Internet of Things (IoT)

see

CSE237A

Introduction to Embedded Computing

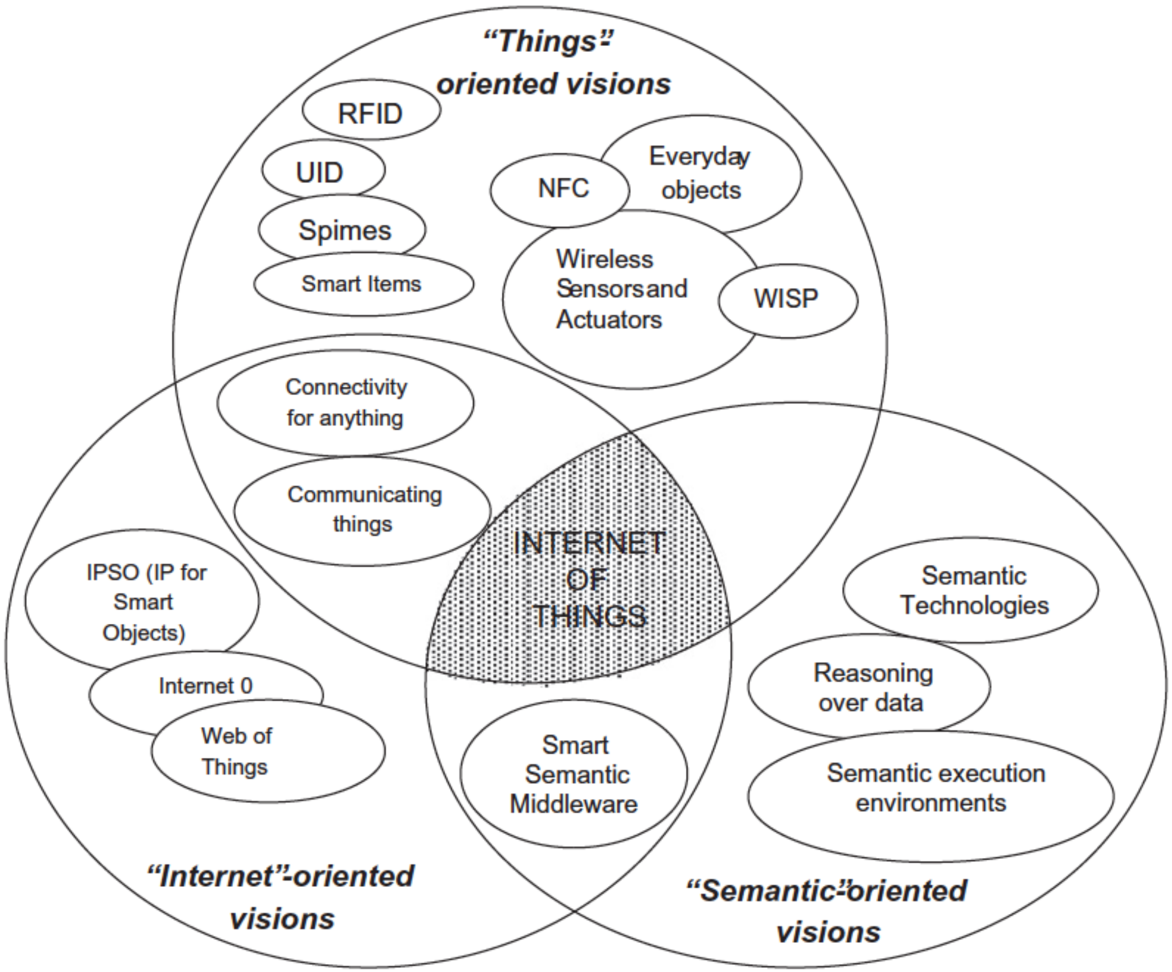
Outline

- Introduction to IoT
- Enabling technologies
- Open problems and future challenges
- Applications

What is IoT?

- A phenomenon which connects a variety of ***things***
  - Everything that has the ability to communicate

Connection of Multiple Visions



Source: Atzori et al. 2010

IoT Definitions

- The Internet of Things, also called The Internet of Objects, refers to a wireless network between objects, usually the network will be wireless and self-configuring, such as household appliances. **(Wikipedia)**

- The term "Internet of Things" has come to describe a number of technologies and research disciplines that enable the Internet to reach out into the real world of physical objects. **(IoT 2008)**

- "Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts". **(IoT in 2020)**

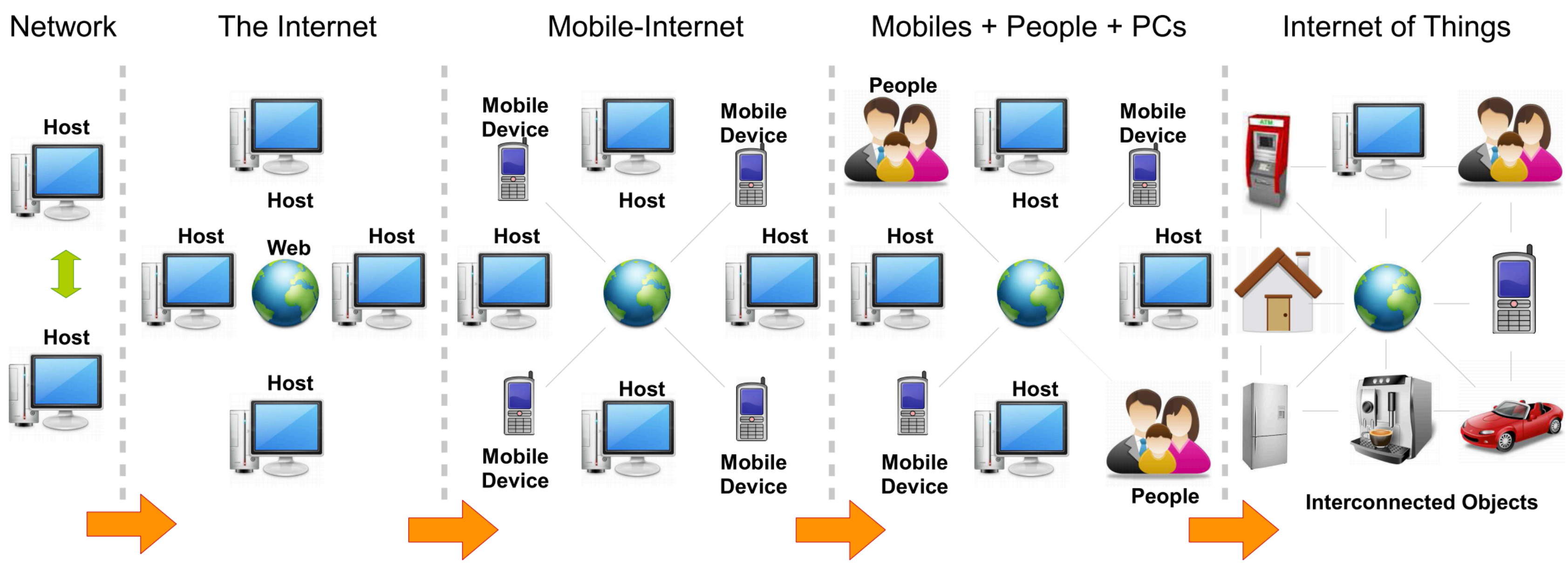
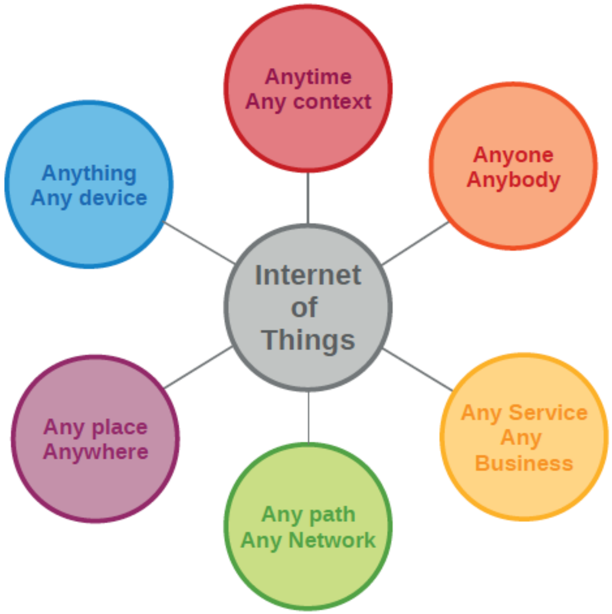
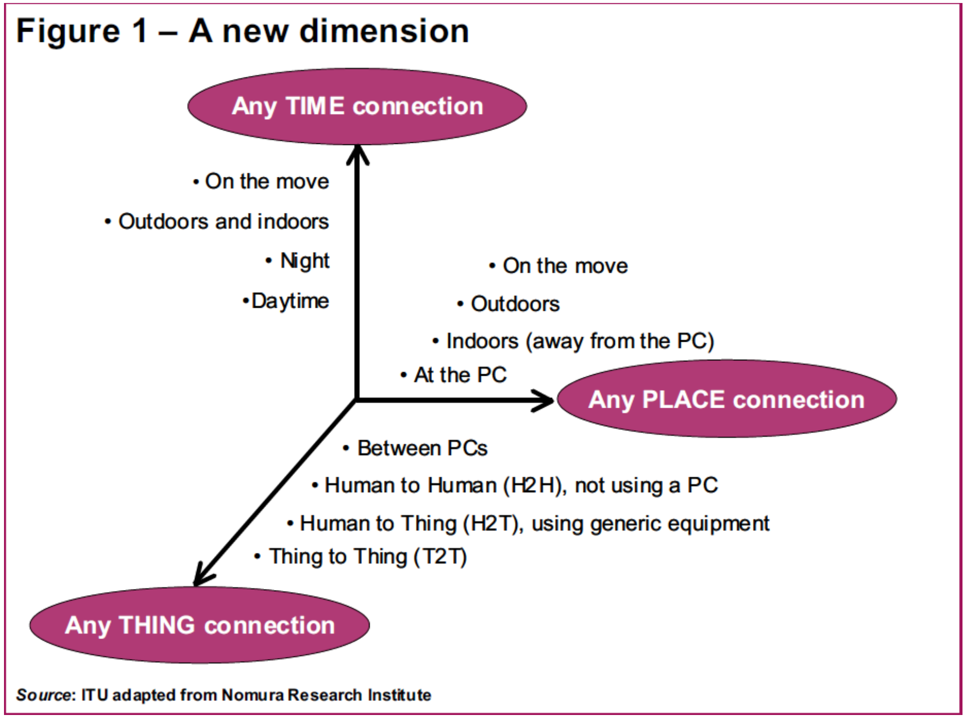


FIGURE 4. Evolution of the Internet in five phases. The evolution of Internet begins with connecting two computers together and then moved towards creating World Wide Web by connecting large number of computers together. The mobile-Internet emerged by connecting mobile devices to the Internet. Then, peoples' identities joined the Internet via social networks. Finally, it is moving towards Internet of Things by connecting every day objects to the Internet.

Any-X Point of View



Source: Perera et al. 2014

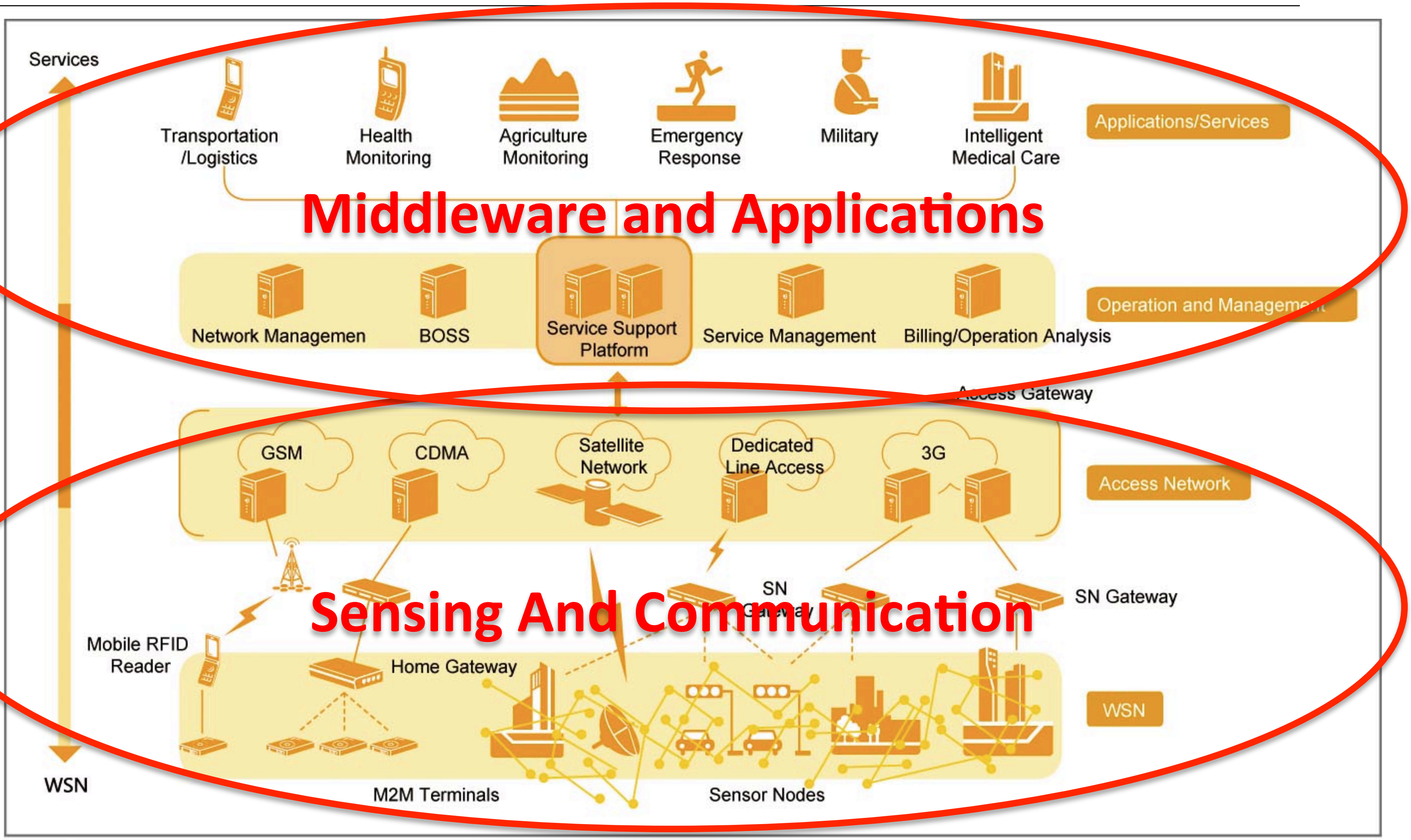


- The Internet of Things allows people and things to be connected Anytime, Anyplace, with Anything and Anyone, ideally using Any path/ network and Any service.

Characteristics of IoT

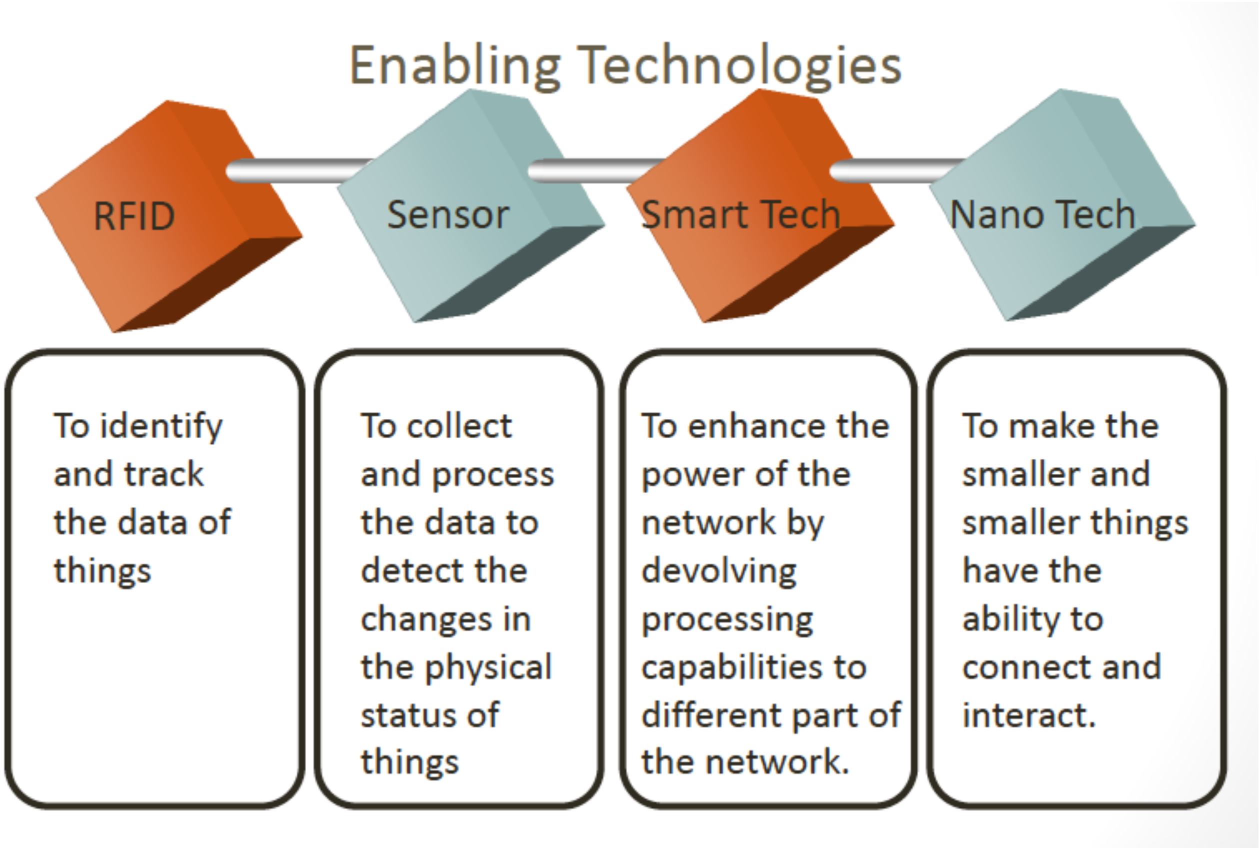
1. Intelligence
   - Knowledge extraction from the generated data
2. Architecture
   - A hybrid architecture supporting many others
3. Complex system
   - A diverse set of dynamically changing objects
4. Size considerations
   - Scalability
5. Time considerations
   - Billions of parallel and simultaneous events
6. Space considerations
   - Localization
7. Everything-as-a-service
   - Consuming resources as a service

IoT Layered Architecture



Source: ZTE

Networking and Communication

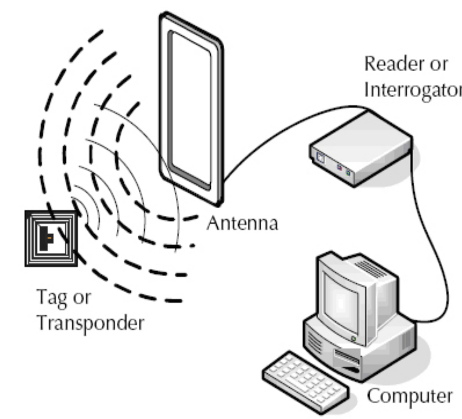


- RFID to smallest enabling technologies, such as chips, etc.

Source: Qian Zhang. Lecture notes. 2013

RFIDs

- The reduction in terms of size, weight, energy consumption, and cost of the radio takes us to a new era
  - This allows us to integrate radios in almost all objects and thus, to add the world ‘‘anything” to the above vision which leads to the IoT concept
- Composed of one or more readers and tags
- RFID tag is a small microchip attached to an antenna
- Can be seen as one of the main, smallest components of IoT, that collects data



Wireless Technologies

- Telecommunication systems
  - Initial/primary service: mobile voice telephony
  - Large coverage per access point (100s of meters – 10s of kilometers)
  - Low/moderate data rate (10s of kbit/s – 10s of Mbits/s)
  - Examples: GSM, UMTS, LTE
- WLAN
  - Initial service: Wireless Ethernet extension
  - Moderate coverage per access point (10s – 100s meters)
  - Moderate/high data rate (Mbits/s – 100s)
  - Examples: IEEE 802.11(a-g), Wimax

Source: Geert Heijenk. Mobile and Wireless Networking. Lecture Notes. 2014

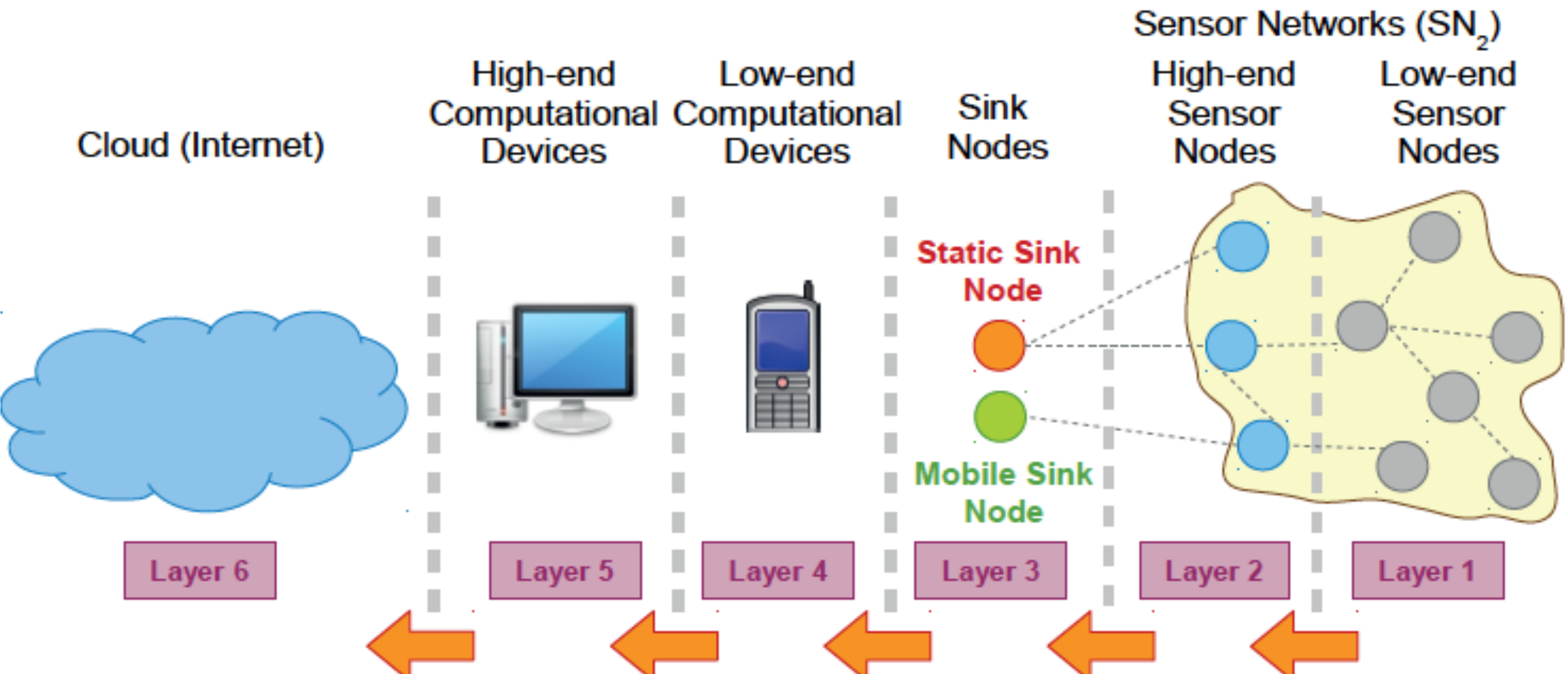
Wireless Technologies

- Short range:
  - Direct connection between devices – sensor networks
  - Typical low power usage
  - Examples: Bluetooth, Zigbee, Z-wave (house products)
- Other examples:
  - Satellite systems
    - Global coverage
    - Applications: audio/TV broadcast, positioning, personal communications
  - Broadcast systems
    - Satellite/terrestrial
    - Support for high speed mobiles
  - Fixed wireless access
    - Several technologies including DECT, WLAN, IEEE802.16, etc.

Source: Geert Heijenk. Mobile and Wireless Networking. Lecture Notes. 2014

Sensor Networks (SNs)

- Consist of a certain number (which can be very high) of sensing nodes (generally wireless) communicating in a wireless multi-hop fashion



Source: Perera et al. 2014

Sensor Networks (SNs)

- SNs generally exist without IoT but IoT cannot exist without SNs
- SNs have been designed, developed, and used for specific application purposes
  - Environmental monitoring, agriculture, medical care, event detection etc.
- For IoT purposes, SNs need to have a middleware addressing these issues:
  - Abstraction support, data fusion, resource constraints, dynamic topology, application knowledge, programming paradigm, adaptability, scalability, security, and QoS support

Example: Indoor Localization

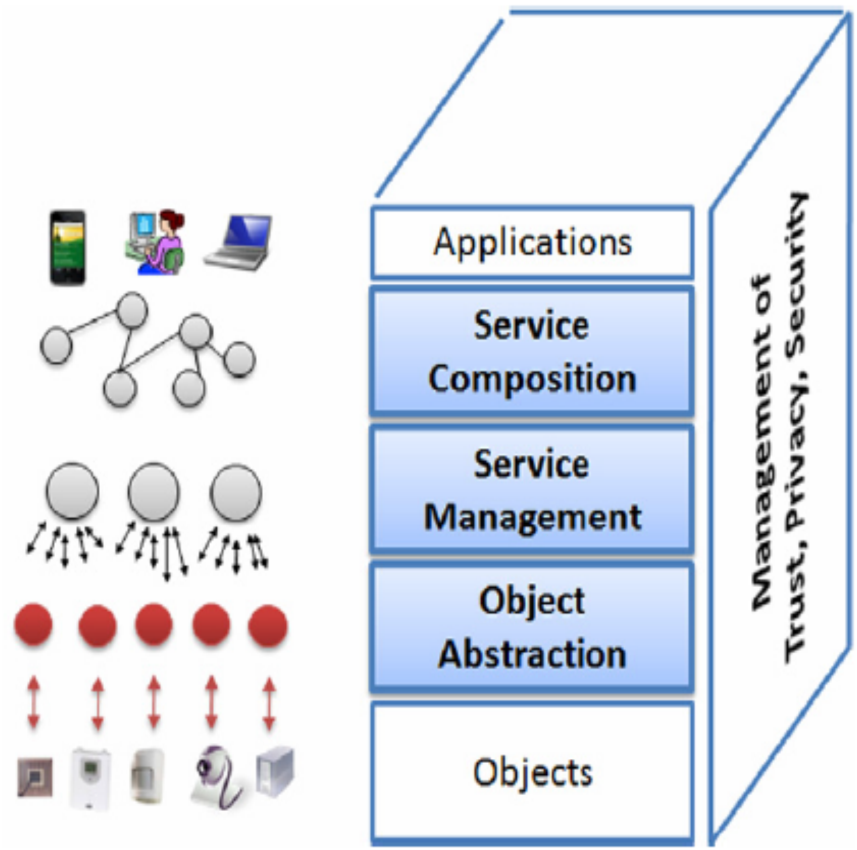
- An indoor positioning system (IPS) is a solution to locate objects or people inside a building using radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices.
- For indoor localization:
  - Any wireless technology can be used for locating
  - GPS, WiFi, Bluetooth, RFID, Ultrawide band, Infrared, Visible light communication, Ultrasound

Middleware

- *Middleware is a software layer that stands between the networked operating system and the application and provides well known reusable solutions to frequently encountered problems like heterogeneity, interoperability, security, dependability [Issarny, 2008]*

- IoT requires stable and scalable middleware solutions to process the data coming from the networking layers

Service Oriented Architecture (SOA)



Source: Atzori et al. 2010

- Middleware solutions for IoT usually follow SOA approaches
- Allows SW/HW reuse
  - Doesn’t impose specific technology
- A layered system model addressing previous issues
  - Abstraction, common services, composition

Other Middleware Examples

- Fosstrak Project
  - Data dissemination/aggregation/filtering/interpretation
  - Fault and configuration management, lookup and directory service, tag ID management, privacy
- Welbourne et al.
  - Tag an object/create-edit location info/combine events collected by antennas
- e-Sense Project
  - Middleware only collects data in a distributed fashion and transmits to actuators
- UbiSec&Sens Project
  - Focuses on security → secure data collection, data store in memory, etc.

Open Problems and Challenges

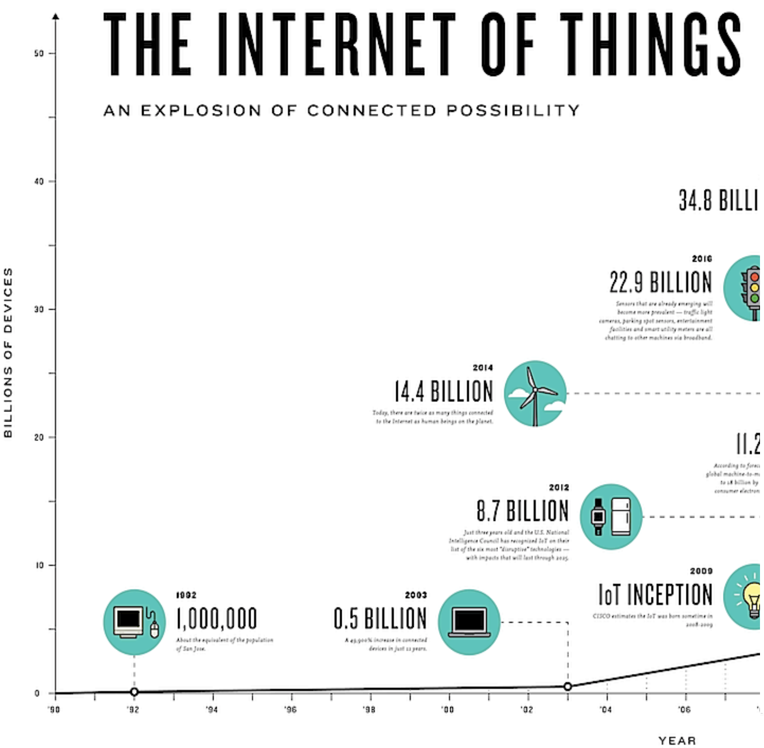
- Lack of standardization
- Scalability
  - Addressing issues
  - Understanding the big data
- Support for mobility
- Address acquisition
- New network traffic patterns to handle
- Security/Privacy issues

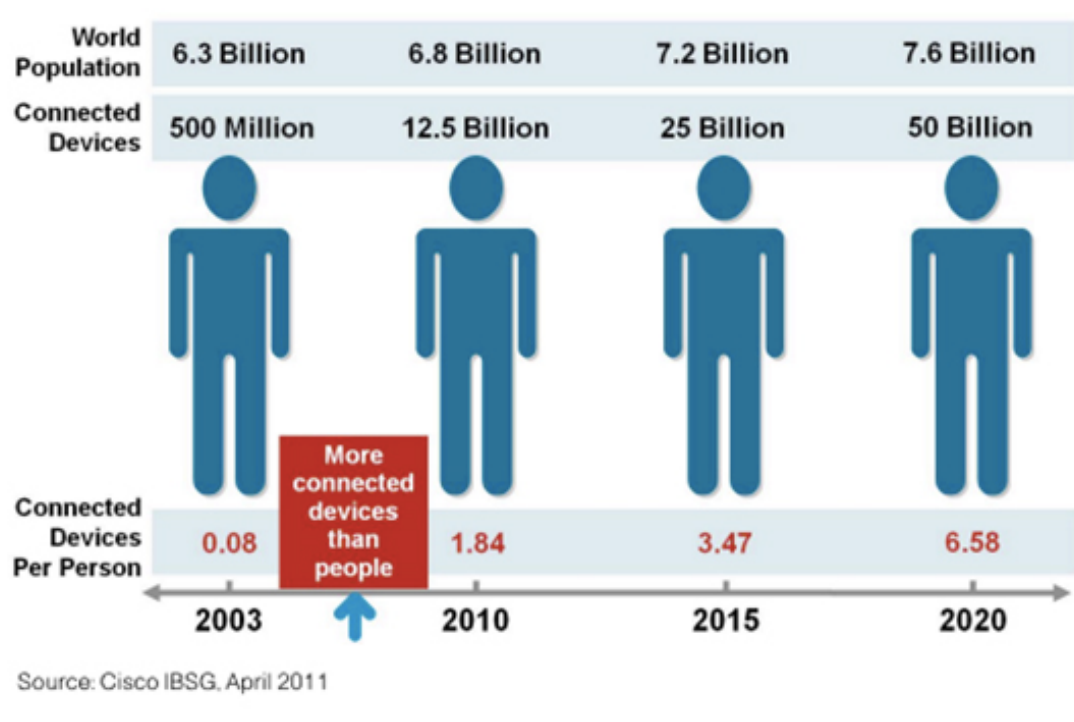
Standardization

- Several standardization efforts but not integrated in a comprehensive framework
- Open Interconnect Consortium: Atmell, Dell, Intel, Samsung and Wind River
- Industrial Internet Consortium: Intel, Cisco, GE, IBM
- AllSeen Alliance: Led by Qualcomm, many others

Standard	Objective	Status	Comm. range (m)	Data rate (kbps)	Unitary cost ($)
Standardization activities discussed in this section					
EPCglobal	Integration of RFID technology into the electronic product code (EPC) framework, which allows for sharing of information related to products	Advanced	~1	$\sim 10^2$	~0.01
GRIFS	European Coordinated Action aimed at defining RFID standards supporting the transition from localized RFID applications to the *Internet of Things*	Ongoing	~1	$\sim 10^2$	~0.01
M2M	Definition of cost-effective solutions for machine-to-machine (M2M) communications, which should allow the related market to take off	Ongoing	N.S.	N.S.	N.S.
6LoWPAN	Integration of low-power IEEE 802.15.4 devices into IPv6 networks	Ongoing	10–100	$\sim 10^2$	~1
ROLL	Definition of routing protocols for heterogeneous low-power and lossy networks	Ongoing	N.S.	N.S.	N.S.
Other relevant standardization activities					
NFC	Definition of a set of protocols for low range and bidirectional communications	Advanced	$\sim 10^{-2}$	Up to 424	~0.1
Wireless Hart	Definition of protocols for self-organizing, self-healing and mesh architectures over IEEE 802.15.4 devices	Advanced	10–100	$\sim 10^2$	~1
ZigBee	Enabling reliable, cost-effective, low-power, wirelessly networked, monitoring and control products	Advanced	10–100	$\sim 10^2$	~1

Scalability

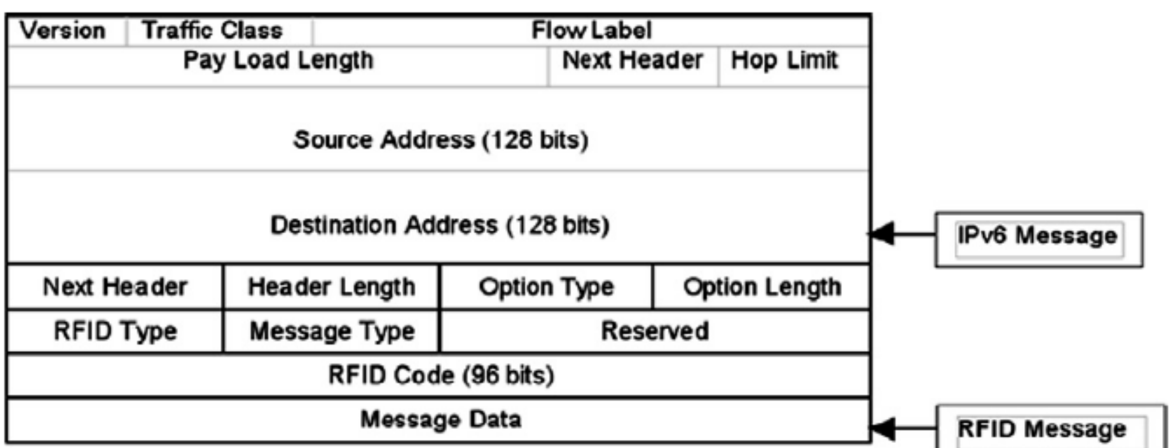




- Number of devices increasing exponentially
  - How can they uniquely be tagged/named?
  - How can the data generated by these devices be managed?

Addressing Issues

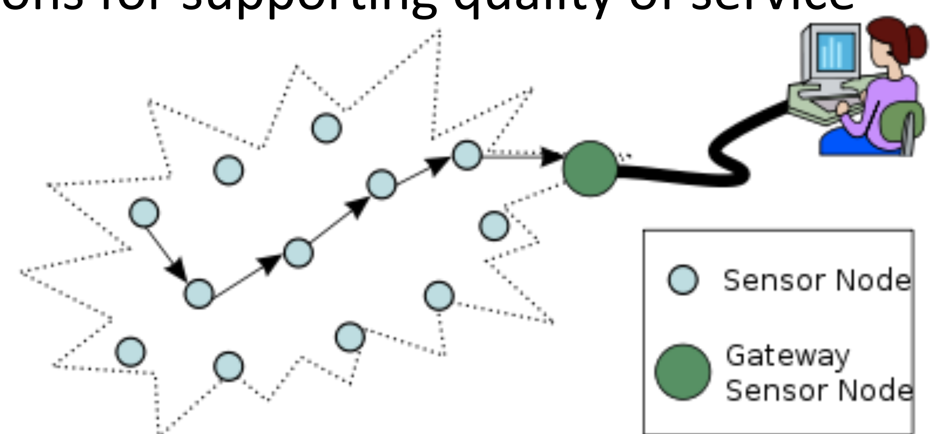
- Incredibly high number of nodes, each of which will produce content that should be retrievable by any authorized user
  - This requires effective addressing policies
  - IPv4 protocol may already reached its limit. Alternatives?
  - IPv6 addressing has been proposed for low-power wireless communication nodes within the 6LoWPAN context
- IPv6 addresses are expressed by means of 128 bits →1038 addresses, enough to identify objects worth to be addressed
- RFID tags use 64–96 bit identifiers, as standardized by EPCglobal, solutions to enable the addressing of RFID tags into IPv6 networks



Encapsulation of RFID message into an IPv6 packet.
Source: Atzori et al. (2010)

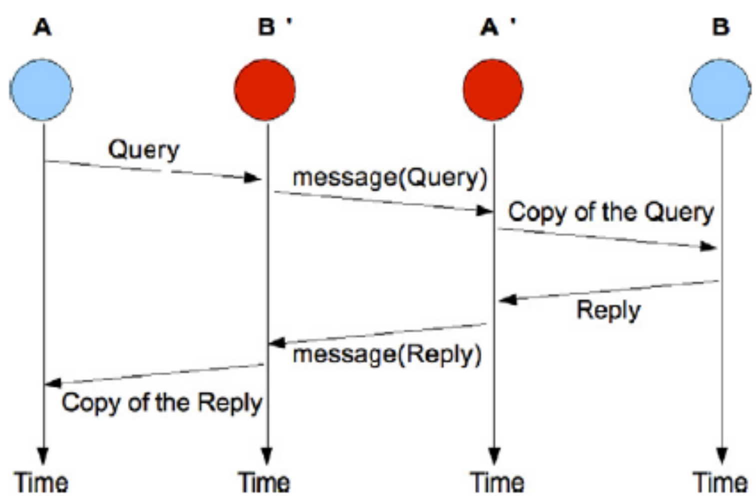
New Traffic to Handle

- The characteristics of the smart objects traffic in the IoT is still not known
  - Important → basis for the design of the network infrastructures and protocols
- Wireless sensor networks (WSNs) traffic characterization
  - Strongly depend on the application scenario
  - Problems arise when WSNs become part of the overall Internet
  - The Internet will be traversed by a large amount of data generated by sensor networks deployed for heterogeneous purposes → extremely different traffic characteristics
  - Required to devise good solutions for supporting quality of service



Security

- The components spend most of the time unattended
  - It is easy to physically attack them
- IoT components are characterized by low capabilities in terms of both energy and computing resources
  - They can't implement complex schemes supporting security
- Authentication problem
  - Proxy attack, a.k.a. man in the middle attack problem

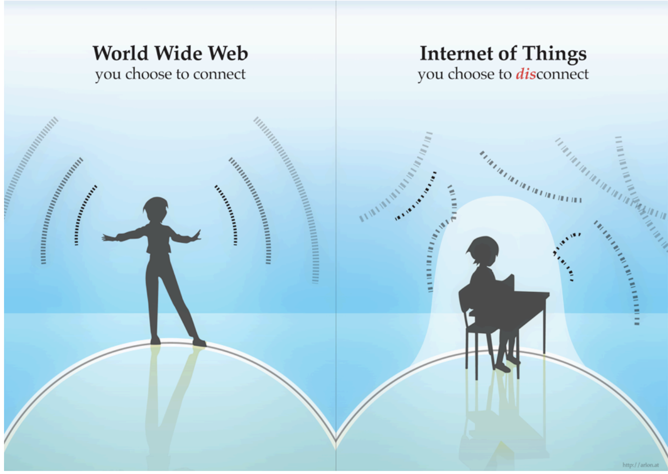


Man in the middle attack Source: Atzori et al. (2010)

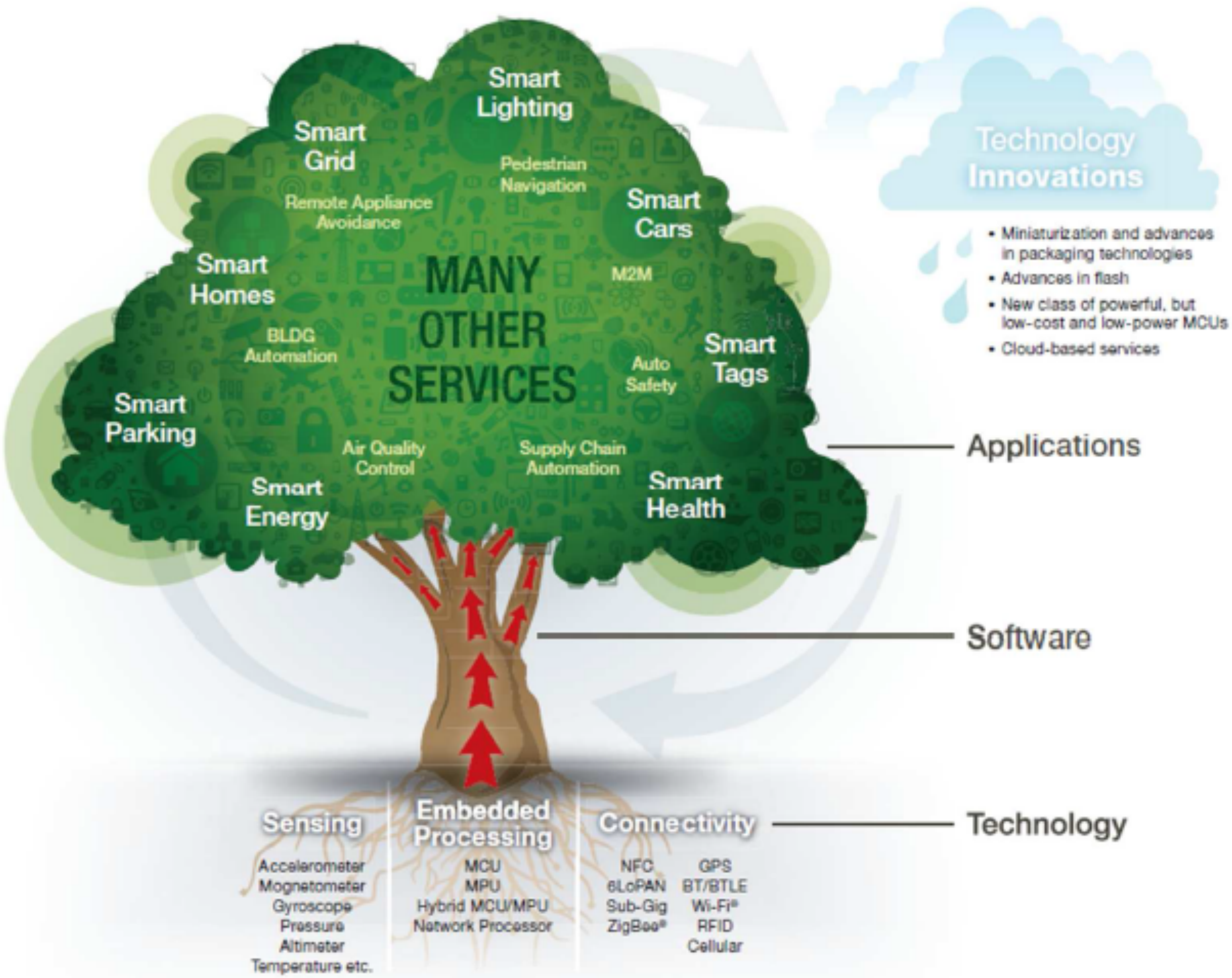
- Data integrity
  - Data should not be modified without the system detecting it
  - Attacks on the node
    - Memory protection
  - Attacks over the network
    - Keyed-Hash Message Auth. Code

Privacy

- How is it different than traditional privacy?
  - Legislative issues
  - Ethics issues
- Easy for a person to get involved in IoT even if he/she does not know
- Data can be stored indefinitely
- Current solutions are not enough
  - Encryption, pseudo-noise signal, privacy broker

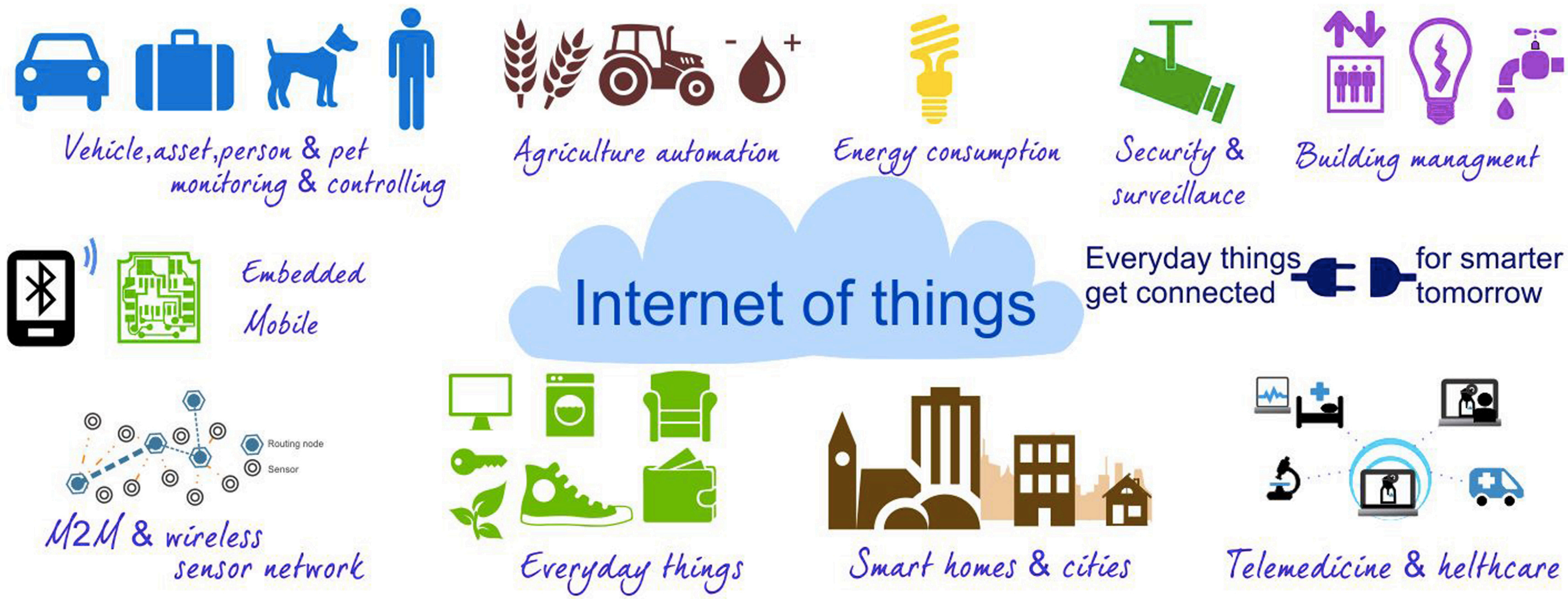


Again - Overall Picture



Source: “What the Internet of Things (IoT) Needs to Become a Reality,” White Paper, by K. Karimi and G. Atkinson

Applications



- Several different domains
  - Transportation and logistics
  - Healthcare
  - Smart environment (home, office, etc.)
  - Personal and social domain

Application Domains and Scenarios

- **Transportation and logistics**
  - Logistics
  - Assisted driving
  - Mobile ticketing
  - Environment monitoring
  - Augmented maps
- **Heathcare**
  - Tracking
  - Identification, authentication
  - Data collection
  - Sensing
- **Smart environments**
  - Comfortable homes/offices
  - Industrial plants
  - Smart museum and gym
- **Personal and social**
  - Social networking
  - Historical queries
  - Losses
  - Thefts
- **Futuristic**
  - Robot taxi
  - City information model
  - Enhanced game room

Source: Atzori et al. 2010

Healthcare Applications

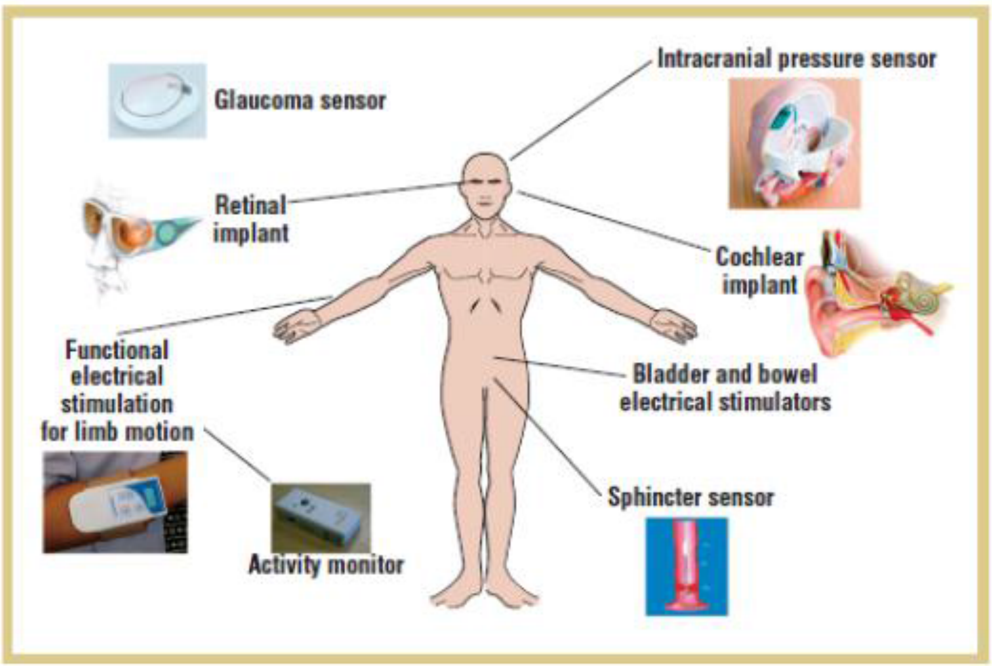


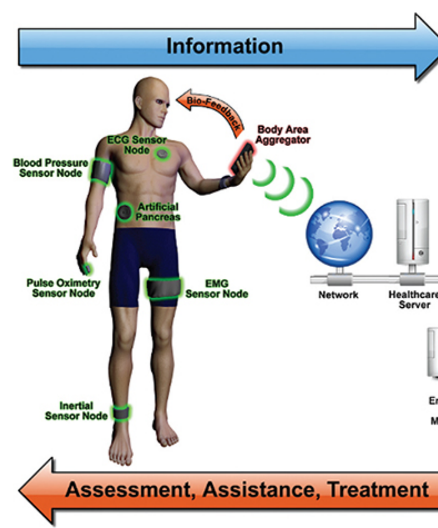
Figure 6. Fully implantable wireless sensor for the intracranial pressure monitoring system.

Source: Qian Zhang. Lecture notes. 2013

- Various sensors for various conditions
- Example ICP sensor: Short or long term monitoring of pressure in the brain cavity
- Implanted in the brain cavity and senses the increase of pressure
- Sensor and associated electronics encapsulated in safe and biodegradable material
- External RF reader powers the unit and receives the signal
- Stability over 30 days so far

Healthcare Applications

- Other applications:
  - National Health Information Network
  - Electronic Patient Record
  - Home monitoring and control
    - Pulse oximeters, blood glucose monitors, infusion pumps, accelerometers
  - Bioinformatics
    - Gene/protein expression
    - Systems biology
    - Disease dynamics



Source: Qian Zhang. Lecture notes. 2013

Environmental Application: CitiSense

- Air quality monitoring project in UCSD CSE

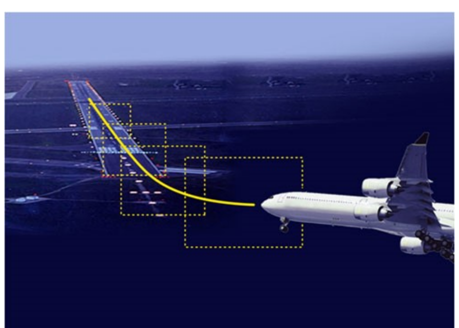
- Environmental application

- Electrochemical **sensors**, **microcontroller** for data collection and transmission to an **Android** app

- **Actuation**: air quality is immediately reported, as well as retransmitted to a backend for larger-scale analysis

Transportation Applications

- **Vehicle control:** Airplanes, automobiles, autonomous vehicles
  - All kinds of sensors to provide accurate, redundant view of the world
  - Several processors in cars (Engine control, break system, airbag deployment system, windshield wiper, door locks, entertainment system, etc.)
  - Actuation is maintaining control of the vehicle
  - Very tight timing constraints and requirements enforced by the platforms

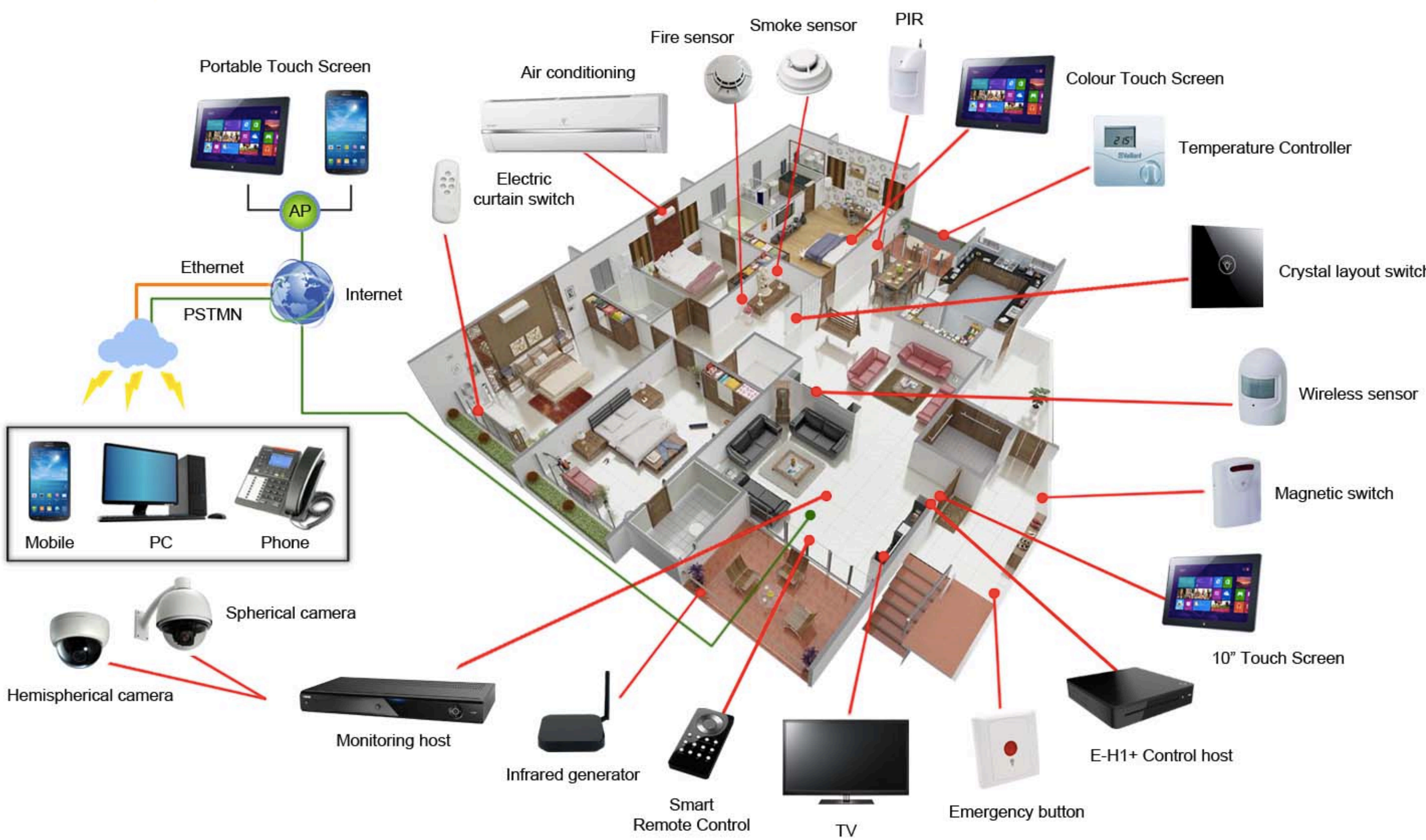


Example Transportation Scenarios

1. A network of sensors in a vehicle can interact with its surroundings to provide information
   - Local roads, weather and traffic conditions to the car driver
   - Adaptive drive systems to respond accordingly
2. Automatic activation of braking systems or speed control via fuel management systems.
   - Condition and event detection sensors can activate systems to maintain driver and passenger comfort and safety through the use of airbags and seatbelt pre-tensioning
3. Sensors for fatigue and mood monitoring based on driving conditions, driver behavior and facial indicators
   - Ensuring safe driving by activating warning systems or directly controlling the vehicle

Source: Qian Zhang. Lecture notes. 2013

Smart Home Applications



- Smart meters, heating/cooling, motion/temperature/ lighting sensors, smart appliances, security, etc.

A Futuristic Application: Shopping

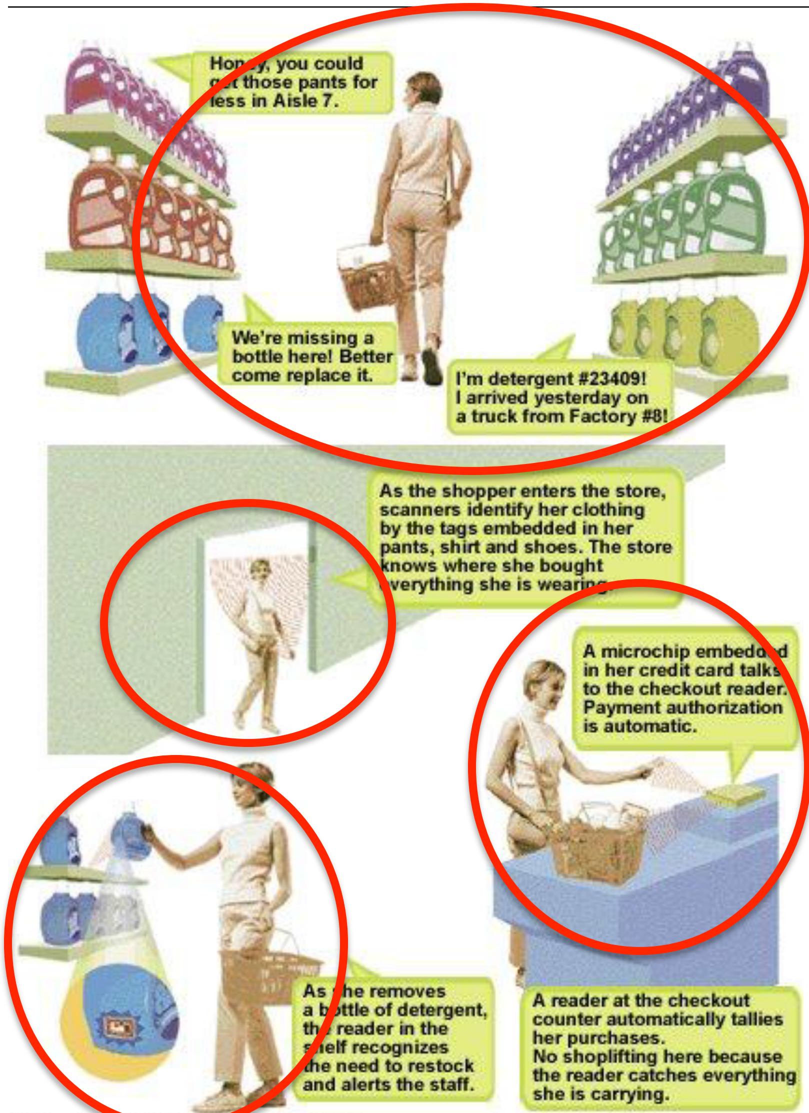


Illustration by Lisa Knouse Braiman for Forbes

- When entering the doors, scanners will identify the tags on her clothing.
- When shopping in the market, the goods will introduce themselves.
- When paying for the goods, the microchip of the credit card will communicate with checkout reader.
- When moving the goods, the reader will tell the staff to put a new one.

Source: Qian Zhang. Lecture notes. 2013

An exciting future!