (for each interface)
(ii) Upper network layer (for the mobile terminal)

Open Transport Protocol (OTP)

- Wireless network differs from wired network regarding the transport layer
- In all TCP versions the assumption is that lost segments are due to network congestion
- In wireless, the loss is due to higher bit error ratio in the radio interface
- 5G mobile terminals have transport layer that is possible to be downloaded & installed – Open Transport Protocol (OTP)
- Transport layer + Session layer = OTP

Application (service) Layer

- Provides intelligent QoS (Quality of Service) management over variety of networks
- Provides possibility for service quality testing & storage of measurement information in information database in the mobile terminal
- Select the best wireless connection for given services
- QoS parameters, such as, delay, losses, BW, reliability, will be stored in DB of 5G mobile
- Presentation layer + Application layer = Application

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Hardware & Software of 5G

➢ 5G Hardware:
- Uses UWB (Ultra Wide Band) networks with higher BW at low energy levels
- BW is of 4000 Mbps, which is 400 times faster than today's wireless networks
- Uses smart antenna
- Uses CDMA (Code Division Multiple Access)

➢ 5G Software:
- 5G will be single unified standard of different wireless networks, including LAN technologies, LAN/WAN, WWWW- World Wide Wireless Web, unified IP & seamless combination of broadband
- Software defined radio, encryption, flexibility, Anti-Virus

Features of 5G

- High resolution for crazy cell phone users
- Bi-directional large BW
- Less traffic
- 25 Mbps connectivity speed
- Enhanced & available connectivity just about the world
- Uploading & Downloading speed of 5G touching the peak (up to 1 Gbps)
- Better & fast solution
- High quality service based on policy to avoid error
- Support virtual private networks
- More attractive & effective
- Provides subscriber supervision tools for fast action

Conclusion

- 3G- Operator Centric,

  4G- Service Centric whereas

  5G- User Centric
- We have proposed 5G wireless concept designed as an open platform on different layers
- The new coming 5G technology will be available in the market at affordable rates, high peak future & much reliability than preceding technologies

THANK YOU!!!!!

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RFID Tagging in the physical world, Sensor Networks & Embedded Systems

Outline

- Introduction
- RFID Tagging in the Physical World
- Sensors and Sensor Networks
- Micro Sensing, Actuation & MEMS
- Embedded Systems and Real-time Systems
- Control Systems (For Physical World Tasks)
- Robots

Introduction

- To enable Smart (Physical) Environments, devices should:
  - Spread more into the physical environment, becoming part of more user activities in physical environment
  - Be cheap to operate: autonomous energy etc
  - Be low maintenance: automatic
  - Be able to interact with physical environment context
  - And also be small enough so as to …
  - Be able to be encapsulated and embedded
  - Be cheap to manufacture

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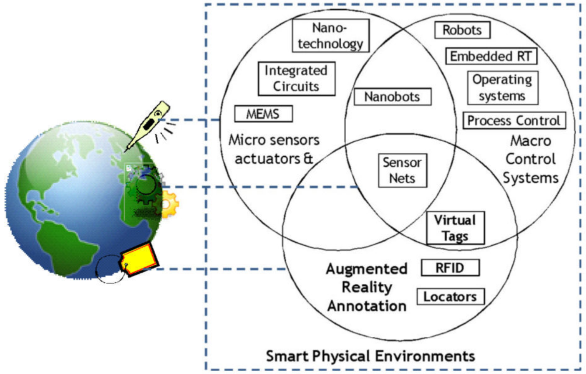
Introduction

- **Key Enablers of Smart Computing**



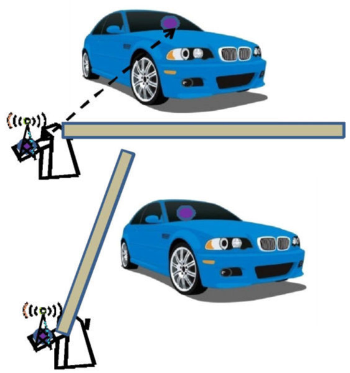
Tagging the Physical World

- Physical tags(Digital Tags) - are networked electronic devices with an identity.
- e.g. RFID (Radio Frequency Identifier) tag
- When tags are attached to or linked to physical objects, they provide a way to audit physical spaces
- **Motivation for the use of physical world tags**
  - To support context-based querying and tracking of physical world objects.
  - mapping physical world objects into computer artefact objects for more conveniently access

Tagging the Physical World

- **Tagging: Applications**
- Locate items
- Retrieve annotations associated with physical objects (augmented reality)
- Security
- Tracking
- Automated Routing: of physical objects
- Automated Physical Access
- Google photos…what's so unique?
- GPS enabled fleet

Tagging Apps: Automated Physical Access



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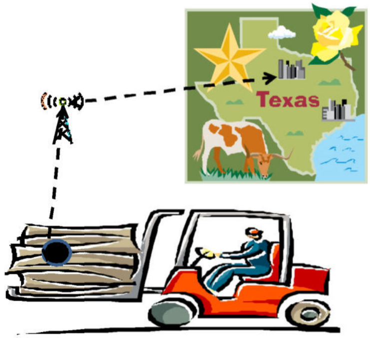
Tagging Applications: Asset Tracking



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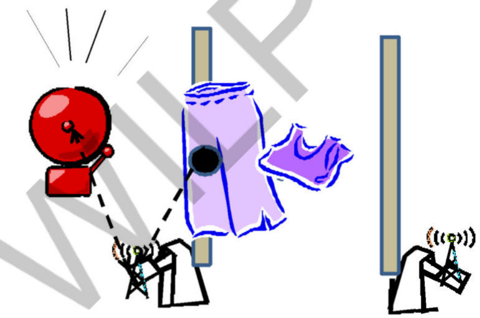
Tagging Applications: Security



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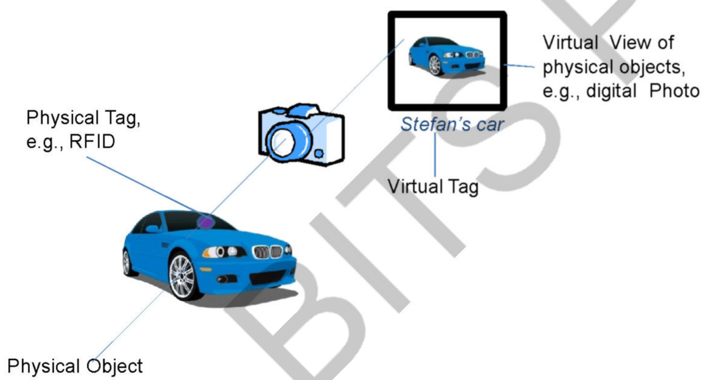
Physical versus Virtual Tags



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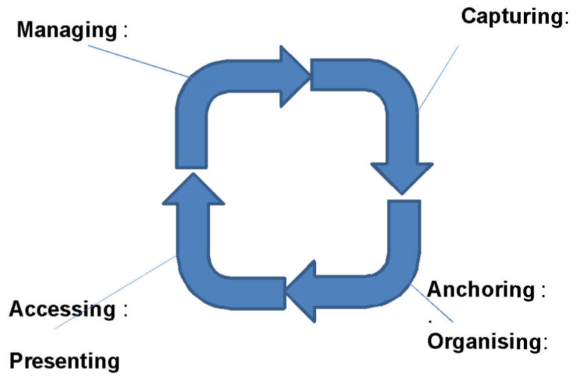
Life-cycle for Tagging Physical Objects



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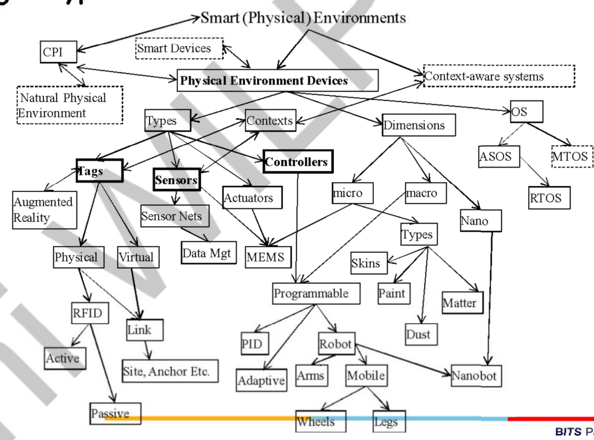
Tagging the Physical World

- **Life-Cycle for Tagging Physical Objects**
- **Capturing** a physical view or recording of physical objects or some object feature such as:
  - moving or placing a reader3 in range of a tag;
  - moving tags in range of readers;
- **Identifying** physical objects
  - detecting a preassigned object IDs. looking up which object has that ID
  - assigning an ID to a physical view of the object
- **Anchoring** or relating objects:
  - defining the attributes and relationship of objects with respect to a physical and virtual view.
- **Organization** or structuring
- **Presentation**:
- **Management**:
  - managing the annotation processes and data including, creating editing, removing, recycling

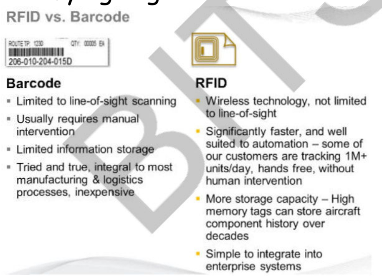
Tagging the Physical World

- **Tags: Types and Characteristics**
-



Tagging the Physical World

- **RFID Tags**
- tags can be attached to objects to enable identification of objects in the world over a wireless link.
- it **does not require a line of sight** and **manual orientation** to read the identifying tag



RFID applications

- Automatically tag, interrogate and track rental cars, luggage, mail packages and hospital patients
- Mobile readers embedded in phones to support quicker no touch access to pay for local goods and to access local resources e.g. hotel rooms
- Keep track of LIVE stock, Track pets
- Medicine history of patient…speed up diagnostic
- Monitor Expiry date of items in fridge
- Automatic calculation of total amount of products added to cart

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RFID Tags

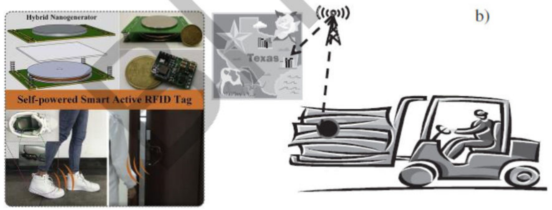
- RFID chips often operate in a promiscuous mode:
- reply to a **generic scan** rather than wait for a reader to provide an activation code – authentication
- RFID tags may be classified into
- whether or not they have their own energy supply – ***Active tags***
- whether or not they have they have energy supply for the reader – ***Passive Tags***

RFID Tags

- RFID chips often operate in a promiscuous mode:
- reply to a **generic scan** rather than wait for a reader to provide an activation code – authentication
- RFID tags may be classified into:
- whether or not they have their own energy supply – ***Active Tags***
- whether or not they have they have energy supply for the reader – ***Passive Tags***
- Active tags are more expensive and require more maintenance but have a longer range compared to passive tags.

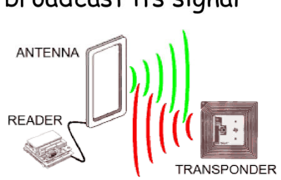
Active RFID Tags

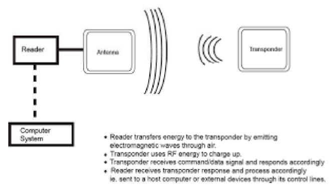
- Active RFID tags used on large, more expensive assets.
- Typically operate at 0.455, 2.45 or 5.8 GHz frequencies
- Have a read range of 20 M to 100 M, cost 10 to 50 USD (in 2005)
- Complex active tags could also incorporate sensors
- 2 types of active tags: **Transponders** and **Beacons**



Active RFID Tags

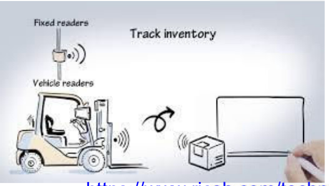
- **Transponders** and **Beacons**
- Active transponders are woken up when they receive a signal from a reader.
  - e.g. Toll payment collection, checkpoint control
- The transponder then broadcasts its unique ID to the reader.
- Transponders conserve battery life by having the tag broadcast its signal

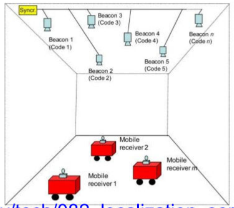




Active RFID Tags

- **Transponders** and **Beacons**
- Beacons are used in a location-based systems where the precise location of an asset needs to be tracked within a region .
- Longer range location-based systems could utilize GPS or mobile phone trilateration.
- A beacon emits a signal with its unique identifier at predetermined intervals.
- The beacon's signal is picked up by at least three reader
- antennas positioned around the perimeter of the area where assets are being tracked

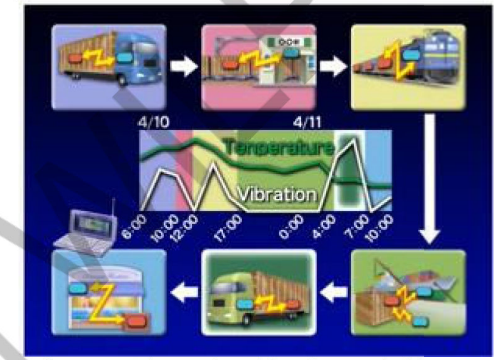




https://www.ricoh.com/technology/tech/082_localization_service

Active RFID Tags

- RFID Tags Classification
-



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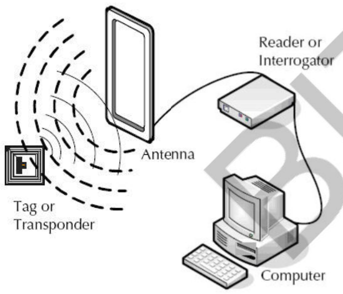
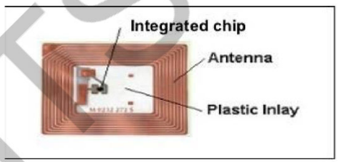
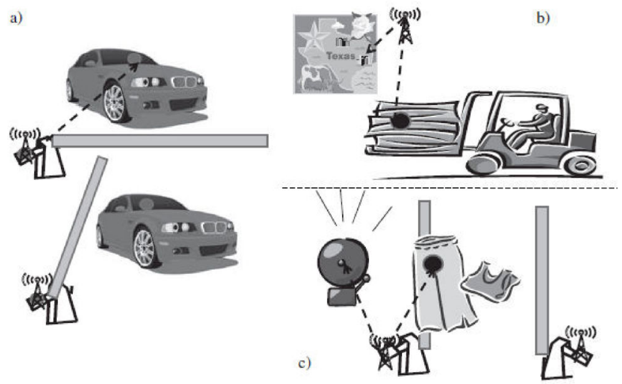
Active RFID Tags

- A typical RFID system consists of two main components:
- The **tag** itself and a **reader** that scans the tag for its ID
- Also contains additional computation, data storage and communication facilities





Active RFID Tags

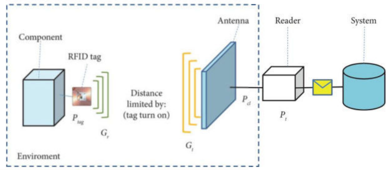


Transponders vs Beacons

Beacons	Transponders
• Beacons are used in Real-Time Location Systems (RTLS) …used in distribution yard along a transport route • Longer range RTLS could utilise GPS or mobile phone GSM trilateration • In RTLS, a beacon emits a signal with its unique identifier at pre-set intervals (every 3 secs to once per day)	• Active transponders are woken up when they receive a signal from a reader. • Transponders conserve battery life • Important application of active transponders is in toll payment collection, checkpoint control and other systems

Passive RFID Tags

- Passive RFID tags contain no power source and no active transmitter.
- power to transmit their information, typically between 10 mW and 1 mW, comes from the reader.
- They are lower maintenance and much shorter (read access) range than active tags, typically from a few cm to 10 m.
- A passive RFID transponder consists of a microchip attached to an antenna



Passive RFID Tags

Passive tags can operate at 3 frequency ranges:

- low frequencies (124 kHz, 125 kHz or 135 kHz),
- high frequency (13.56 MHz) and
- ultra high frequencies (UHF: 860 MHz to 960 MHz).

Passive RFID Tags

Low Frequency (LF) RIFD

- used in access control, livestock tracking, and other applications where a short read range is acceptable.

High Frequency (HF) RFID

- **used in** electronic ticketing and payment and data transfer
- smart card and proximity card payment and security systems also use HF technology

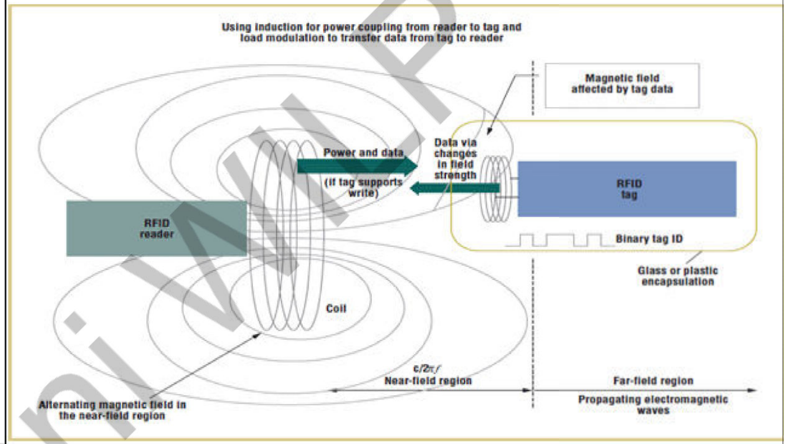
Ultra-High Frequency (UHF) RFID

- Commonly used in retail inventory tracking, pharmaceutical anti-counterfeiting, and other applications where large volumes of tags are required

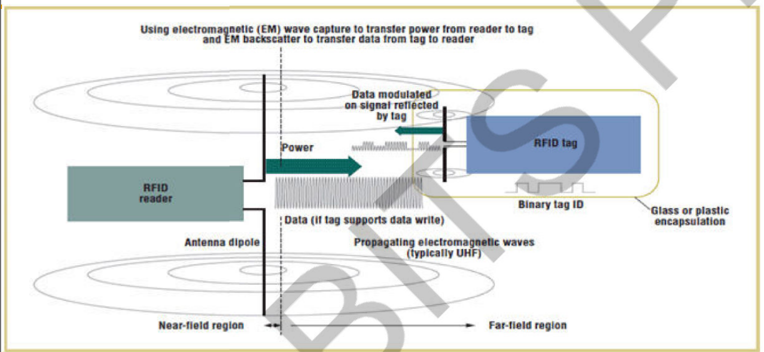
Passive Tags: Near Field

- Passive RFID interaction based upon electromagnetic induction.
- An RFID reader passes a large alternating current through its electromagnetic coil (antenna), resulting in an alternating magnetic field in its locality.
- If a tag that incorporates a smaller coil is placed in this field, an alternating voltage will appear across the tag.
- This voltage can then be rectified and coupled to a capacitor which can then accumulate sufficient charge to power the tag chip.
- Similarly, the tag reader can then use that energy to vary the magnetic field through its antenna to send a signal containing the tag ID to the reader antenna.

Passive Tags: Near Field

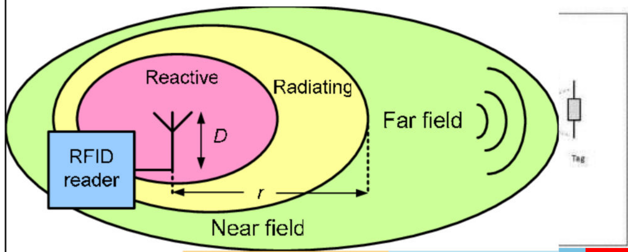


Passive Tags: Far Field



Passive Tags: Far Field

- In the far field technique, the tag captures EM waves transmitted from the dipole antenna which is attached to the reader.
- The small dipole antenna receives this energy in the form of alternating potential difference that appears across the arms of the dipole.



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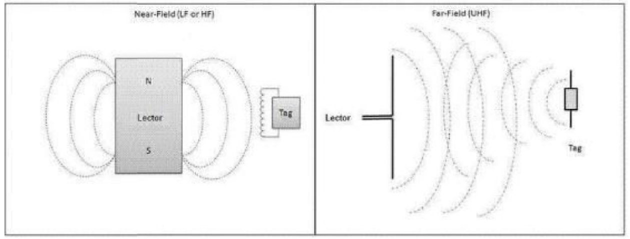


Sensors and Sensor Networks

- ***What are Sensors?***
- Type of transducer that converts some physical phenomenon such as heat, light, sound into electrical signals.
- Sensors often act as an enabler.
- Wireless sensors
- Sensors can be networked – sensor nets

Sensors can be used to:

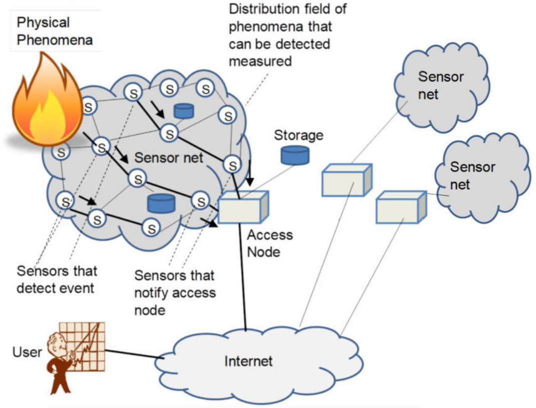
- Instrument and monitor environments
- Track assets through time and space with respect to some workflow or process;
- Detect changes in the environment defined to be of significance that humans are unable or are put at risk to perceive; Coal mines, chemical/nuclear factories
- Control a system with respect to the environment within a defined range of changes;
- Adapt services to improve their utility

Sensors and Sensor Networks

- Sensors like RFID tags are networked.
- The basic architecture is similar:
- sensors can act as data generators,
- intermediate or services nodes receive, post process and store data, possibly remotely.
- Tags just generate a fixed electrical signal, sensor data may change because it is the output from a transducer that converts varying physical phenomena into varying signals.
- Sensors may range in scale from nano sensors to macro sensors such as a windsock used to indicate the wind direction.

Overview of Sensor Net Components and Processes

- The main components of a typical sensor network system



Overview of Sensor Net Components and Processes

- Main components of a sensor network system are networked sensors nodes serviced by sensor access node.
- Sensors as being of three types of node:
  - *common nodes responsible for collecting data*
  - *sink nodes – receive, store, process and aggregate data from common nodes*
  - *gateway (access) - connect sink nodes to external entities*
- Some sensors in the network can act as sink nodes within the network in addition to the access node.
- Concepts of sensor node & sensor net can be ambiguous:
  - A sensor can act as a node in a network of sensors versus there is a special sensor network server often called a sensor (access) node

Sensor Net: Functions

- The main functions of sensor networks can be layered in a protocol stack according to:
  - physical network characteristics,
  - data network characteristics
  - data processing and sensor choreography
- Use small network protocol stack for sensor nets
- Other conceptual protocol layered stacks could also be used instead to model sensor operation

Sensor Net: Functions

Data processing	Collaborative processing	Event definition & processing	Data discovery
	Data storage	In -situ processing	Data uncertainty
Internetwork	Routing Intra vs. inter node	Addressing	
Sensor to Network	Sensor distribution & density	RF, Optical transmission characteristics	Physical environment characteristics
Sensor Electronics	DSP	Power management	

Sensor Network Protocol Stack

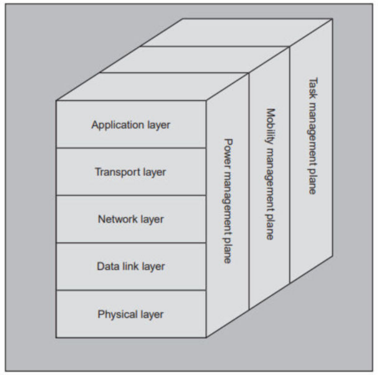
- 

Fig1. Sensor Network Protocol Stack

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Sensor Network Protocol Stack

- **Physical layer:**
- Responsible for frequency selection, carrier frequency generation, signal detection, modulation and data encryption.
- The 915 MHz ISM band has been widely suggested. 'Ultra wideband (UWB)
- Modulation depends on transceiver and hardware design constraints
- Aim for simplicity low power consumption, and low cost per unit

Sensor Network Protocol Stack

- **Data Link Layer:**
- The data link layer is responsible for multiplexing data streams, data frame detection, medium access and error control.
- It ensures reliable point-to-point and point-to-multipoint connections in a communication.
- The MAC must establish communication links for data transfer in wireless multihop self organizing sensor network.
- The main features of MAC are periodic listen and sleep, collision and over hearing avoidance, and message passing.

Sensor Network Protocol Stack

- **Network Layer:**
- The network layer takes care of routing the data supplied by the transport layer.
- Power efficiency is always an important consideration: Energy efficient routes are found like the route with maximum available power (PA); route with minimum energy consumption (ME); route with minimum hops (MH)
- Sensor networks are mostly data centric: The data is given only to the node which will perform task.

Sensor Network Protocol Stack

- **Transport layer :**

The transport layer helps to maintain the flow of data if sensor network application requires it.

It is needed when a system is planned to be accessed through internet or other external networks.

- TCP(2 parts) : One connects sensor network to the other network like internet and the other connects the sink node to sensor nodes.

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Sensor Network Protocol Stack

- **Application Layer :**
- Depending on sensing tasks, different types of application software can be built and used on application layer.
- Three such protocols are 'Sensor management protocol (SMP)' 'Task assignment and data advertisement protocol (TADAP)', 'Sensor query and data dissemination protocol (SQDDP).
- SMP provides software operations needed to perform tasks such as introducing rules related to data aggregation, attribute-based naming, clustering sensor nodes; time synchronization of sensor nodes; moving sensor nodes, etc.

Power, Mobility and Task Management Planes :

When the power level of a sensor node is low, it broadcasts to its neighbors that it is low in power and cannot participate in routing messages. This is managed by power management plane.

The mobility management plane detects and registers movement of sensor nodes. The sensor nodes can keep track of who their neighbors are.

The task management plane balances and schedules sensing tasks given to a specific region. Not all sensor nodes perform sensing at same time.

Sensor Characteristics

- *Characteristics of the phenomena being sensed.*
- type of physical phenomenon sensed includes location, temperature, etc.
- *Variability*
- of the type of environment being sensed
- *Sensor physical characteristics, including power, mobility, and size*
- Passive sensors – Powered by reader
- Active sensors – Self powered
- Sensors may vary in size from nanometers and up
- Sensors may be anchored in

Sensor Characteristics

- *Functional complexity*
- Sensors have no autonomy and have simple functionality
  - convert some physical phenomena into data that is simply reported to human users
- Sensors can have more autonomy and can be preconfigured to automatically detect pre defined events.
- Sensors can be reconfigurable, self configurable and self optimising

Sensor Electronics

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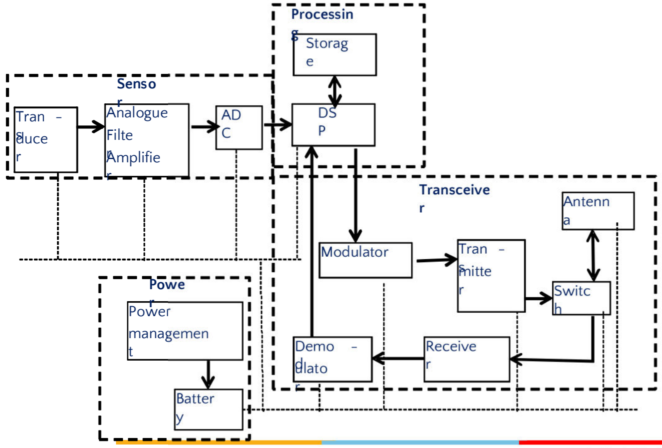


Challenges in design/deploying sensors

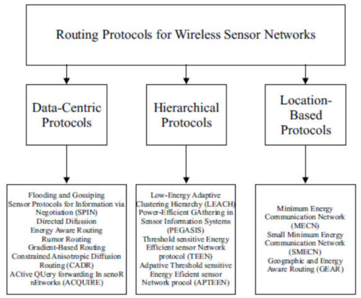
Challenges of a sensor net system	Design solutions
Sensor energy is a scarce resource for data transmission	Use a sensor net that deploys, low power, short range transmissions Network sensors into mesh networks and use multi hop transmissions Filter data in situ and transmit only filtered data
Limited memory and computation power in sensors	Harvest renewable energy from the environment and store
Dynamic and non deterministic spatial temporal distribution of events. May not be able to pre determine how to optimally deploy individual sensors	Use a sensor net to increase the sensor density around estimated signal source positions when deterministic; Design sensor distributions to be reconfigurable, self organising, to be mobile Support variable sampling and support bursty data collection
Sensor failure is common due to a lack of power, physical damage, active (jamming) or passive environmental interference of the transceiver, access node or non optimal positioning	Use dense networks of low power sensors with redundant paths to route data through the network Use of counter measures and frequency shifts Locators and trackers are needed to locate (moving) sensors and can be used to position them
Multi hop sensor networks may have a dynamic topology. No global knowledge about structure of network may be known	Use specialised routing protocols to work over dynamic mesh topologies
Sensors can be too costly to update once deployed	Design sensors and sensor access nodes to be low maintenance. Support sensor redundancy
Sensors can generate huge quantities of data	Use in situ data processing both in the sensor and the sensor access node

Sensor Net Design: Positioning & Coverage

- Given: sensor field (either known sensor locations, or spatial density)
  - Where to add new nodes for max coverage?
  - How to move existing nodes for max coverage?
- Can Control
  - Area coverage
  - Detectability
  - Node coverage

Data Network: Addressing and Routing

- Nodes in any kind of distributed system may need to be uniquely addressable.
- In Distributed systems, the address of nodes makes use of the topological location of a node in the network.



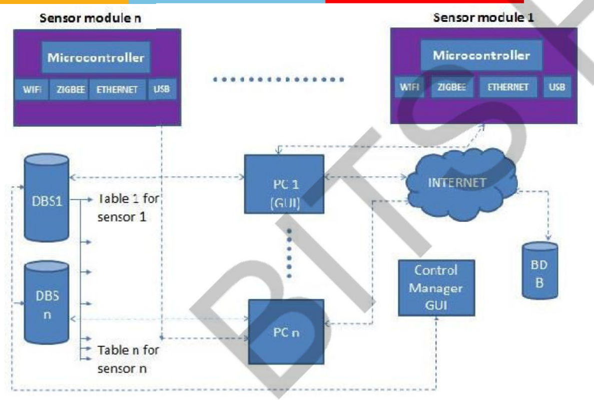
Data Network: Addressing and Routing

- **Routing Protocol Examples:**
- Sensor Protocols for Information via Negotiation (SPIN)
  - SPIN-BC: This protocol is designed for broadcast channels.
  - SPIN-PP: This protocol is designed for a point to point communication, i.e., hop-by-hop routing.
  - SPIN-EC: This protocol works similar to SPIN-PP, but with an energy heuristic added to it.
  - SPIN-RL: When a channel is lossy, a protocol called SPIN-RL is used where adjustments are added to the SPIN-PP protocol to account for the lossy channel.
- Rumor routing
- Minimum Cost Forwarding Algorithm (MCFA)
- Gradient-Based Routing
- Hierarchical Routing

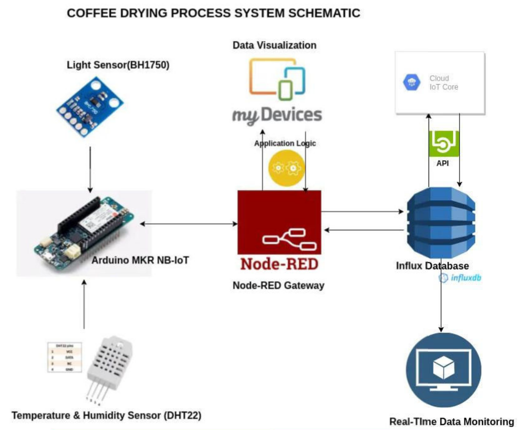
Sensor Database System

- A traditional centralized data storage approach could be used with many sensors generating data transactions that cause updates in a data warehouse.
- Data events extracted from sensors could be stored in a RDBMS server. Query processing takes place at data server nodes only
- Multiple data from RDBMS could be aggregated into a data warehouse system and SQL could be used to query sensor data identified using an attribute based addressing and routing scheme
- Data processing such as data aggregation can be more expediently performed in the network, at or near the data source sensor nodes
- Distributed DB techniques could be used

Sensor Database System



Sensor Database System



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Micro Actuation and Sensing: MEMS

- Micron to Millimetre scale electronic devices
- Two functions: Micro-Actuators or Micro-Sensors (Transducers converting one form of energy into another)
- MEMS actuators convert an electrical signal into physical phenomena to move or control mechanisms such as motors, pneumatic actuators, hydraulic pistons and relay
- MEMS sensors convert temperature, humidity and pressure into an electrical signal
- Smart Surfaces, Skin, Paint, Matter and Dust
- Downsizing to Nanotechnology and Quantum Devices

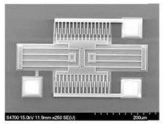
Trend: Miniaturisation

- Electronic components become smaller, faster, cheaper to fabricate, lower power & lower maintenance, they can be more easily deployed on a massive and pervasive scale
- *MicroElectro Mechanical Systems* (MEMS) are based upon IC Chip design
- Possibilities for miniaturization extend into all aspects of life, & potential for embedding computing & comms technology quite literally everywhere is becoming a reality
- IT as an invisible component in everyone's surroundings
- Extending the Internet deep into the physical environment

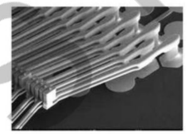
Sensera

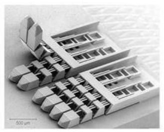
Corporate Headquarters: 200 Turnpike Road, Chelmsford, MA
Microfabrication Facility: 15 Presidential Way, Woburn, MA 01801
www.sensera.com

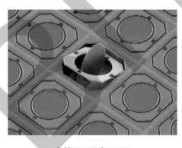
Examples of MEMS Devices

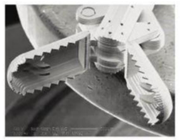

Resonator


Accelerometer


Probe

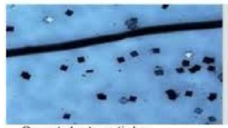

Robotic Hands


Micro mirrors


Biopsy forceps

Trend: Miniaturisation

- **Smart Dust: MEMS**
  - MEMS can be sprayed into physical environment
  - E.g., Smart Dust project (Pister, UC,Berkely)
- **Smart Skins: MEMS**
  - MEMS can be permanently attached to some fixed substrate forming
    - smart surfaces
    - smart skin
  - E.g. Paint that is able to sense vibrations
  - Organic Displays


Smart dust particles


smartdust on a finger

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Embedded Systems: Introduction

- Is a component in a larger system
- Is programmable
- Performs a single, dedicated task
- May or may not be visible as a computer to a user of that system
- May or may not have a visible control interface
- May be local or remote
- fixed or mobile

Embedded System Characteristics (Embedded vs. MTOS Systems)

- Traditionally, embedded systems differ from MTOS systems
- OS of Embedded systems differ vs. MTOS system
  1. Specialised to **single task** enactment (APP SPECIFIC OS - ASOS)
  2. Actions on physical world tasks are often scheduled with respect to **real-time** constraints (RTOS)
  3. Safety-criticality is considered more important
- Often have constraints concerning power consumption
- Often are designed to operate over a wide-range of physical environmental conditions compared to PC
- Often operate under moderate to severe real-time constraints
- System failures can have life-threatening consequences

Embedded Systems: Hardware

- Microprocessors
- Microcontroller
- FPGA (Field Programmable Gate Arrays)
- **Applications**
  - ✔Transport vehicles
  - ✔Robots used in manufacturing and for unmanned (robot) self steering vehicles
  - ✔ Modern cars network multiple embedded systems for antilock brake systems (ABS), cruise control, climate control, wing mirrors, locomotion and drive sensor data monitoring, etc.

Real-Time System (RTS)

- Any system in which the time at which the output is produced is significant.
  - The input corresponds to some moment in the physical world and the output has to relate to that same moment.
  - The lag from input time to output time must be very small for acceptable timeliness.
- RTS are those which must produce correct responses within a definite time limit.
- A real time system reads inputs from the plant and sends the control signals to the plant at times determined by plant operational considerations not times limited by the computer system

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Classification of RTSs based on Time Constraints

- **HARD REAL-TIME SYSTEM:**
- A system whose operation is degraded if results are not proceeded according to specified timing requirements.
- System response occur within a specified deadline. Failure to meet such a timing requirement can have catastrophic consequences.
- Systems where it is absolutely imperative that responses occur within the required deadline.
- Example: Flight control systems, automotive systems, robotics etc.

Classification of RTSs based on Time Constraints

- **SOFT REAL-TIME SYSTEMS:**
- A system whose operation is incorrect if results are not produced according to the timing constraints.
- The response times are important but not critical to the operation of the system .
- Systems where deadlines are important but which will still function correctly if deadlines are occasionally missed.
- Example: Banking system, multimedia etc.

Control Systems (for Physical World Tasks)

- Simply type of control
  - Activated only when defined thresholds are crossed
- e.g., a thermostat switches the heating on when the temperature falls below the lower threshold or switches the cooling on when it rises above the upper threshold
- Control Systems: Feedback Control
  - Feedback control uses continuous monitoring of some output using sensors and reacts to their changes in order to regulate the output
  - 2 basic kinds of feedback:
  - Negative feedback
  - Seeks to reduce some change in a system output or state
  - Based upon derivative of output
  - Which is then used to modify input to regulate output.
  - Several types of feedback control: Derivative, Proportional, Integral, PID
  - Positive feedback
  - Acts to amplify a system state or output

Programmable Controllers: Microcontrollers

- Hardware architecture of microcontrollers is much simpler than general purpose processor mother-boards in PCs?
- I/O control support can be simpler as there may not be any video screen output or keyboard input.
- Micro-controllers can range in complexity
- Originally, programmed in assembly language, later in C
- Control programs often developed in an emulator on a PC
- More recent microcontrollers can be integrated with on-chip debug circuitry accessed by an in-circuit emulator

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Main Robot Components

- Greek term – means self steering like Governor or pilot
- Robots consist of:
- End effectors or actuators
- Locomotion
- Drive
- Controller
- Sensor

Robots: Localisation

- Localisation is used to determine a robot's position in relation to its physical environment
- Localisation can be local or global
- Local localisation is often simpler in which a robot corrects its position in relation to its initial or other current reference location
- Global localisation is discussed more in context-aware systems part

Robots: Types

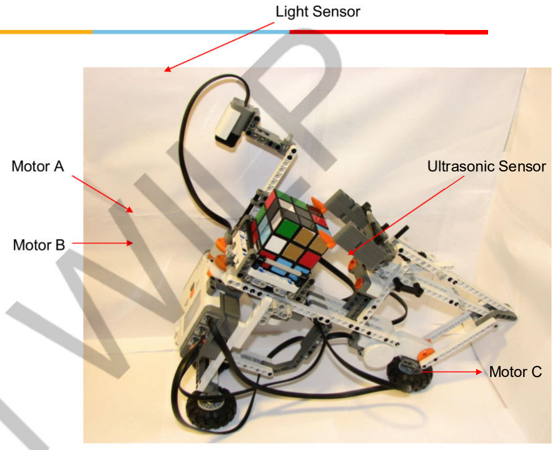
- **3 Main Types**
- Robot manipulator or robot arm
- Mobile robots
- Biologically inspired robots

Mobile Robots

- Mobile robots use various kinds of locomotion systems
- Simplest types of mobile robots to control
- In dynamic non-deterministic environments, control is more complicated
- A more complex, well-known & highly successful use of mobile robots was Mars Explorer Robots

Mobile Robots

- Need ways to navigate obstacles?
- Simple approach: use collision detection
- More complex approach: anticipate & avoid collisions
- Need environment models
- Need to re plan paths to reach goal destinations



Developing UbiCom Robot Applications

Task: robot manipulates a Rubik's Cube to its solved state

Goal: robot performs whole task or guides humans to do it

Design involves

- Design: of the robot mechanics
- Design: how and when the robot senses state of the world
- Planning algorithm: to link individual actions
- Overall architecture: to integrate different sub-tasks