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Networks and Protocols 2

Introduction

Basado en: *Internet of Things: Architectures, Protocols and Applications*

Pallavi Sethi and Smruti R. Sarangi

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Definitions

*"**Interaction** between the physical and digital worlds. The digital world interacts with the physical world using a plethora of **sensors** and **actuators**" (Vermesan et al)*

*"A paradigm in which **computing** and **networking** capabilities are embedded in any kind of conceivable object. We use these capabilities to query the state of the object and to change its state if possible." (Peña-López et al)*

*"New kind of world where almost all the devices and appliances that we use are connected to a **network.** We can use them collaboratively to achieve complex tasks that require a high degree of intelligence." (Sethi et al)*

The era of IoT

- New conception of the cyberphysical world in which (almost) all devices are **interconnected** via networking.

- Possibility of **collaborative** use to fulfill complex tasks that require large amount of data/processing.

The era of IoT

- **IoT is not just one technology:**
  - Group of technologies working in a collaborative fashion.
  - IoT devices include sensors, actuators, processors and **network devices.**

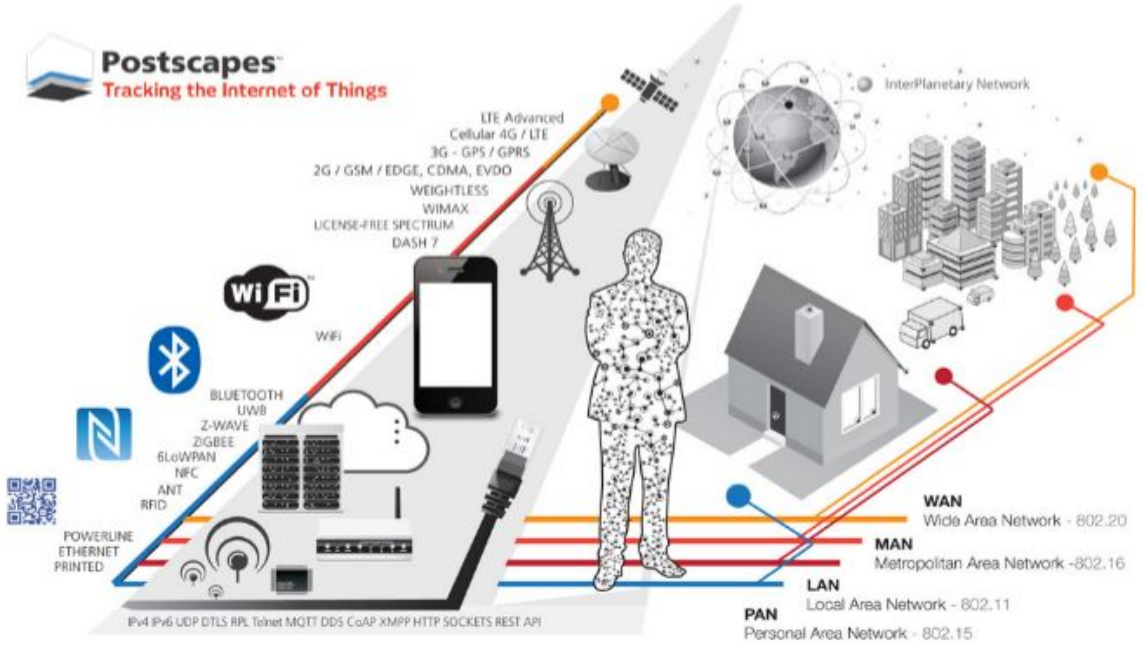
Discussion: Which are, in your opinion, the main limitations imposed to sensors, actuators, processors and network devices in IoT deployments?

Storing, processing, communicating

- Data storage and processing near sensor (edge computing) or in the server (cloud computing).
- If preprocessing is possible, it can be carried out near sensor.
  - Discussion: Why?
- Pre-processed data are submitted to a central server.
- Communication across IoT devices is usually wireless
  - Discussion: Why? Which are the implications?

The era of IoT

- Wireless channels present more distortion, interferences and lack of robustness.
  - But a reliable and (as much as possible) **retransmission-free communication** is desirable.
  - Hence, **communication technologies** play a key role in IoT.



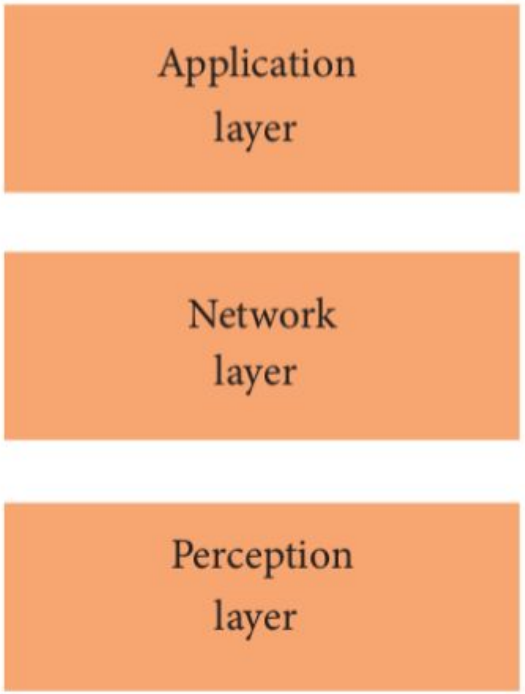
IoT architectures

- There is no agreement in what is an IoT architecture.
- Three different architectures are proposed in the literature:
  - Three-layer and five-layer architecture.
  - Fog and cloud architectures.
  - SIoT (Social Internet of Things)

Three-layer IoT architecture

Simple, introduced at the beginning of IoT

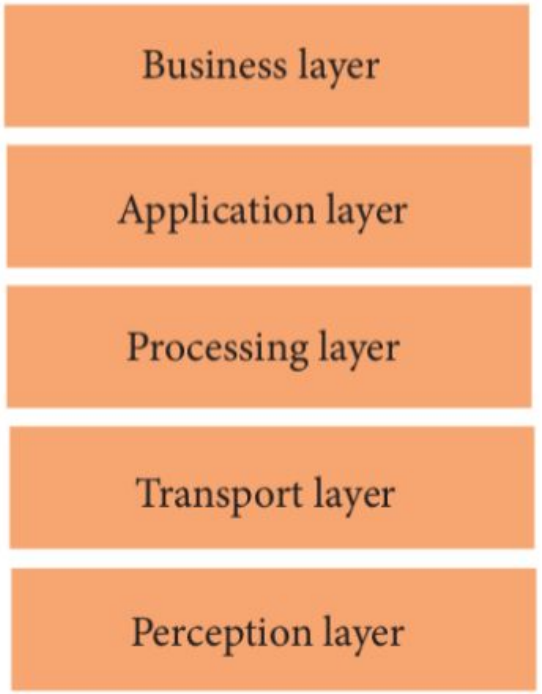
- **Perception layer:**
  - Physical layer
  - Sensors to gather environmental information
  - Gathers physical parameters or identifies close devices
- **Network layer:**
  - Manages connections with other sensor devices, network devices or servers
  - Transmission and data processing from sensors
- **Application layer:**
  - Offers services to users, specific for an application



Five-layer IoT architecture

Extended architecture with two additional layers

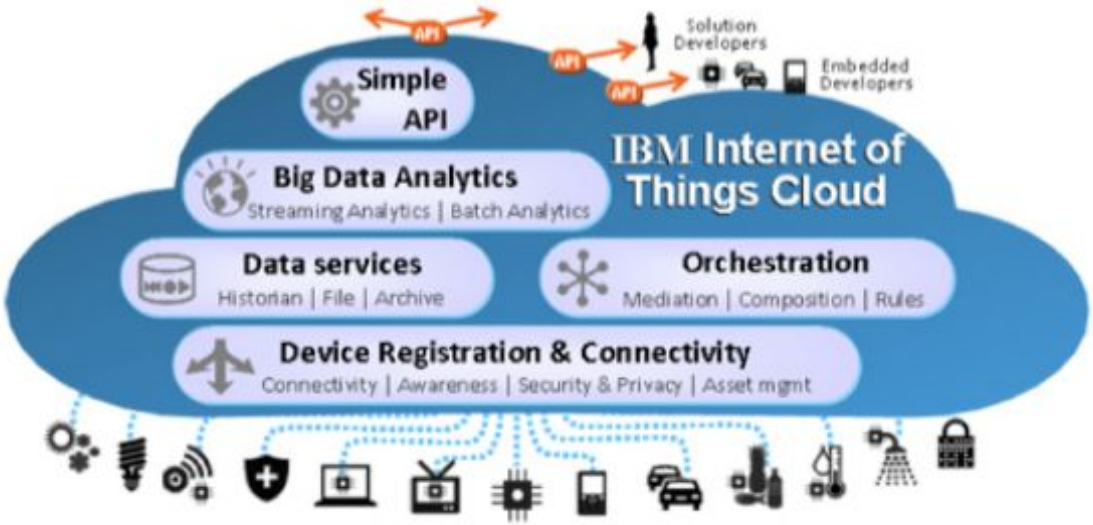
- **Transport layer:**
  - Transfers sensor data from perception layer to processing layer, and vice-versa:
    - Via WiFi, 3G, 4G, 5G, LAN, BLE, RFID, NFC...
  - Specific communication protocols are defined at this level
- **Processing layer (*middleware*):**
  - Stores, analyzes and processes data from transport layer
  - Provides services to lower layers:
    - Decision taking, interoperability across services and platforms, …
- **Business layer:**
  - Manages the overall IoT system, including applications, data models, business model and privacy



Cloud and fog architectures

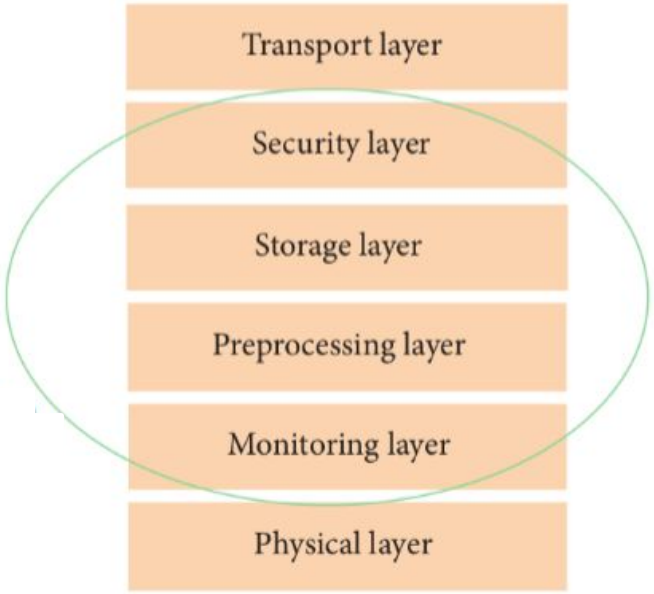
- Centered on processing/generation of data more than in protocols

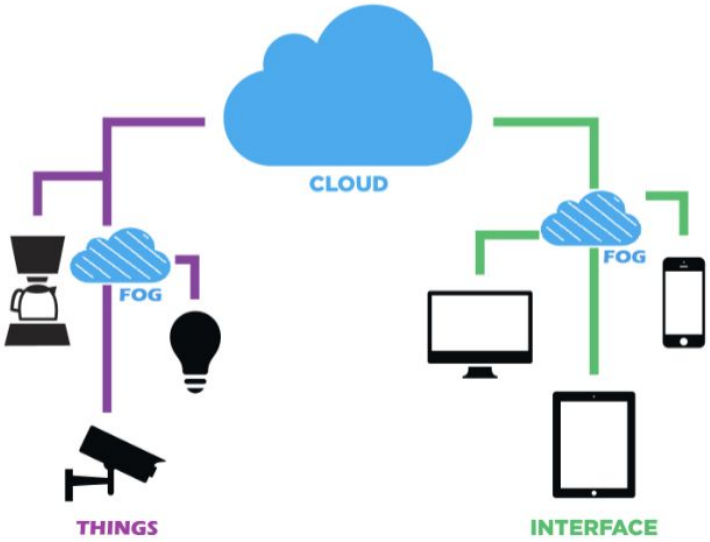
- ***Cloud-centric***
  - Processing is carried out in large centralized infrastructures (*cloud computing*)
    - Pros: flexibility and scalability
    - Provides basic services: infrastructure, software and storage



Cloud and fog architectures

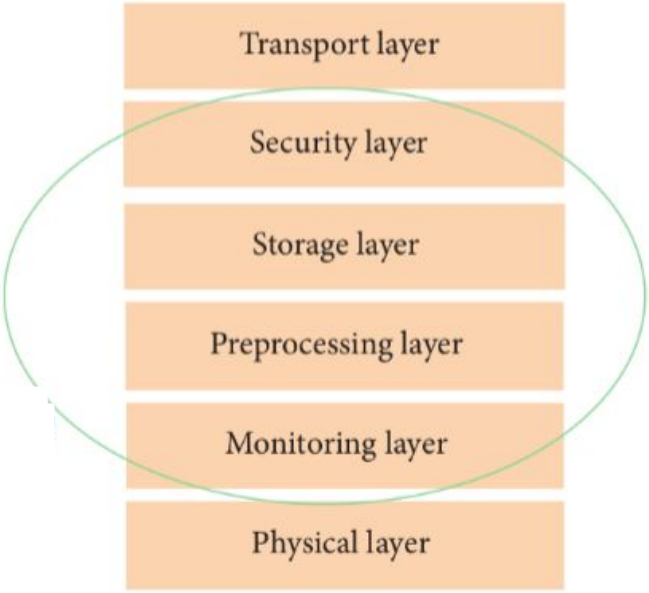
- ***Fog computing***
  - Sensors and gateways (network devices) collaborate in processing and data analysis
  - Inserts **monitorization, pre-processing, storage and security** between physical and transport layer





Cloud and fog architectures

- **Monitorization layer**
  - Monitors energy consumption, resources and services
- **Pre-processing layer**
  - Filtering, processing and analysis
- **Temporary storage layer**
  - Replication, distribution and data storage
- **Security layer**
  - Encryption, integrity and privacy



Monitoring and pre-procesing are carried out at the **edge**, before sending data to the **cloud**

Communication challenges

1. **Addressing and identification**
   - Unique addressing. Billions of devices
2. **Low-power communication**
   - Wireless communication: high power consumption
3. **Routing protocols**
   - Low memory and processing requirements
4. **Speed and data losses**
   - Adapted to application/environment
5. **Mobility**
   - Dynamic routing protocols

Communication challenges

Options:

1. **Connecting via IP**
   - Complex, energy-hungry
   - Complete in functionality

2. **Connecting via no-IP networking**
   - Less energy consumption
   - Connection via gateway
   - Bluetooth, RFID, NFC
   - Limited range (meters)
   - Limited to PAN
   - Additional support for LPWAN (e.g. LoRaWAN)

3. **The best of both worlds**
   - Modifying the IP stack to achieve low power and full IP functionality
   - Example: 6LowPAN

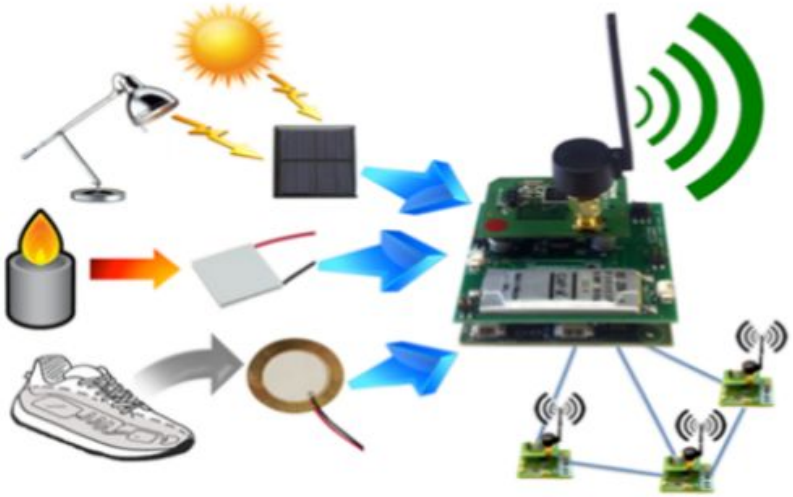
Example no-IP: NFC

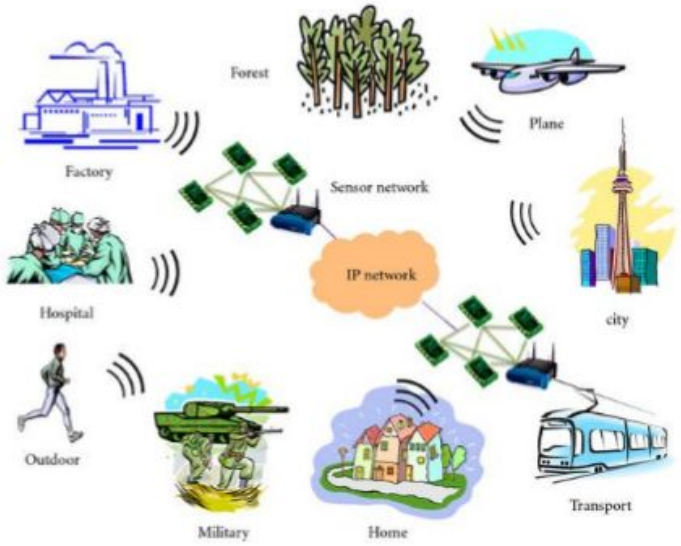
NFC (Near Field Communication)

- Communication technology for ultra-low range scenarios
- Compatible devices can interact at short distances
  - Centimeters (security)
- Based on RFID
  - Uses magnetic field variations to communicate data
  - Operates at 13.56 Mhz, same as RFID. 100-450 kbps
  - Active and passive mode
  - Bidirectional communications
- Discussion: ¿Advantages? ¿Target applications?

Example IP: WSN (Wireless Sensor Networks)

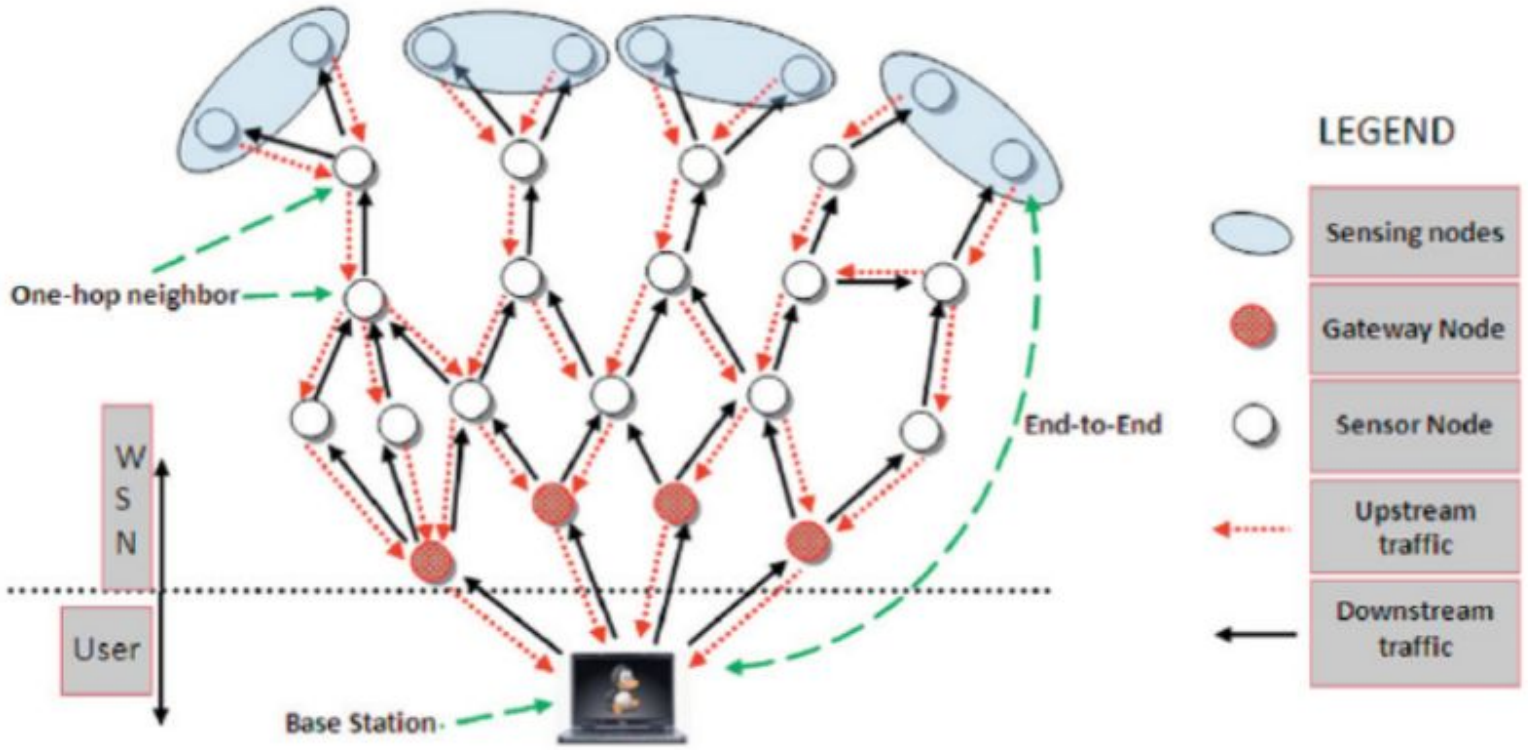
- WSN: thousands of sensor nodes connected via wireless
- Gather environmental data and communicate to gateway devices, that resend data to Internet (e.g. cloud)





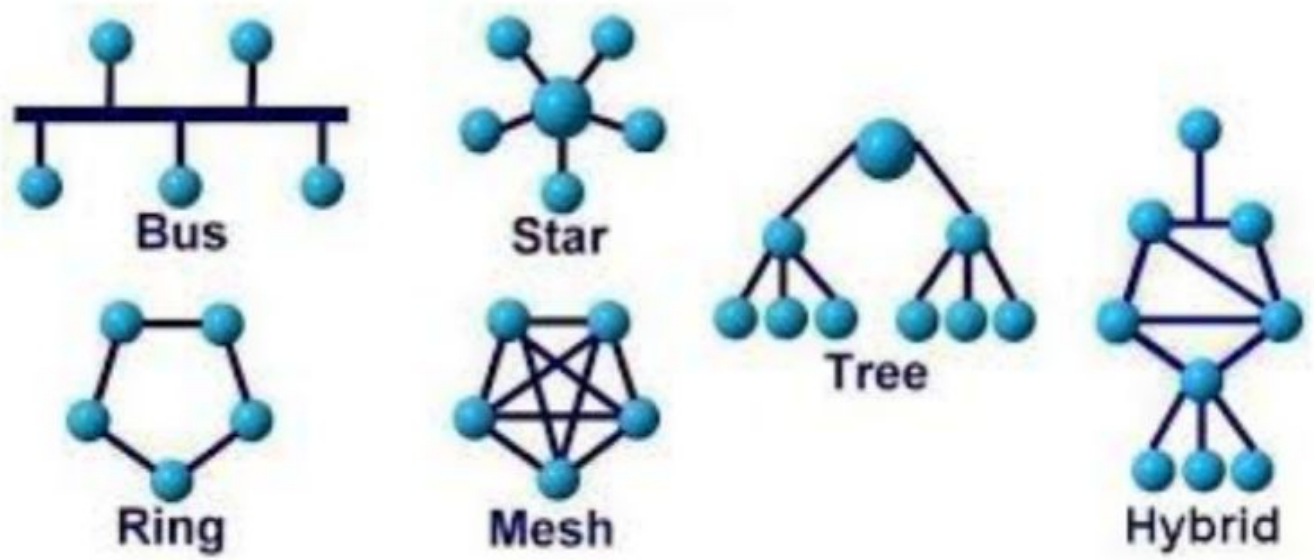
Example: WSN (Wireless Sensor Networks)

- Inter-node communication: direct or multi-hop
- Sensor nodes with limited capabilities
- Gateways with extended and adaptable capabilities



Example: WSN (Wireless Sensor Networks)

- Typical topologies

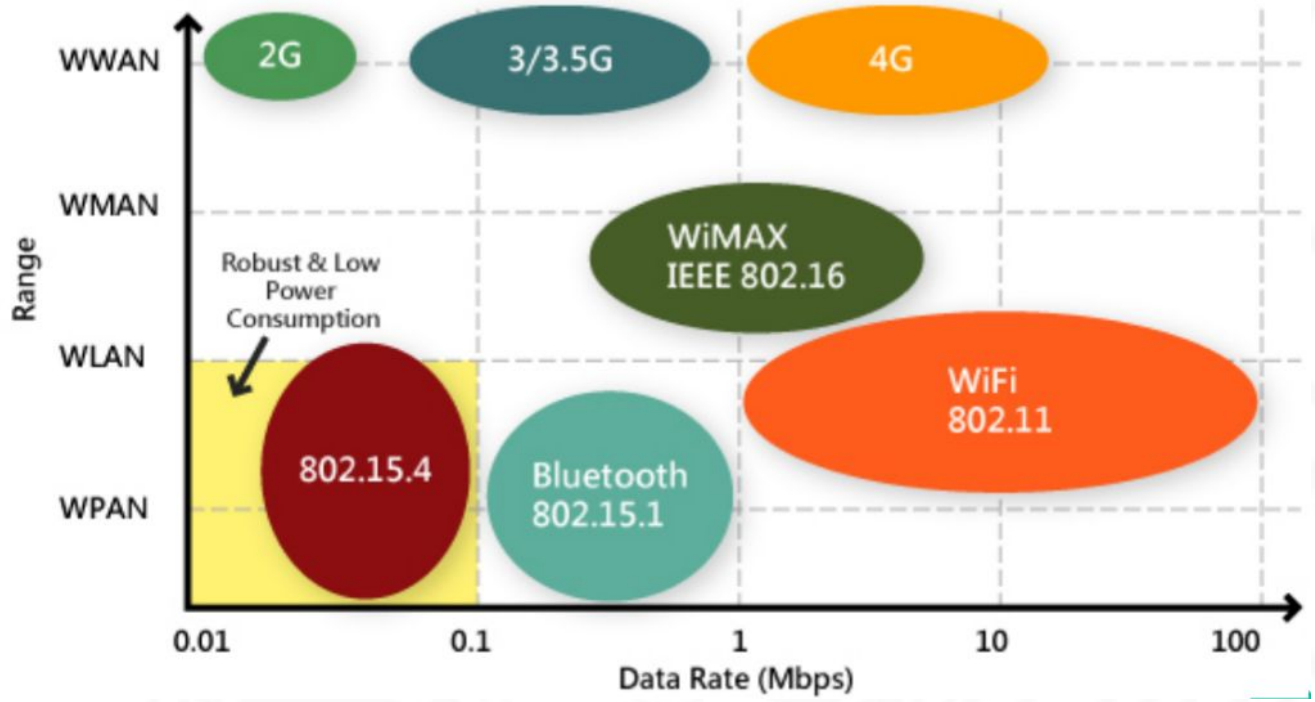


IoT protocol stack

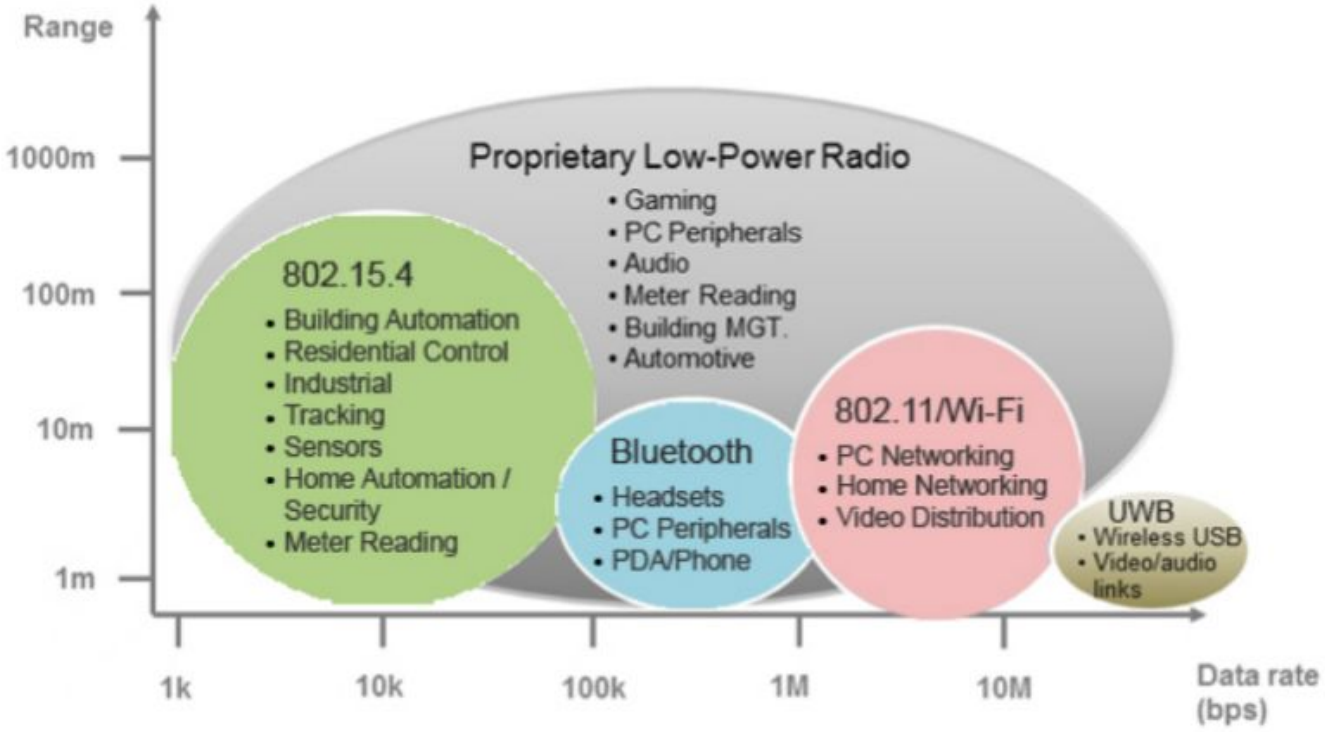
- IETF (*Internet Engineering Task Force*) has developed alternative protocols specifically designed for IoT
  - Using IP
  - IPSO (*Internet Protocol for Smart Objects*) Alliance has published standards and alternative protocols for each layer of the TCP/IP stack

Physical and MAC layers (IEEE 802.15.4)

- Designed to facilitate communication across IoT devices
  - Standards and protocols for physical and link (MAC) layers
  - Targeting compact, memory and energy-restricted devices
  - Short-range, low cost and low-power communication



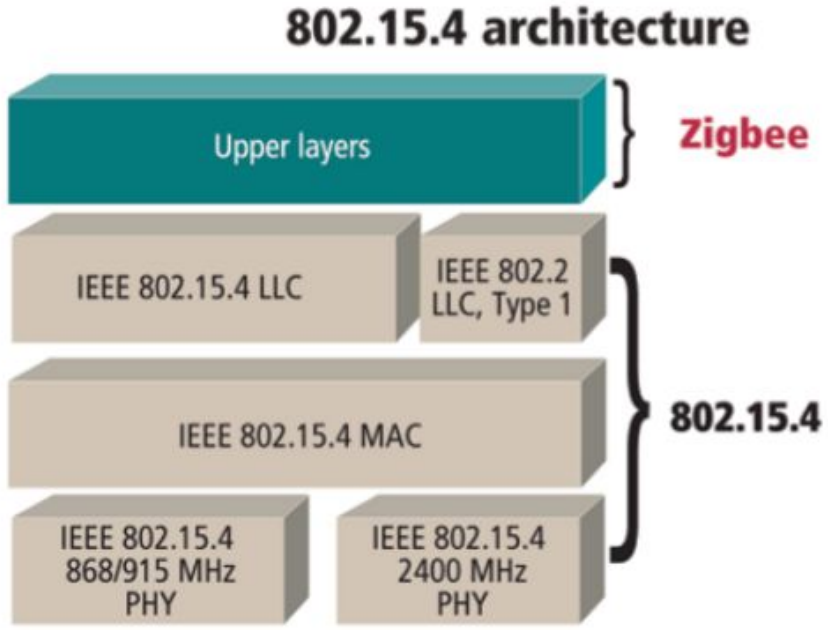
Physical and MAC layer (IEEE 802.15.4)



ZigBee Control your world · 6LoWPAN · WirelessHART · ISA100Wireless · IPSO Alliance

Physical and MAC layer (IEEE 802.15.4)

- Low power -> less range
- Sub-Ghz vs. Super-Ghz
  - Discussion: ¿Pros and cons?



Physical and MAC layer (IEEE 802.15.4)

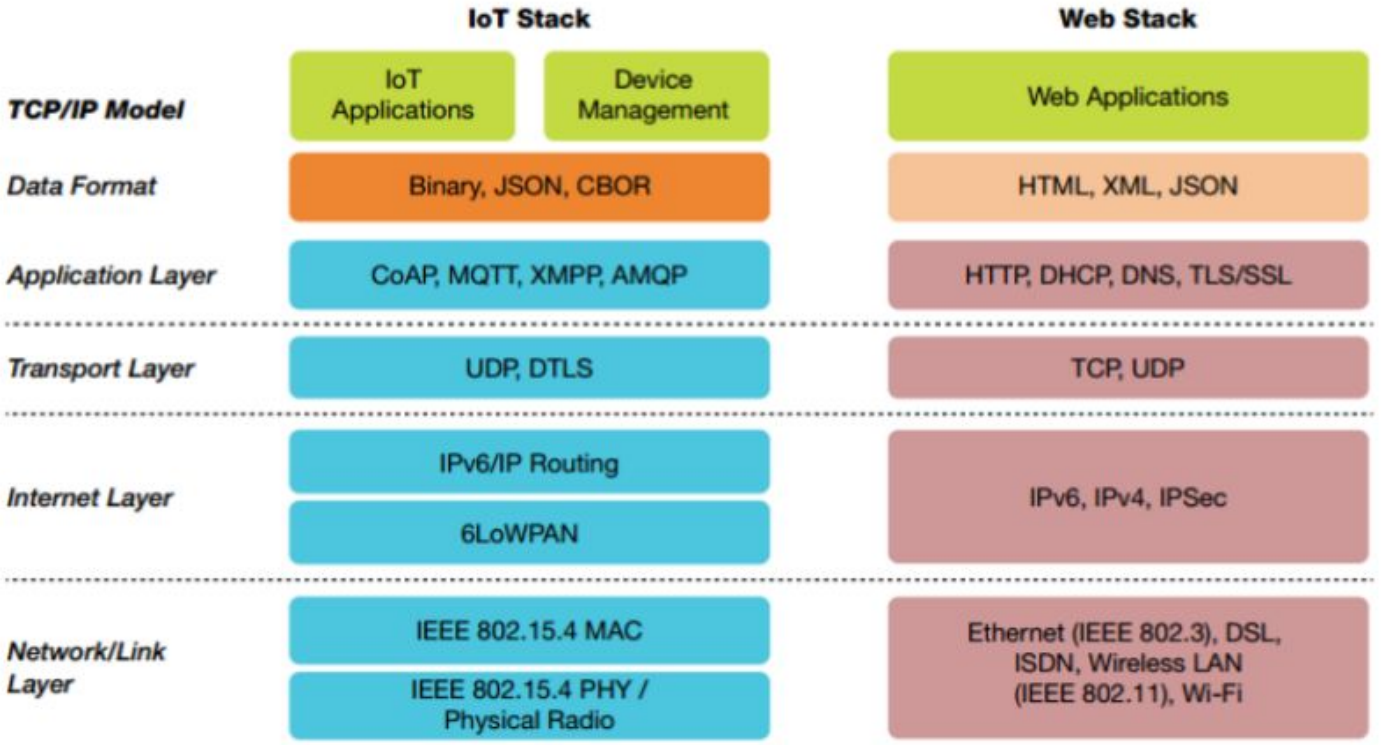
- Due to small range, devices need to co-operate and create a multi-hop architecture to cover large distances.

- Implemented techniques:
  - Packet size reduction (127 bytes). ¿Valid for IoT?
  - Transfer rate reduction (250 Kbps). ¿Valid for IoT?
  - Redundant codes, robust, loss detection, package retransmission… why?
  - Link-layer addresses of 16 bit to reduce overhead

Adaptation layer: IPv6 and 6LowPAN

- IPv6 is an ideal protocol given its stability, addressing space and scalability
- Needs adaptation to work with IEEE 802.15.4: **6LoWPAN**

- **6LowPAN: IPv6 over low power wireless personal area networks**
  - Adaptation between link-layer 802.15.4 and transport layer
  - Compression techniques and adaptation to link-layer



Adaptation layer: IPv6 and 6LowPAN

Optimization techniques for IoT:

1. ***Header compression***
   a. Overhead reduction

2. ***Fragmentation***
   a. Link-layer routing

3. ***Using local MAC addresses***
   a. Communication within the same network

Network layer: RPL

RPL: *Routing Protocol for Low Power and Lossy Networks* (LLN)

- Open protocol
- Based on distance-vector (any other example?)
- Directed graph construction (*DODAGs*)
  - Objective functions in *DODAGs*: energy, hops, distance, …
- Support in many IoT Operating Systems (e.g. Contiki)

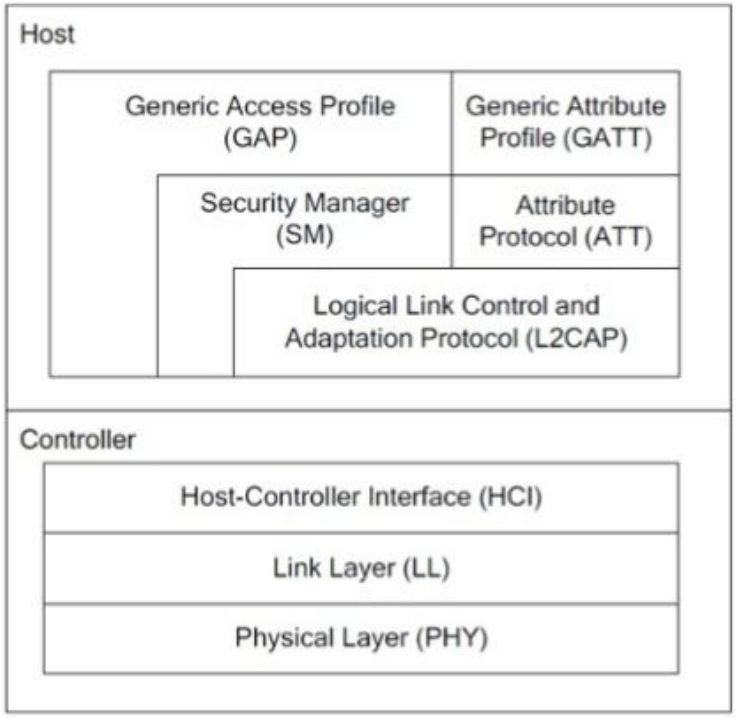
Transport layer: UDP and TCP

- ¿TCP or UDP? ¿why?
- This discussion will be nuclear part of the next sessions

Application layer: CoAP and MQTT

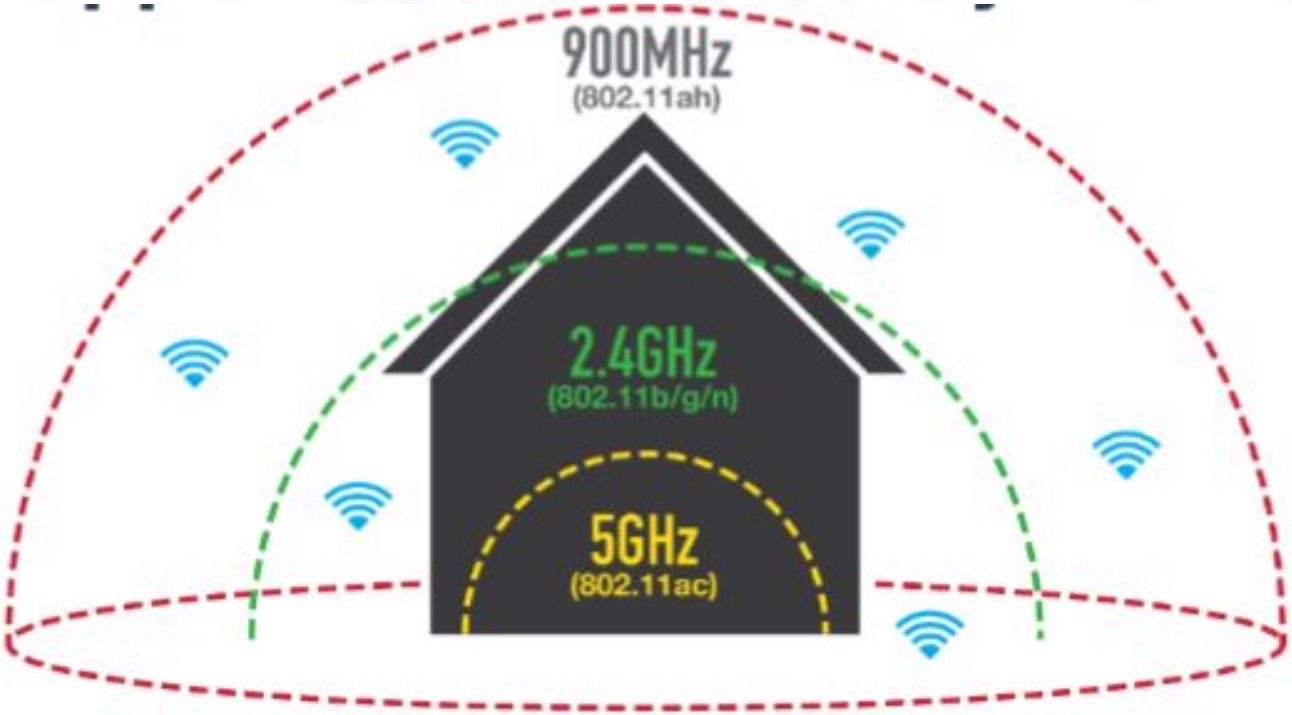
- Two main actors: **CoAP** and **MQTT**
- **CoAP** (*Constrained Application Protocol*)
  - "Based" on HTTP. ¿Why not HTTP?
  - Specific binary encoding formats: EXI, **CBOR**
  - Resource discovering, suscription, congestion control, multicasting
  - Confirmable messages, ACKs, RESET, …
  - DTLS support
- **MQTT** (*Message Queue Telemetry Transport*)
  - Publication/suscription based on TCP (UDP)
  - Broker-based
  - Hierarchical topics to publish/subscribe
  - Verbose (uses text)
  - Uses TCP by design. Not always availabl (e.g. NB-IoT)

- **BLE: Bluetooth Low Energy (Bluetooth Smart)**
  - Short range, low power
  - Not compatible with Bluetooth classic, but share philosophy
  - Does not support data streaming: sending individual packages
  - Master/slave architecture (1-n)



Low Power WiFi (WiFi HaLow)

- **Standard 802.11ah, low power, long range**
  - IP support, star topology, sub-GHz (pros/cons?)

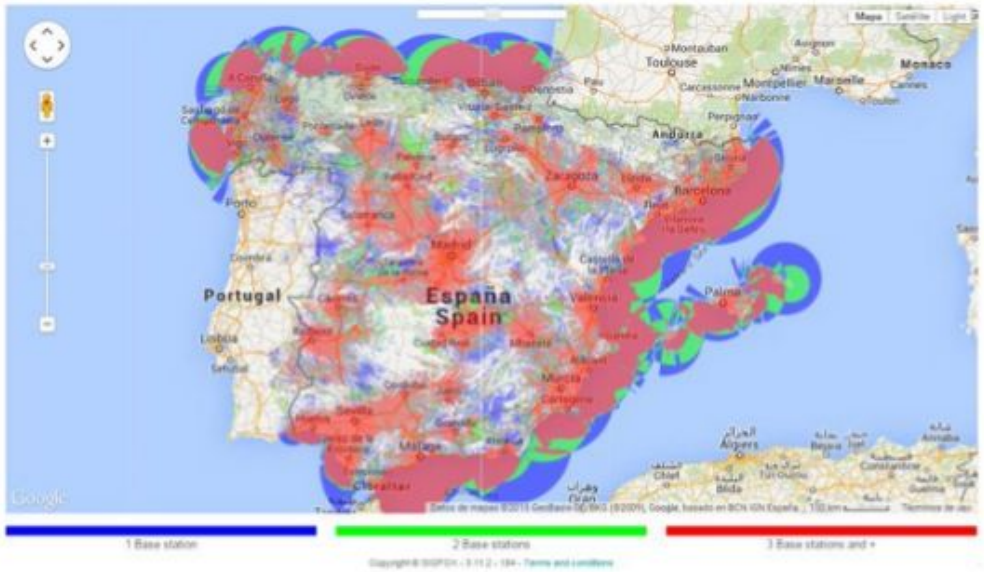


LPWAN

- **LPWAN: Low Power Wide-Area-Networks**
  - *Narrow band IoT*
    - Devices restricted in energy consumption
    - Necessity of reducing bitrate
    - Examples (unlicensed spectrum): Sigfox, LoRA
    - Examples (licensed spectrum): NB-IoT

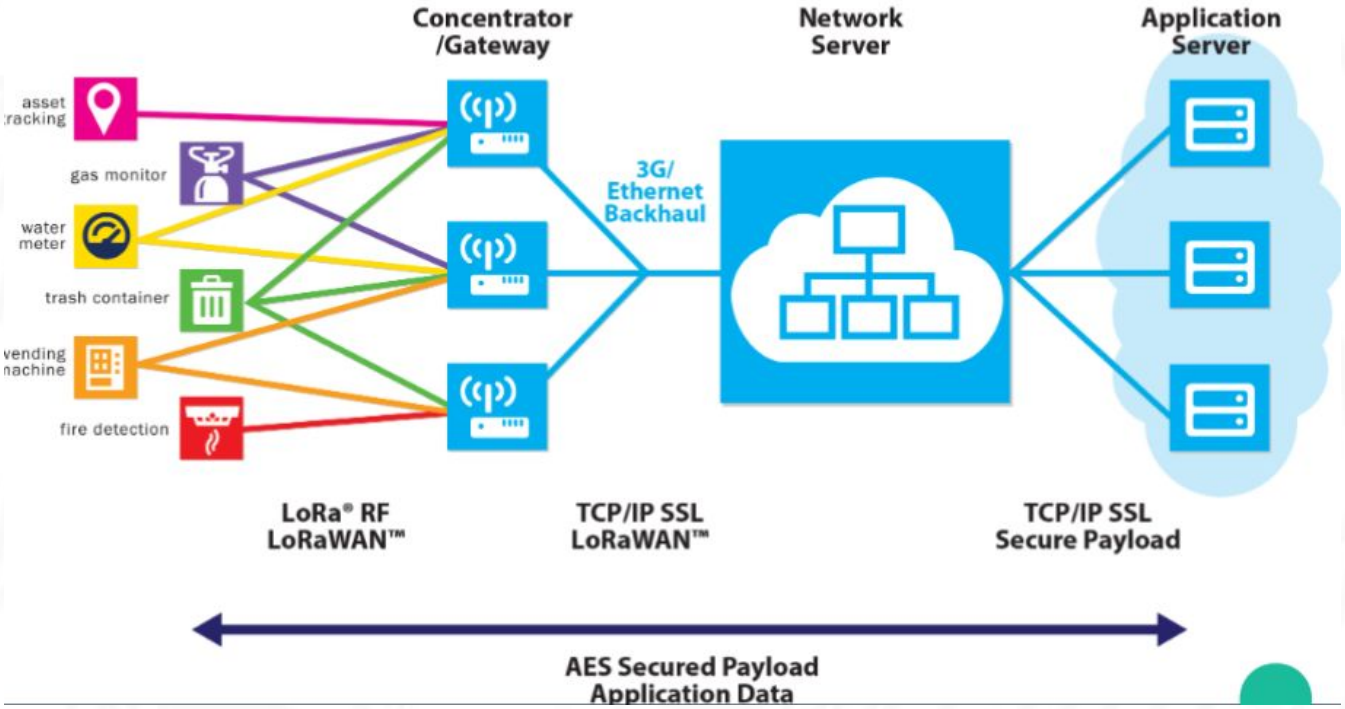
LPWAN. Sigfox

- **Sigfox**
  - Sub-ghz communication, narrow band (10Mhz)
  - Uses unassigned phone company ranges for transmission
  - Limited to messages of 12 bytes, 140 messages per day
  - Energy lower than mobile telephony (<0.1%)



LPWAN. LoRaWAN

- **LoRaWAN**
  - Similar to Sigfox
  - Wide area, low poser
  - Between 0.3 and 50 Kbps, kilometers of range



Perspective

LAN ✓

Short Range
Communicating Devices

35% SOM

- ✓ **Well established standards**
- ✓ **Good for:**
  - Mobile devices
  - In-home
  - Short range
- ❑ **Not good:**
  - Battery life
  - Long range

LPWAN ?

Long Range w/ Battery
Internet of Objects

55% SOM

- ✓ **Emerging PHY solutions**
- ✓ **Good for:**
  - Long range
  - Long battery
  - Low cost
  - Positioning
- ❑ **Not good:**
  - High data-rate

Cellular ✓

Long Range w/Power
Traditional M2M

10% SOM

- ✓ **Well established standards**
- ✓ **Good for:**
  - Long range
  - High data-rate
  - Coverage
- ❑ **Not good:**
  - Battery life
  - Cost

Summary

IoT: Specific technologies targeting specific challenges inherent to IoT

- Low power
- Mobility
- Security
- Latency
- Addressing

Different cases according to specific scenario

- PAN
- MAN
- WAN

Edge computing as a trend

- Latency, security, computation capabilities, mobility

Specific SW/HW support for each technology

- **Individual task: survey of HW/SW capabilities with support for technologies studied during the session. Individual, presenting next session**

Task

HW platform	Network technology	Software / API	Sensors	Cost