Sisteme Încorporate

Cursul 12

Internet of Things

Facultatea de Automatică și Calculatoare
Universitatea Politehnica București

Industrial Revolutions

Embedded Systems Laboratory

1st

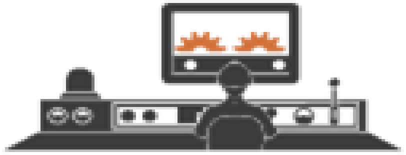
1760s

Steam engine
Mechanization

2nd

1870s

Electricity
Mass production



3rd

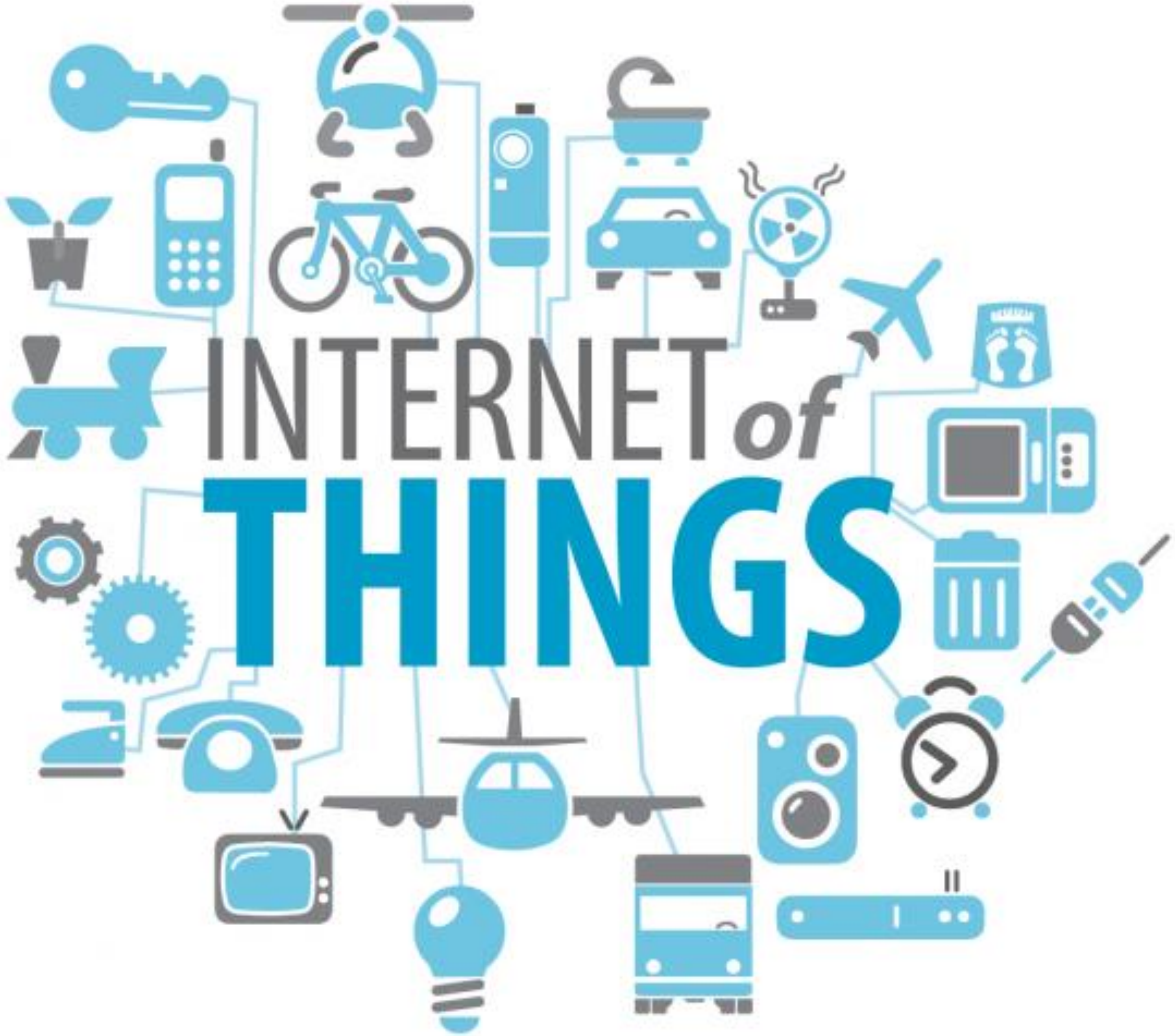
1960s

Computers
Automation
Internet

4th

NOW

Hyper-
connectivity



A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network, often communicate data associated with users and their environments.

Internet of Things

Kevin Ashton – co-inventatorul RFID și inventatorul termenului „IoT”

„ The fact that I was probably the first person to say “Internet of Things,” does not give me any right to control how others use the phrase. But what I meant, and still mean, is this: Today computers—and, therefore, the Internet—are almost wholly dependent on human beings for information.” – [*How to Fly a Horse: The Secret History of Creation, Invention, and Discovery*]


IOT
LIGHTYEAR
IOT DEVICES EVERYWHERE
imgflip.com

Scurtă istorie a IoT

Source: http://events.linuxfoundation.org/sites/events/files/slides/Design%20-%20End-to-End%20%20IoT%20Solution%20-%20Shivakumar%20Mathapathi.pdf

Caracteristici

- Small packet size
- Low bandwidth (10s-100s kbps)
- Star and mesh topology
- Low power, battery operated
- Low cost
- Ad-hoc network, device has limited accessibility
- Unreliable wireless medium

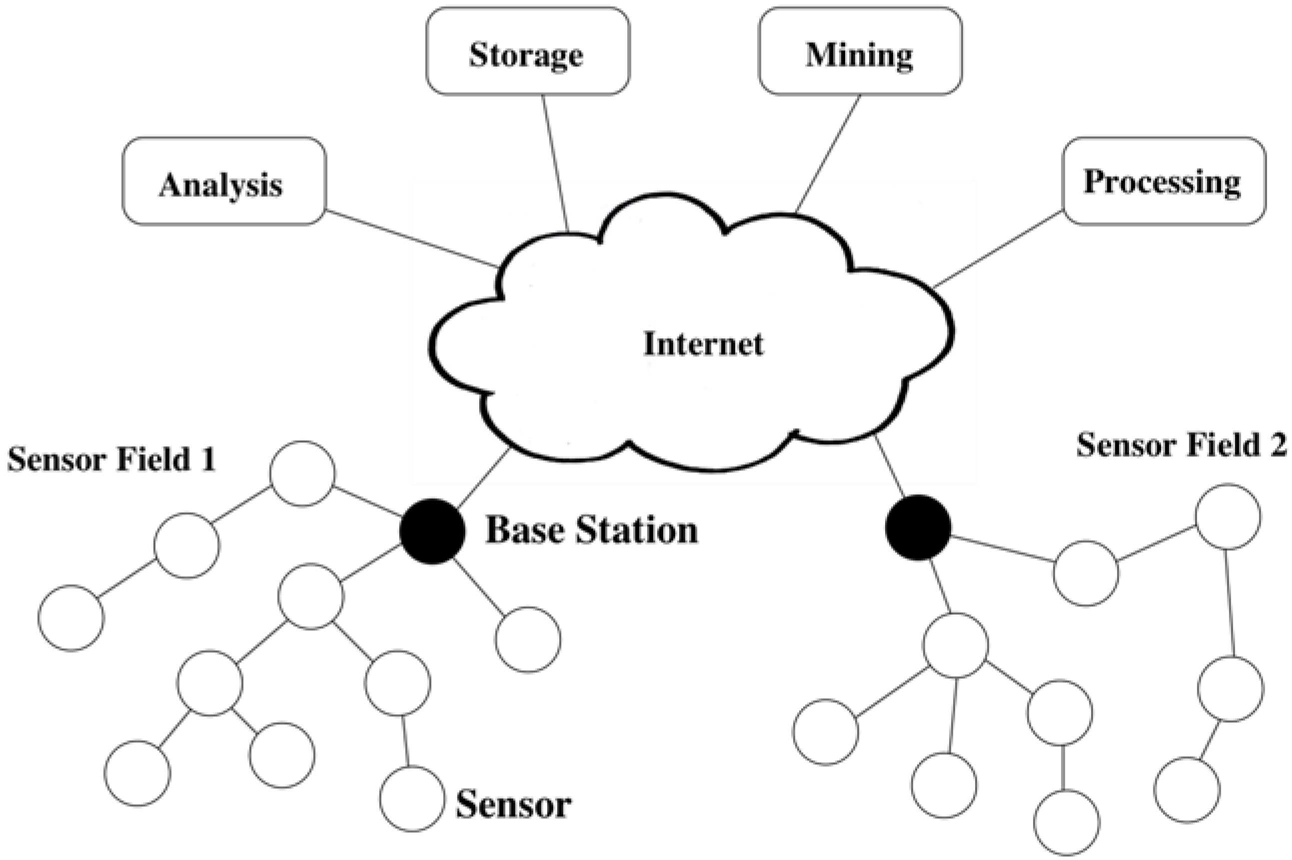
Use Case: Home Networks

IoT Features

- Dynamic, self-adaptation
- Auto-configuration
- Interoperable communication protocols
- Unique identifier
- Integrated into a larger network

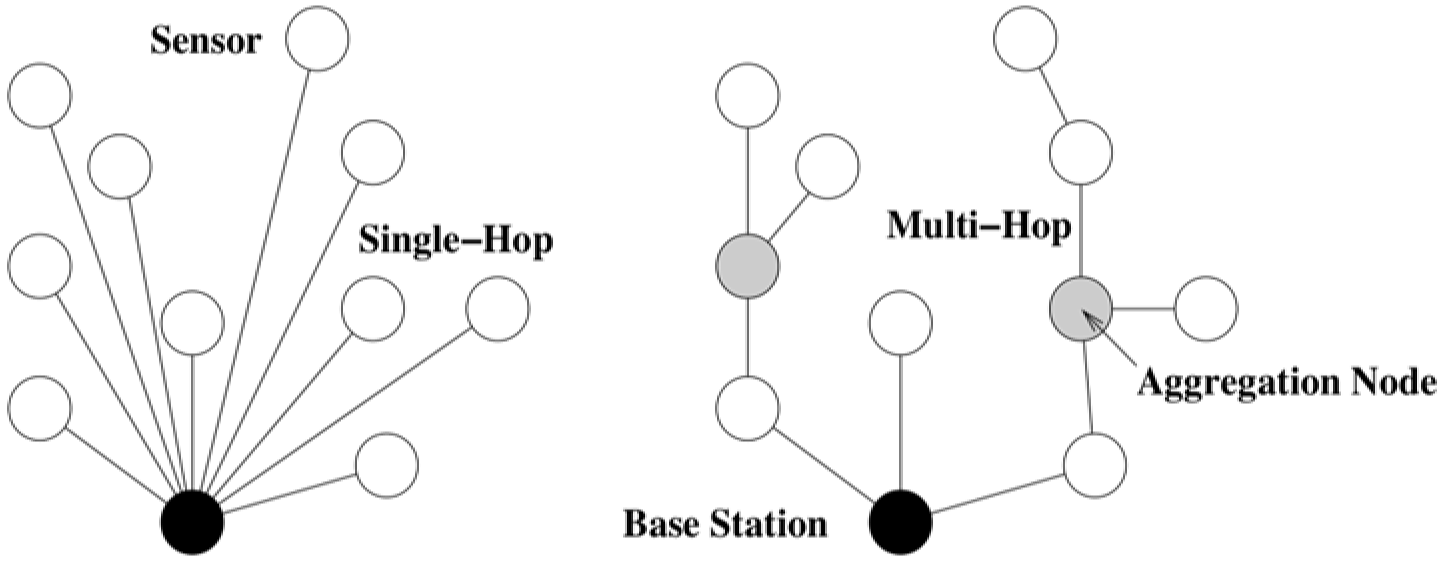
Architecture

- Multiple sensors (sometimes hundreds or thousands) form a network in order to monitor complex or large physical environments
- The collected information is transmitted wirelessly to a base station (BS), which then propagates it to other devices for storage, analysis and processing.



Single-Hop versus Multi-Hop

- Star topology: Each sensor communicates directly (single-hop) with the base station
  - May require high transmission power and may be unfeasible over a wide area Mesh topology
- The sensors act as forwarders for other nodes (multi-hop)
  - It can reduce energy consumption and increase the coverage
  - The routing issue arises



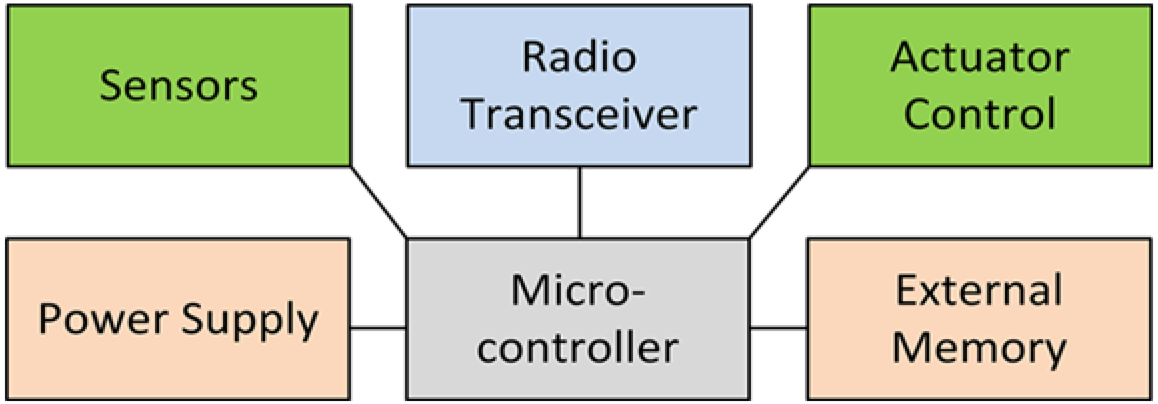
What is a Mote?

- **mote** *noun [C] LITERARY*
  something, especially a bit of dust, that is so small it is almost impossible to see
  ---Cambridge Advanced Learner's Dictionary
  http://dictionary.cambridge.org/define.asp?key=52014&dict=CALD

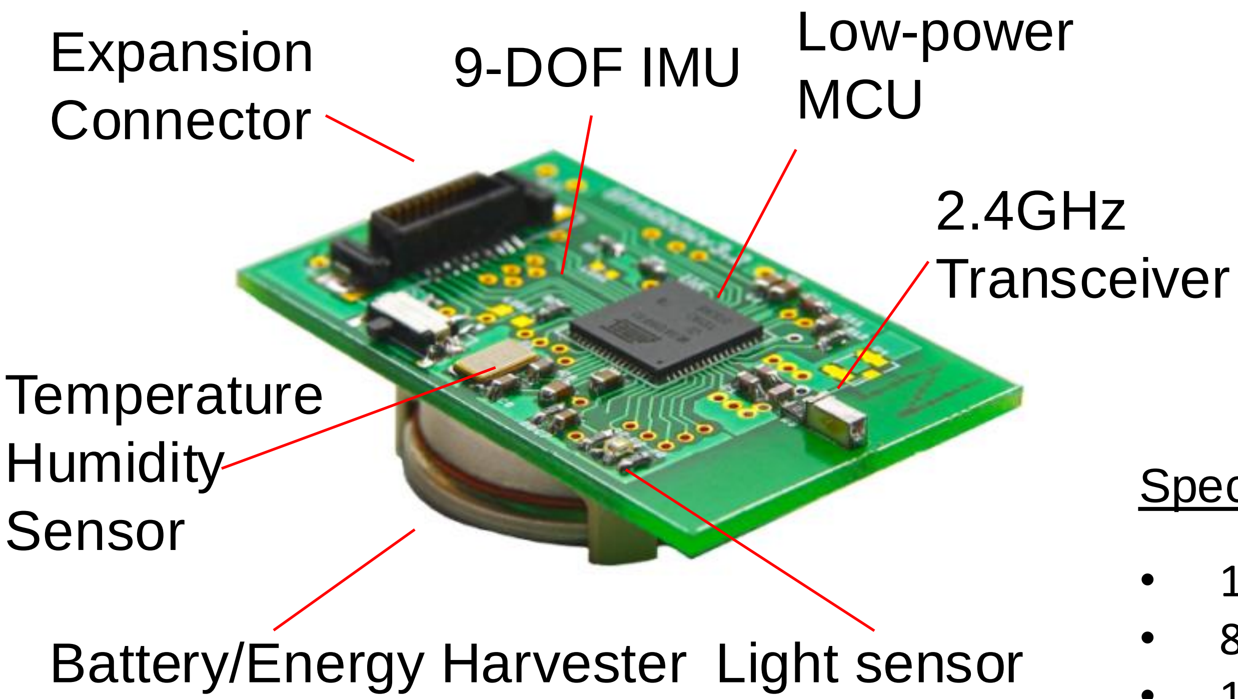
UC Berkeley hardware platform evolution

Node components

- Low-power processor
  - Limited computing power
- Memory
  - Limited capacity
- Radio
  - Low-power
  - Slow data rate
  - Limited range
- Sensors
  - Scalar: temperature, light etc.
  - Image sensors, microphones etc.
- Power supply



Exemplu: Sparrow



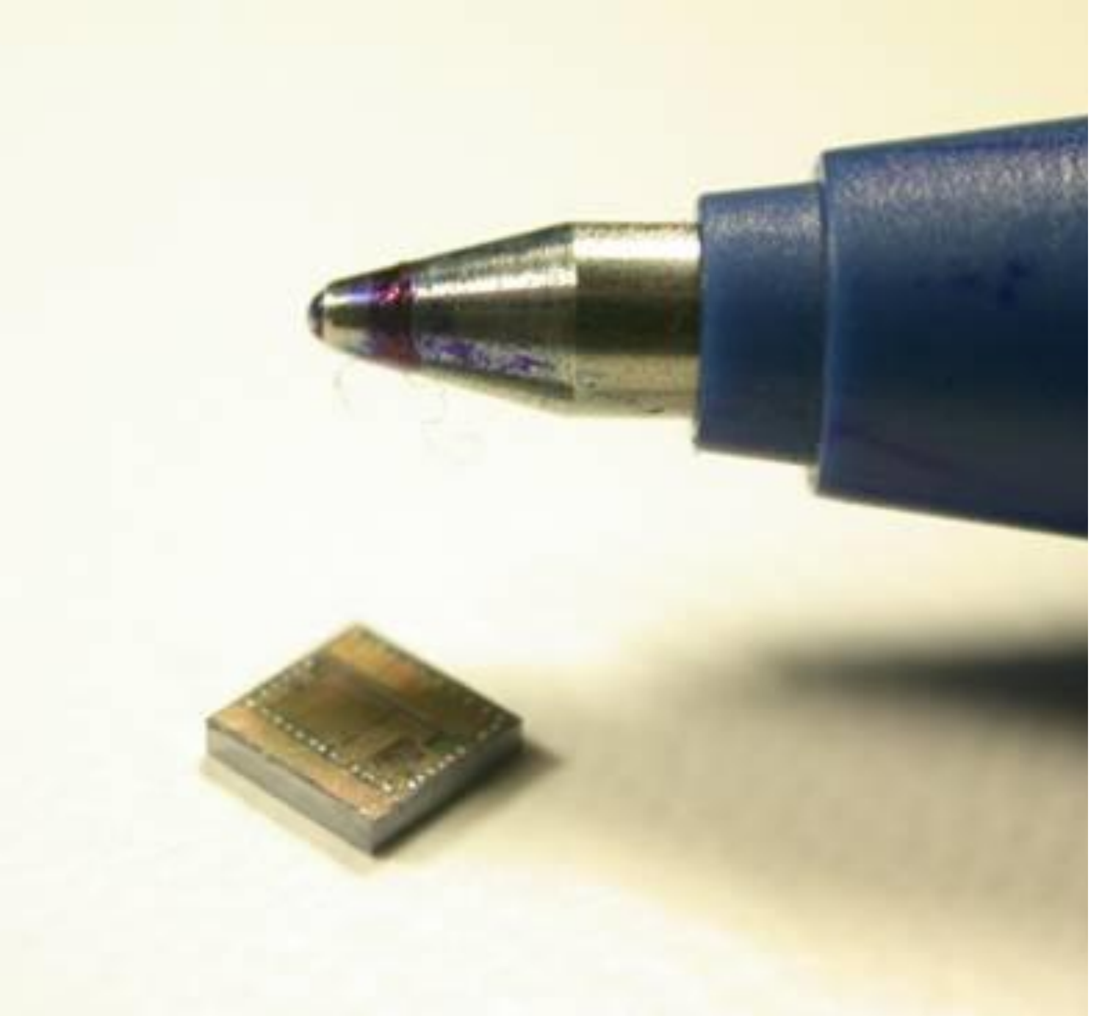
IEEE 802.15.4

256kbps transfer speed

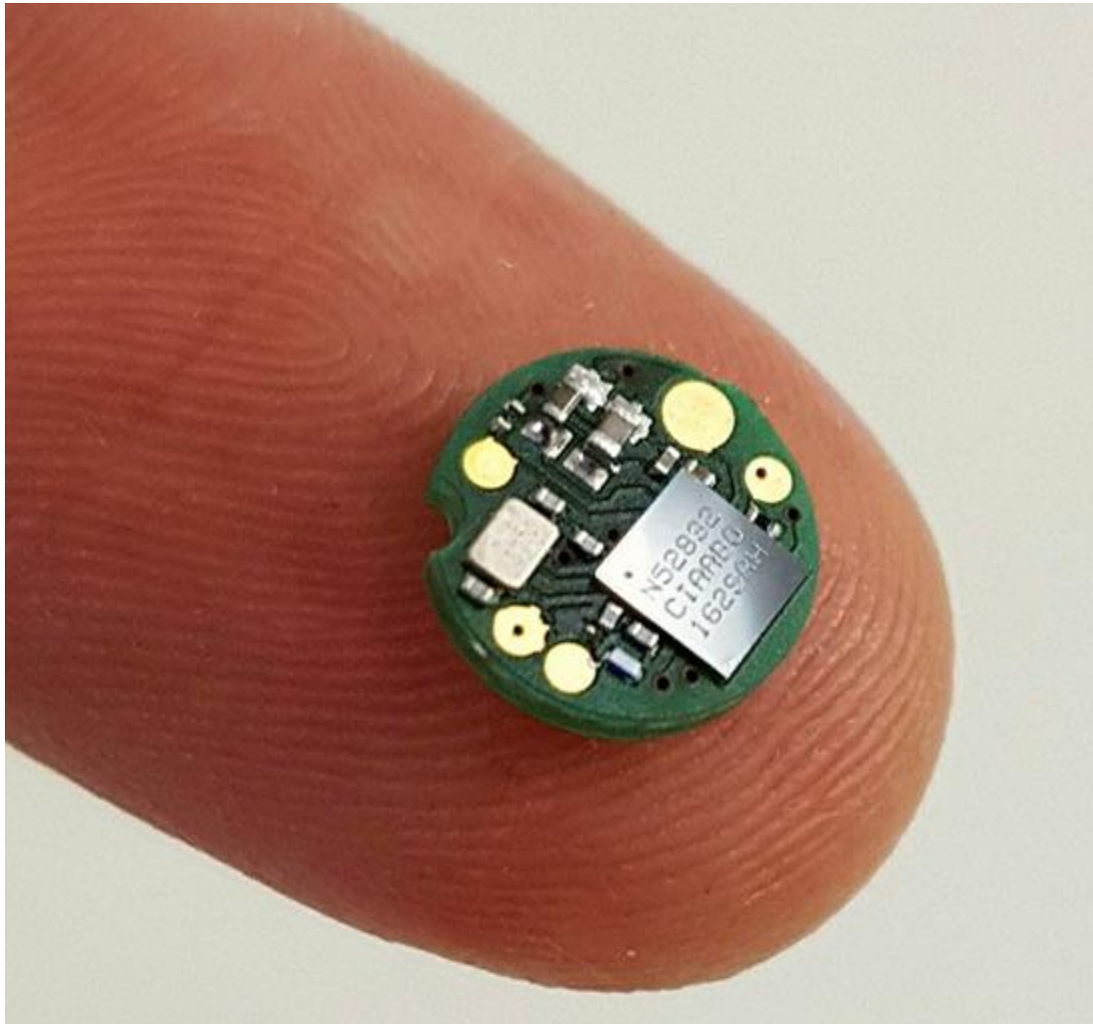
Specs:

- 16MHz
- 8KB RAM
- 128KB Flash
- ~ $10
- 50mW, 36uW (sleep)
- 7g, 50x30x5mm

- 4.77MHz
- 16-256KB RAM
- 160KB Floppies
- ~ $6,000
- ~ 64W
- 12kg, 500x140x400mm



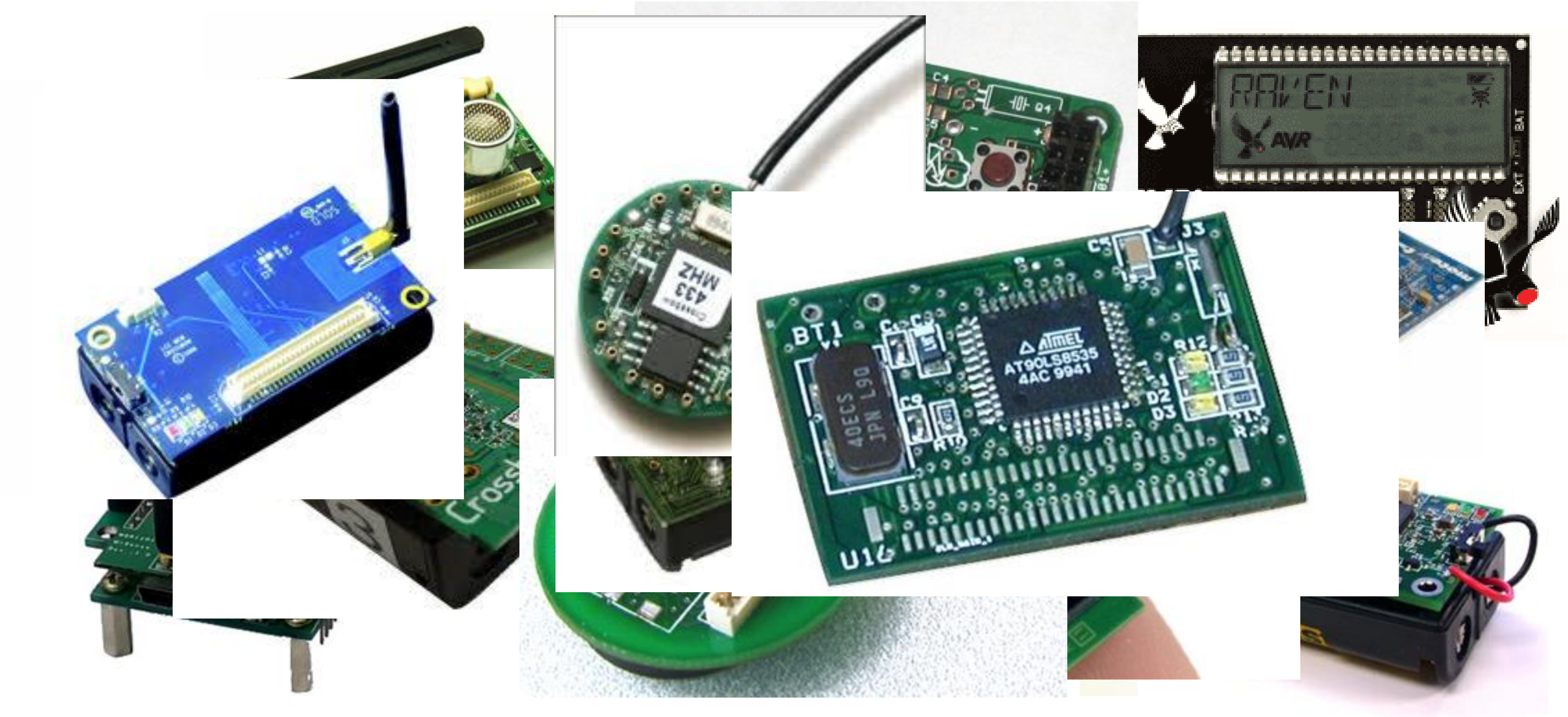
Berkeley Spec (cca. 2000)



UPB Microsal (cca. 2010)

…and many more

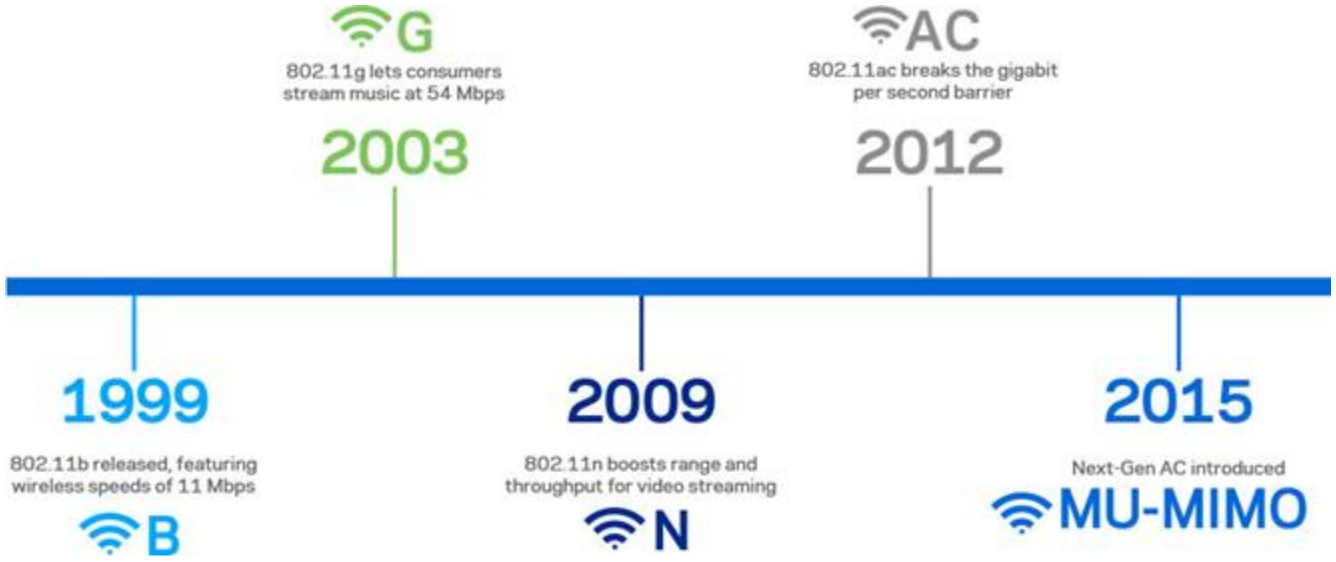
Embedded Systems Laboratory

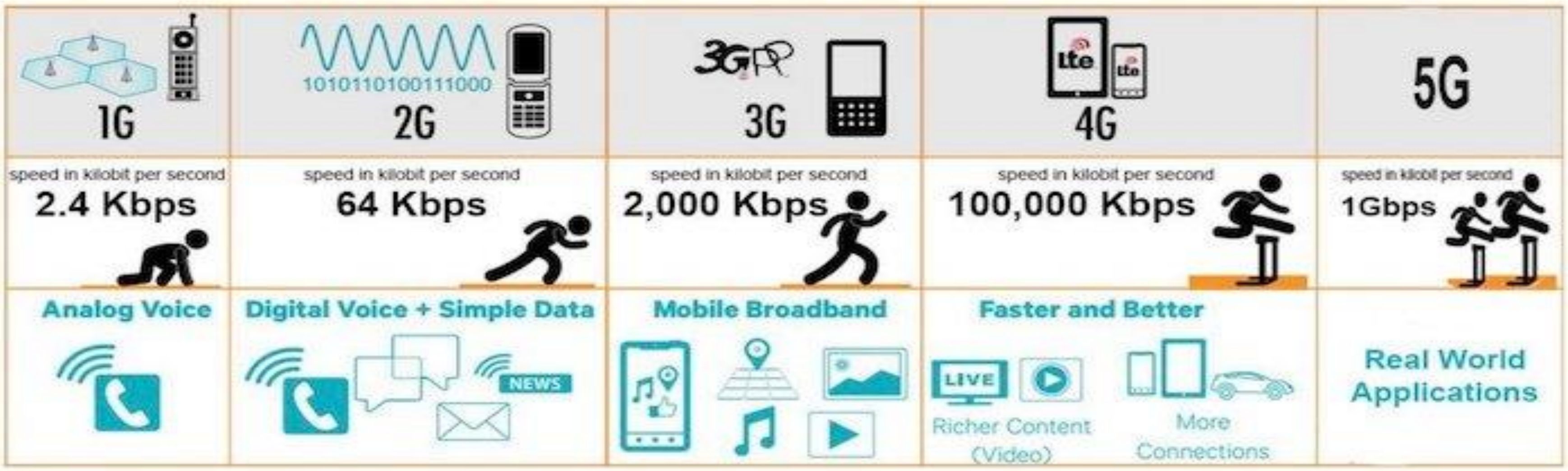


How did we get here?

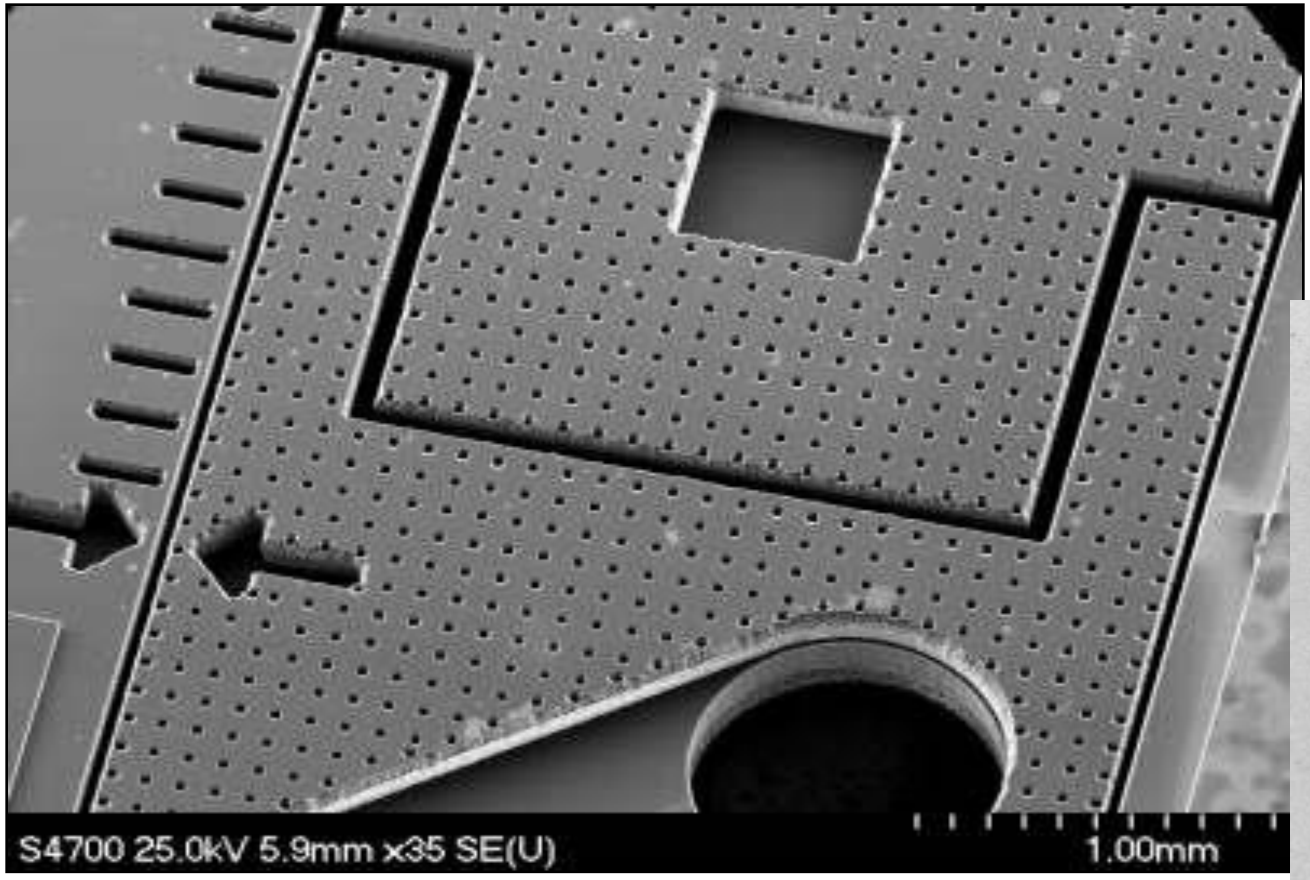
- Development of wireless technology
  - MEMS, VLSI
  - Bandwidth explosion
  - Cultural and legislative changes
- Wireless devices are everywhere and people are increasingly receptive to new applications
  - The concept of network (not only data) is a basic one in our society
  - Open source
- Computer Science
  - Network theory, operating systems
  - Cheap and universally available compilers

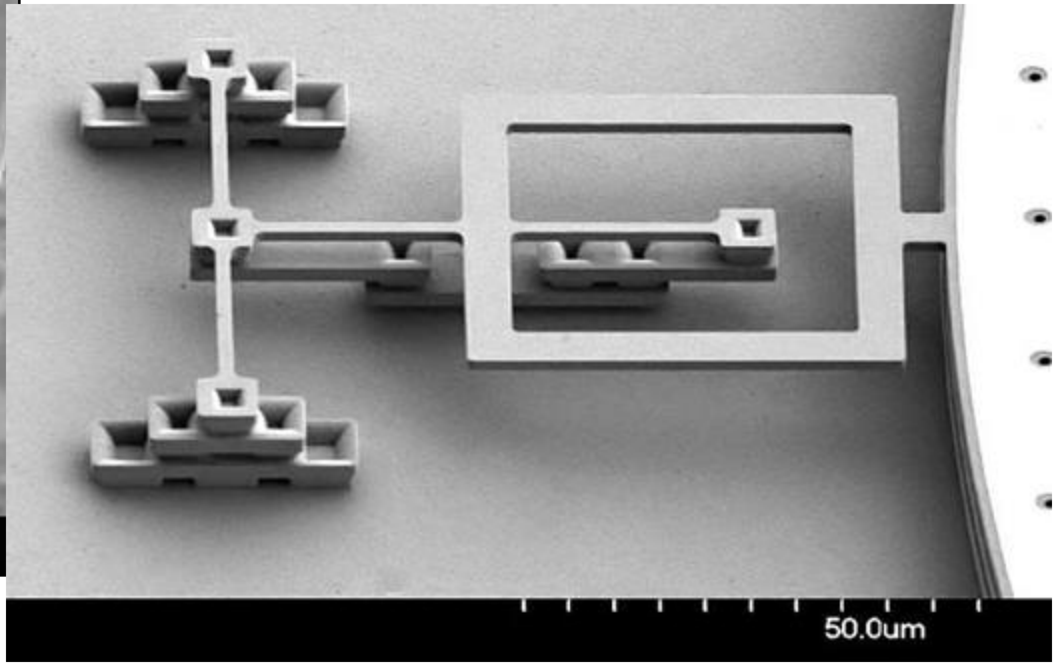
Wireless Bit Rates





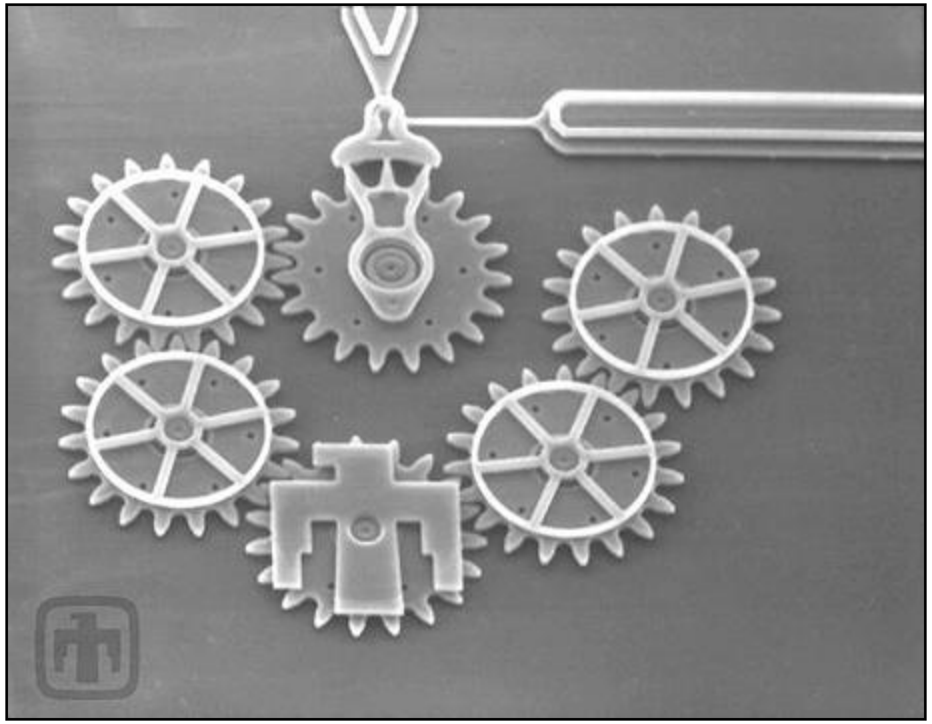
Micro-Electro-Mechanical-Systems (MEMS)



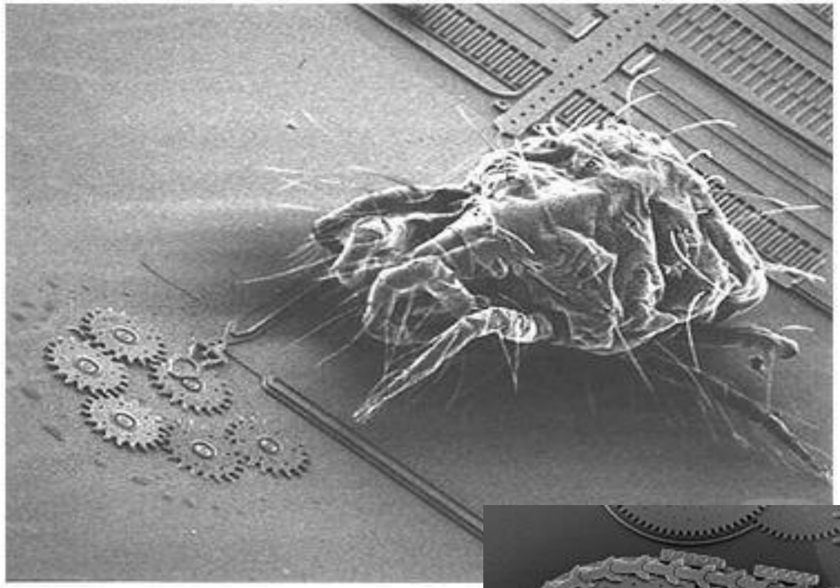


Micro-Electro-Mechanical-Systems (MEMS)

Embedded Systems Laboratory

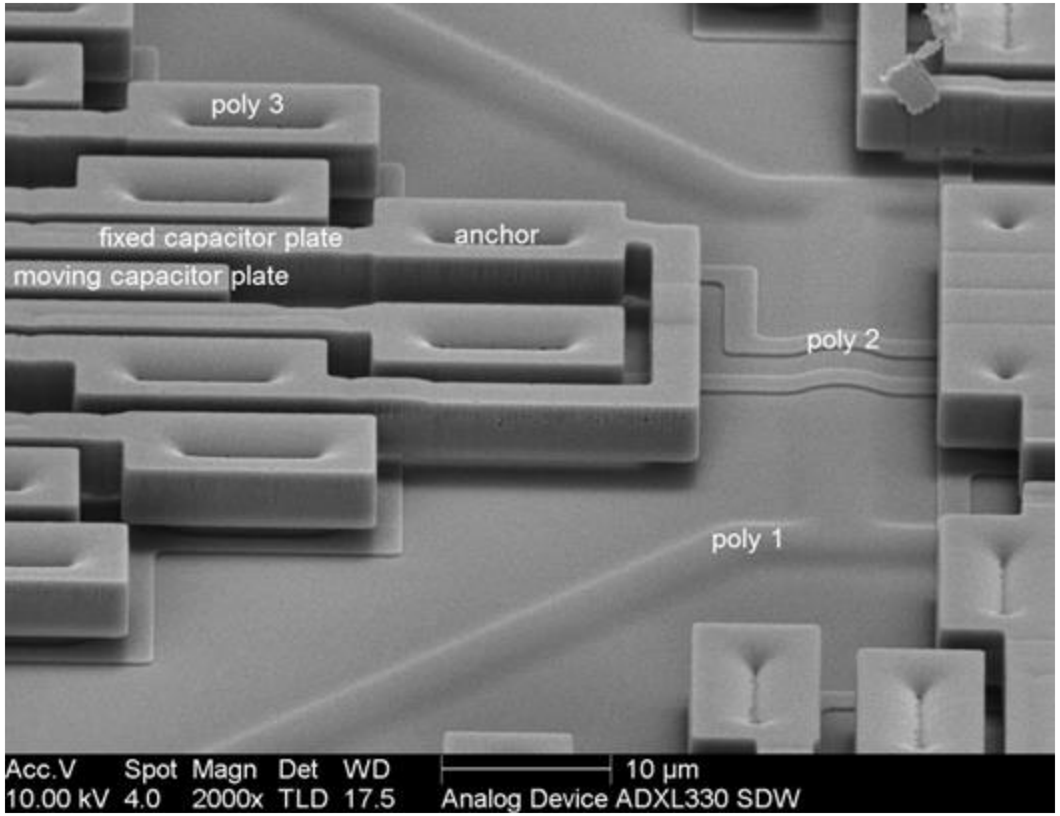


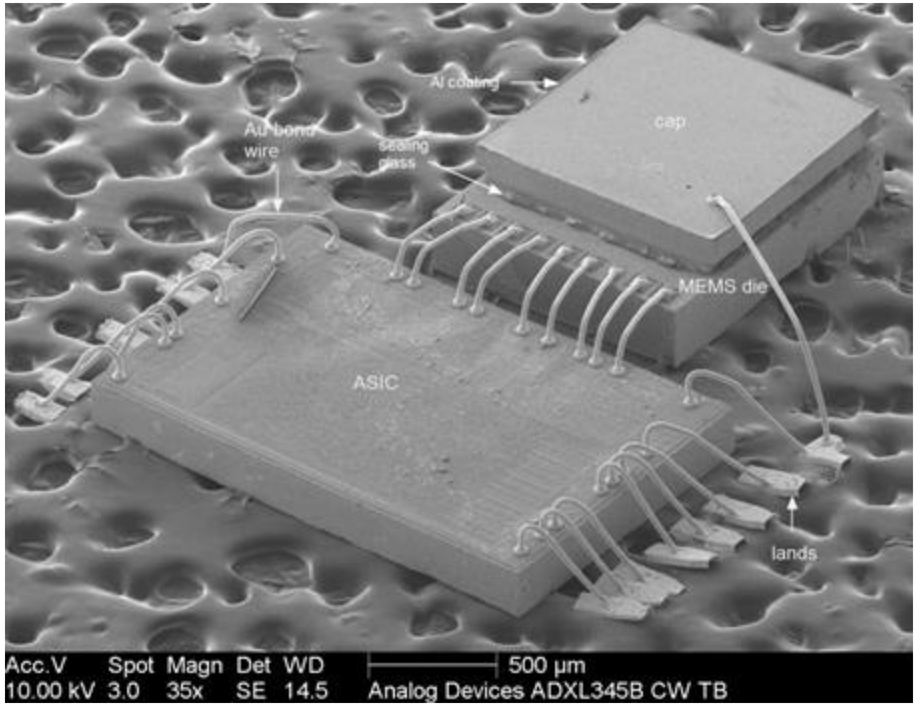
~ 1mm



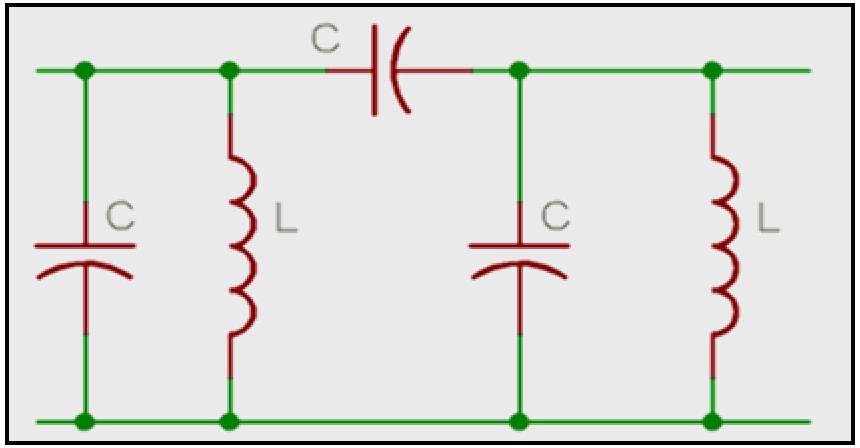
MEMS sensors

Accelerometers, gyroscopes, magnetometers, microphones, speakers etc.

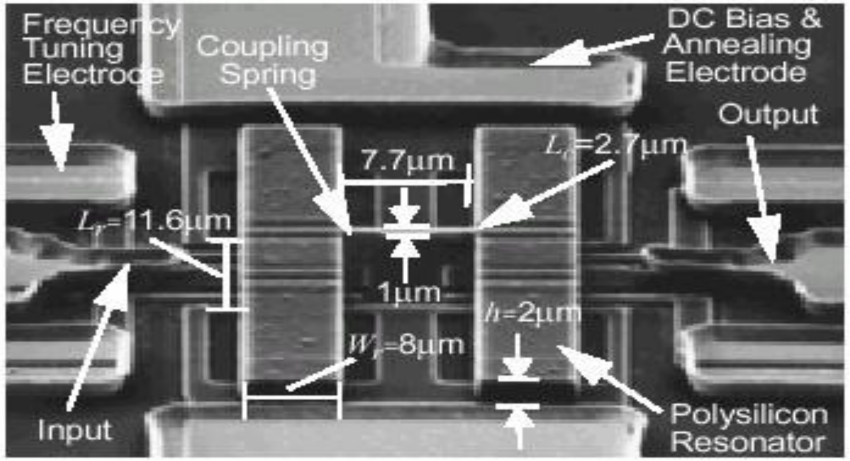


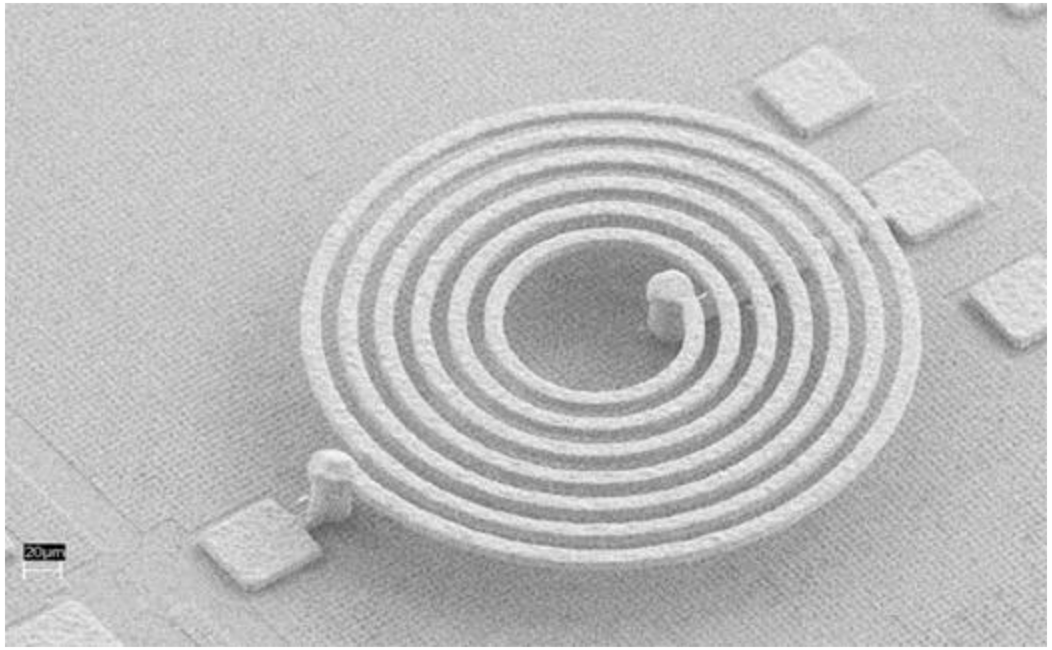


MEMS for RF



Conventional LC filter – Qs aprox. 100-200, takes a lot of space on PCB





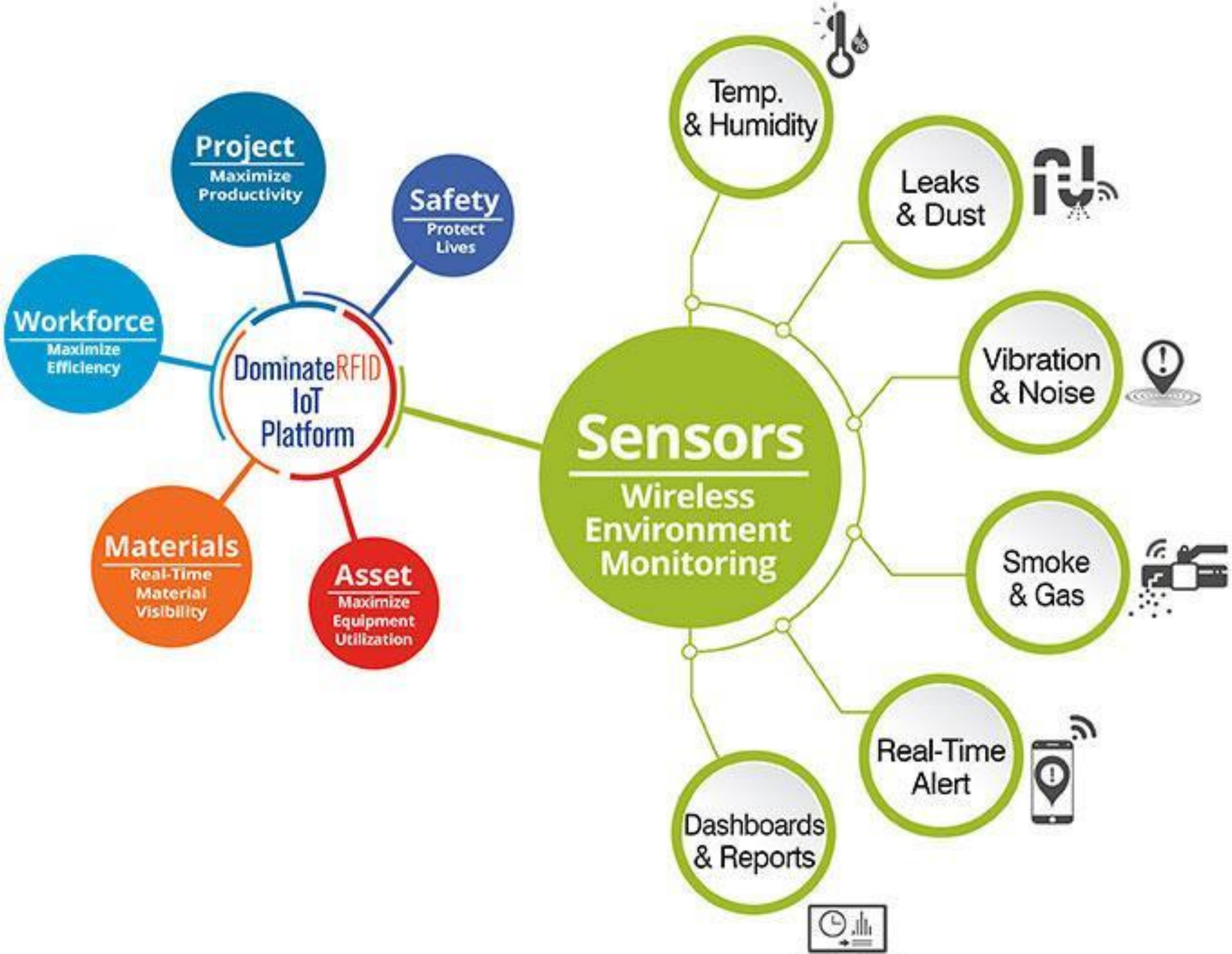
MEMS filter: Qs 98,000, REALLY small

Sensing Capabilities *Regular Smartphone

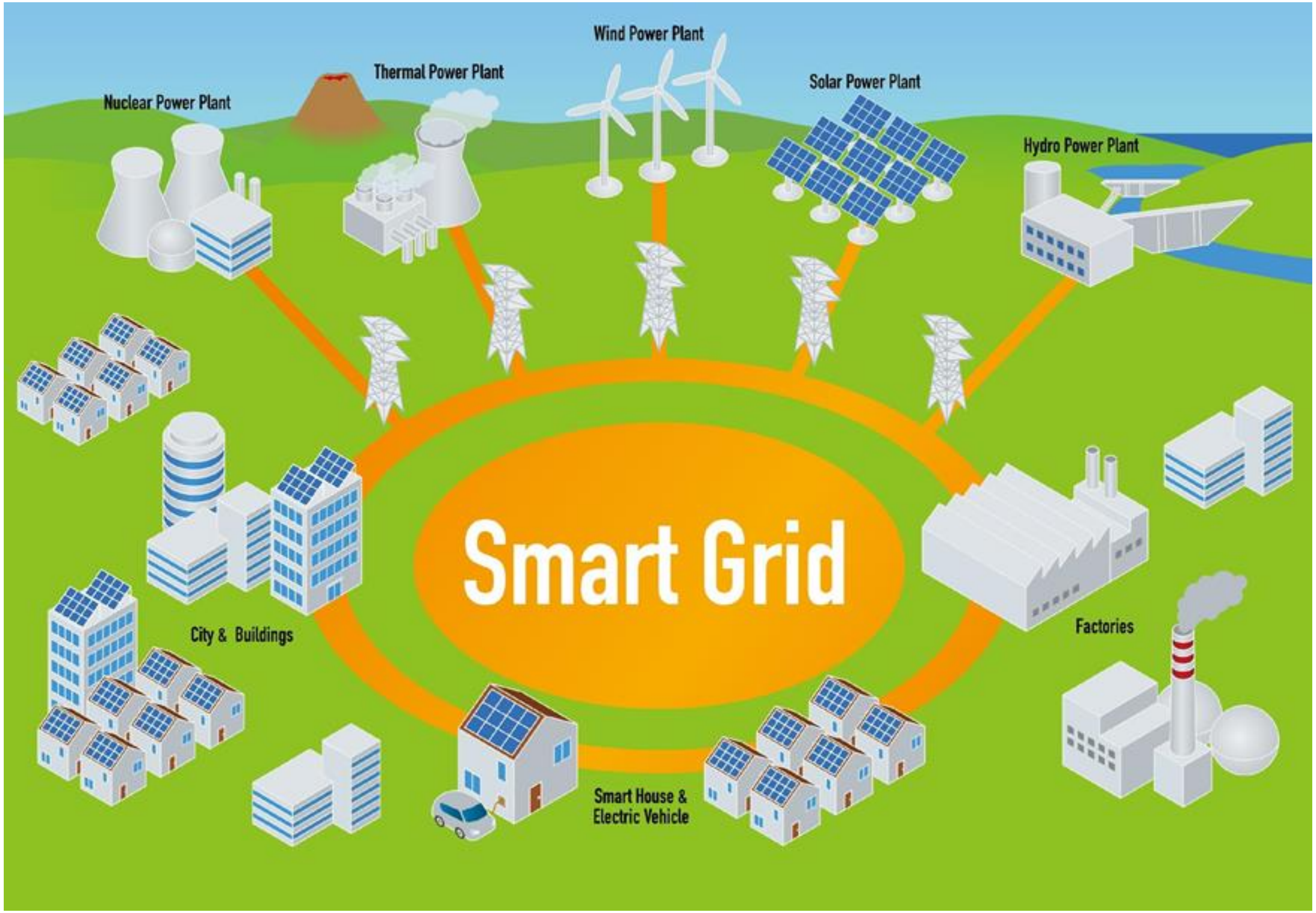
Smart City


Traffic Management
Education
Air Pollution
Open Data
Internet of Things
Smart Street Lights
Smart Parking
Electromagnet
Emissions
Smart Health
Water Quality
Smart Buildings
Public Safety
Smart Hon
Gas & Water
Leak Detection
Smart Environmen
Smart Energy
Electric Vehicle Charging
Waste Management

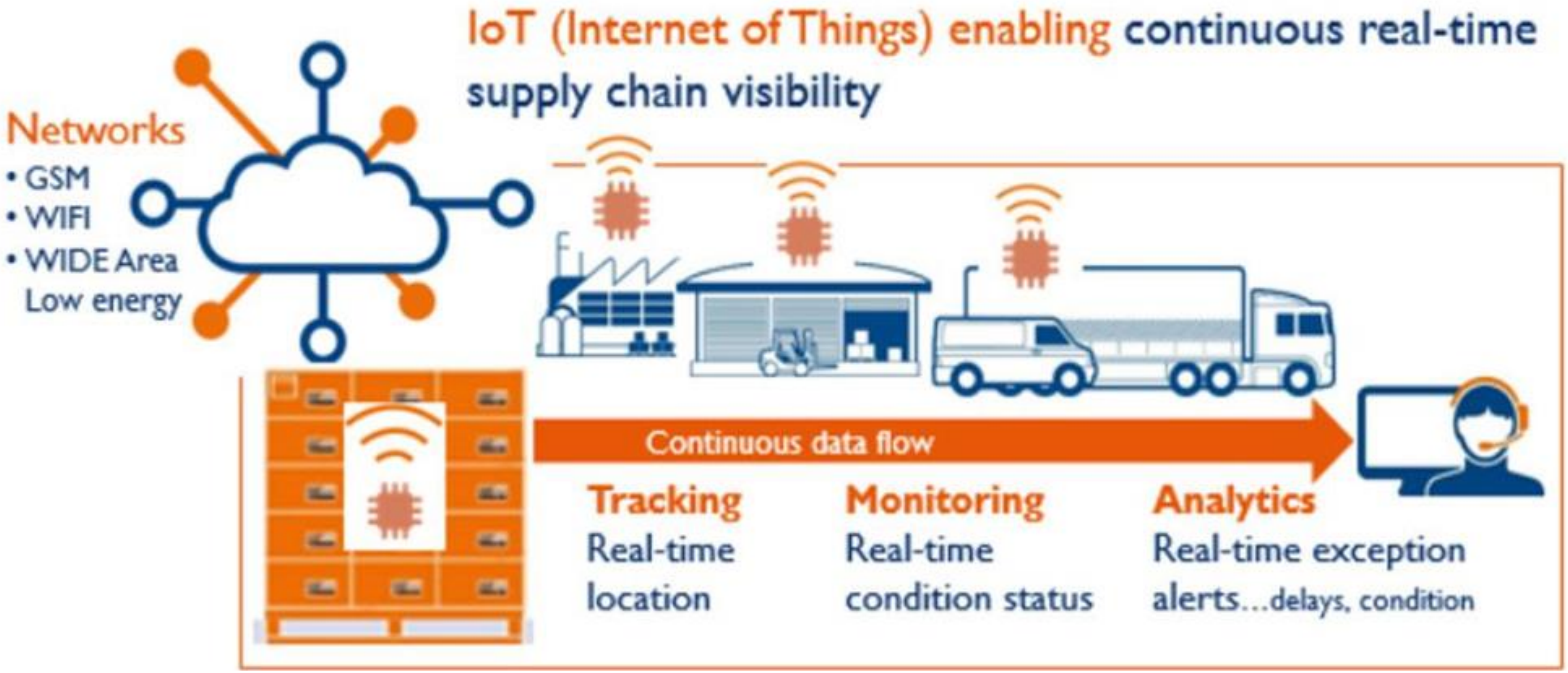
Environment Monitoring

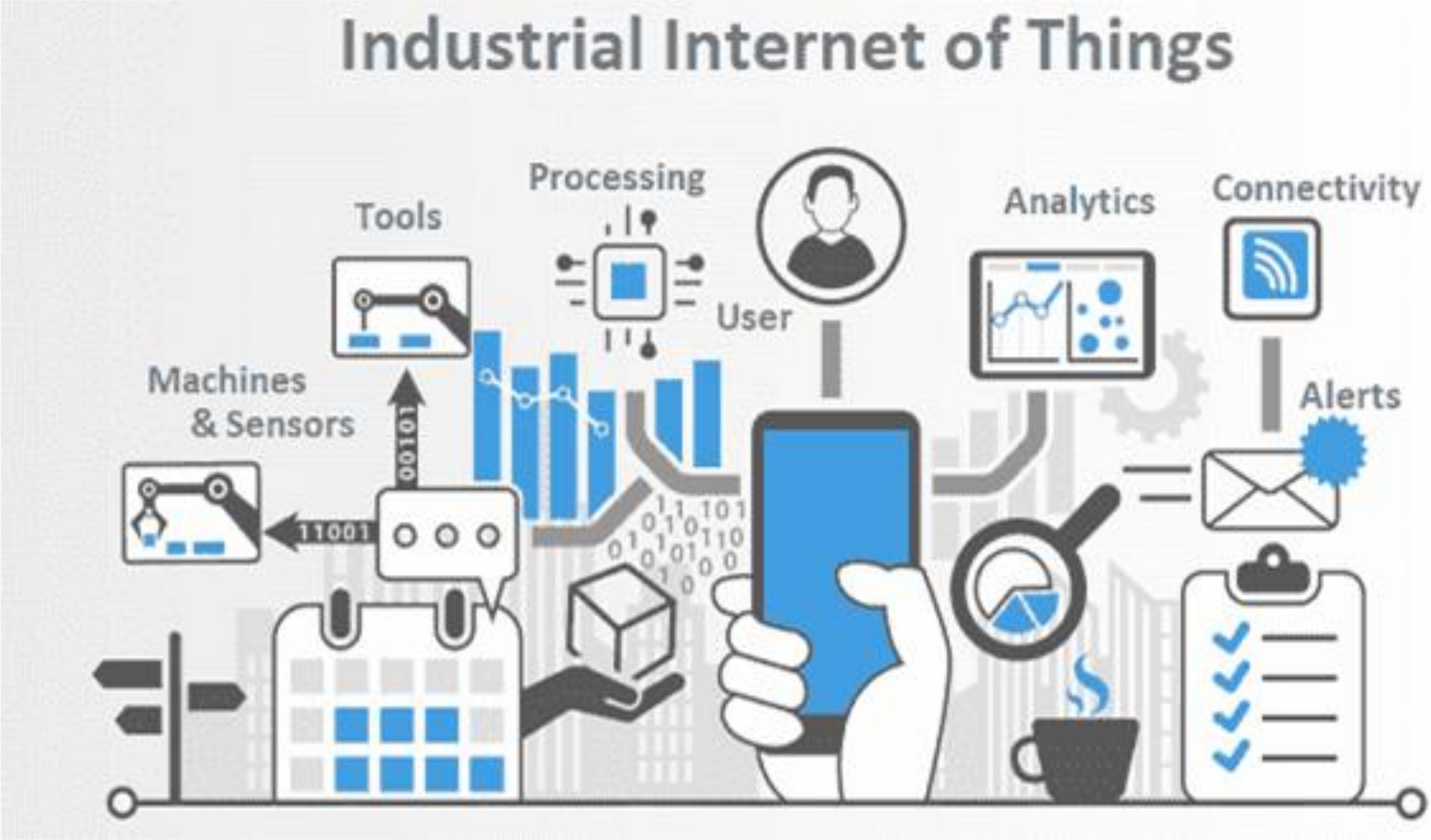


Energy Distribution



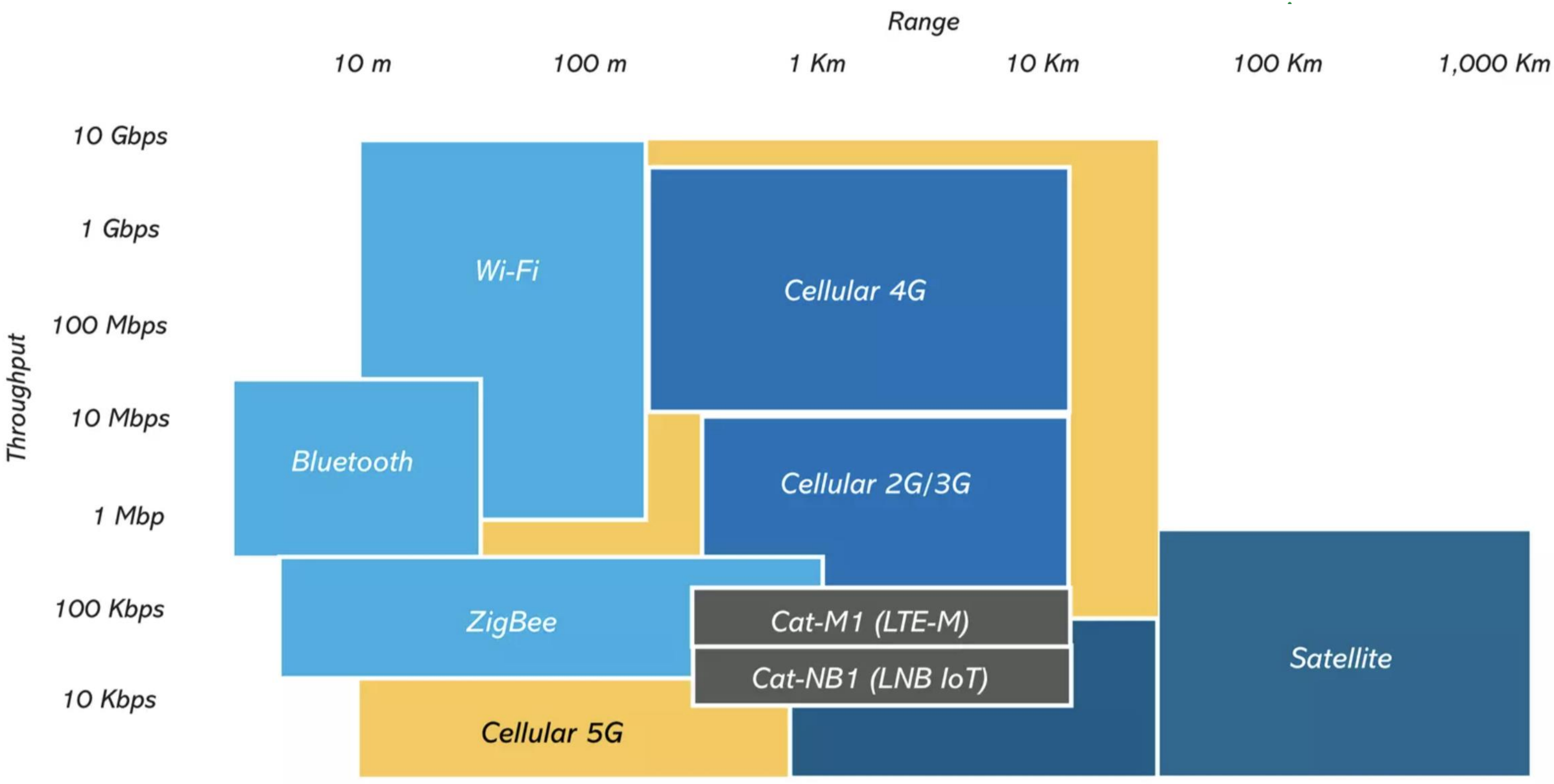
Supply Chain Management




Industrial Internet of Things
Processing
Tools
User
Analytics
Connectivity
Machines
& Sensors
Alerts
10100
11001

IoT Communication

- Characteristics
  - Low data rate (comparable to a dial-up modem)
  - Strong energy constraints
- IEEE 802.11 standard
  - The most common for wireless communication
  - For nodes without big energy constraints
- IEEE 802.15.4 is a standard for short-range communication, specially designed for WSN networks
  - Low data rate & power consumption
  - Widespread use in commercial solutions
- LoRa long range communication based on spread-spectrum modulation
  - Communication range up to several kilometers
  - Low power, low data rate (0.3kbps to 50kpbs per channel)

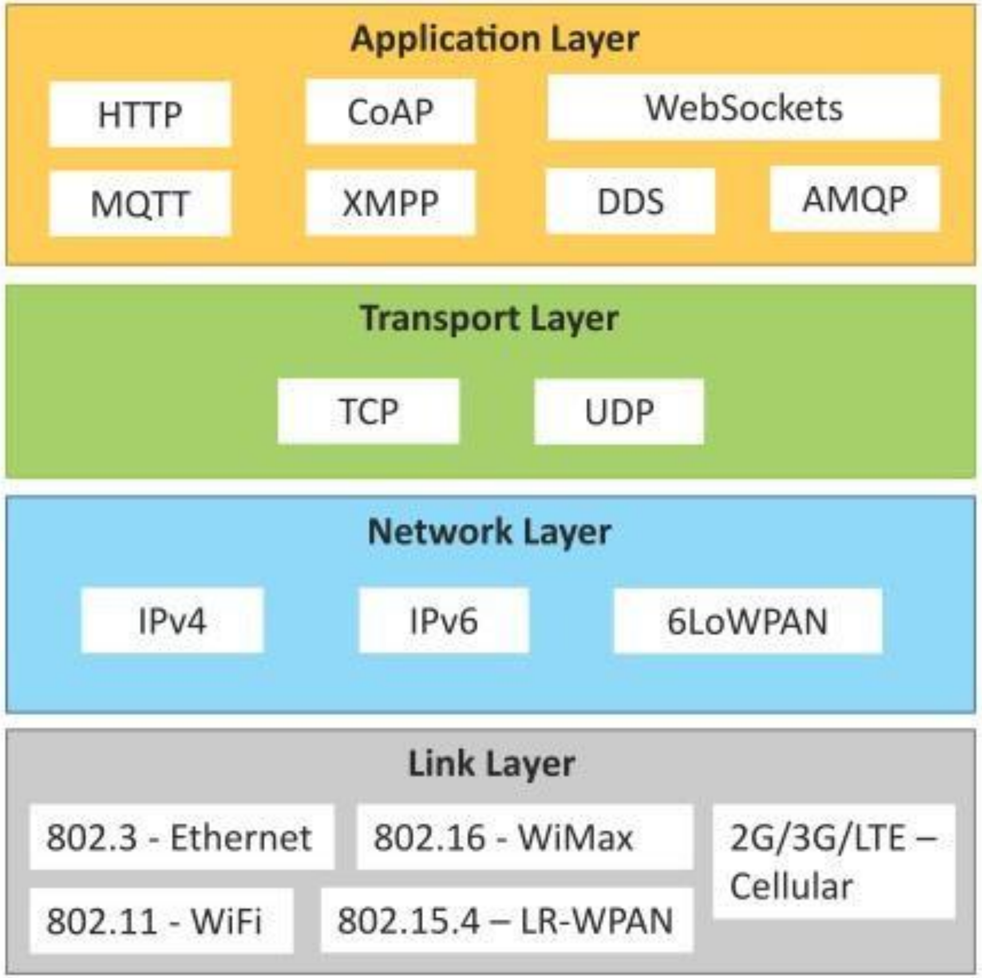

Range
10 m
100 m
1 Km
10 Km
100 Km
1,000 Km
Throughput
10 Gbps
1 Gbps
100 Mbps
10 Mbps
1 Mbp
100 Kbps
10 Kbps
Wi-Fi
Cellular 4G
Bluetooth
Cellular 2G/3G
ZigBee
Cat-M1 (LTE-M)
Cat-NB1 (LNB IoT)
Satellite
Cellular 5G

OSI Layers vs. IoT Layers

HTTP, FTP etc.	CoAP, MQTT etc.
TCP, UDP, ICMP	UDP, ICMPv6
BGP, SPF, OLSR	IPv6, RPL
IPv4, IPv6	6LoWPAN
802.3, 802.11 MAC, Data Link	802.15.4 MAC
802.3, 802.11 PHY	802.15.4 PHY

IoT Protocols

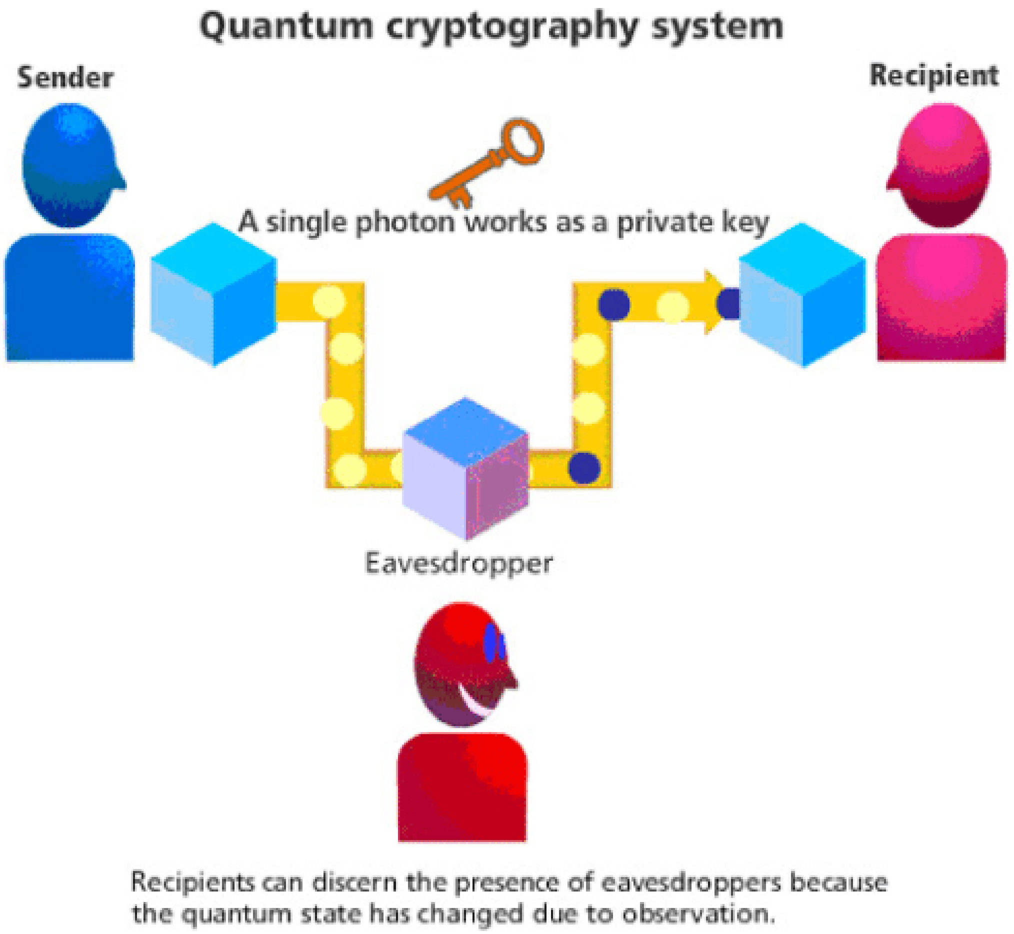
- Link Layer
  - 802.3 – Ethernet
  - 802.11 – WiFi
  - 802.16 – WiMax
  - 802.15.4 – LR-WPAN
  - 2G/3G/4G
- Network/Internet Layer
  - IPv4
  - IPv6
  - 6LoWPAN
- Transport Layer
  - TCP
  - UDP
- Application Layer
  - HTTP
  - CoAP
  - WebSocket
  - MQTT
  - XMPP
  - DDS
  - AMQP



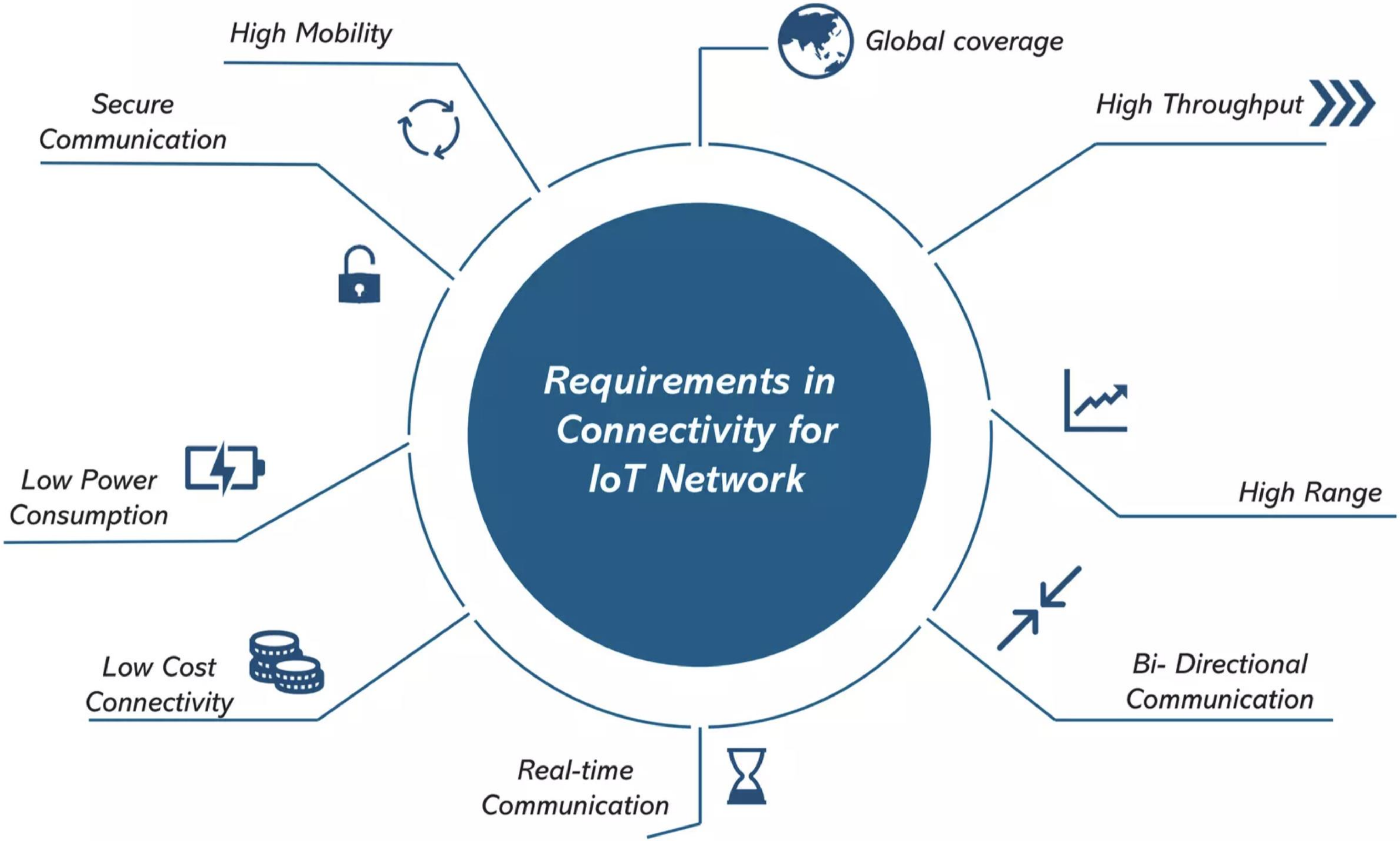
Case Study: IoT & Quantum Computing

IoT & Quantum Computing Convergence

- IoT networks have inherent security issues
  - Subject to multiple types of attacks (data breaches, side channel attacks, man in the middle, data authentication etc.)
  - Encryption schemes and hardware acceleration is limited
- Quantum cryptography could be the point of convergence
  - Using entangled photons to transmit keys
  - In conjunction with regular secret-key methods



Case Study: Satellite Communication for IoT Networks


Requirements in Connectivity for IoT Network
High Mobility
Global coverage
Secure Communication
High Throughput
Low Power Consumption
High Range
Low Cost Connectivity
Bi- Directional Communication
Real-time Communication

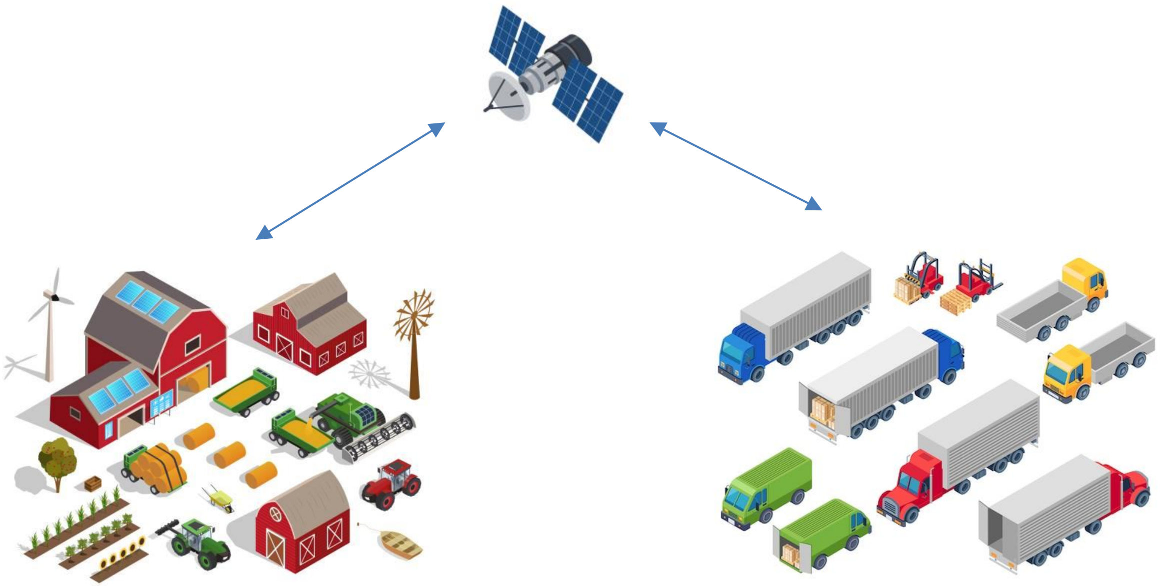
Satellite IoT Benefits

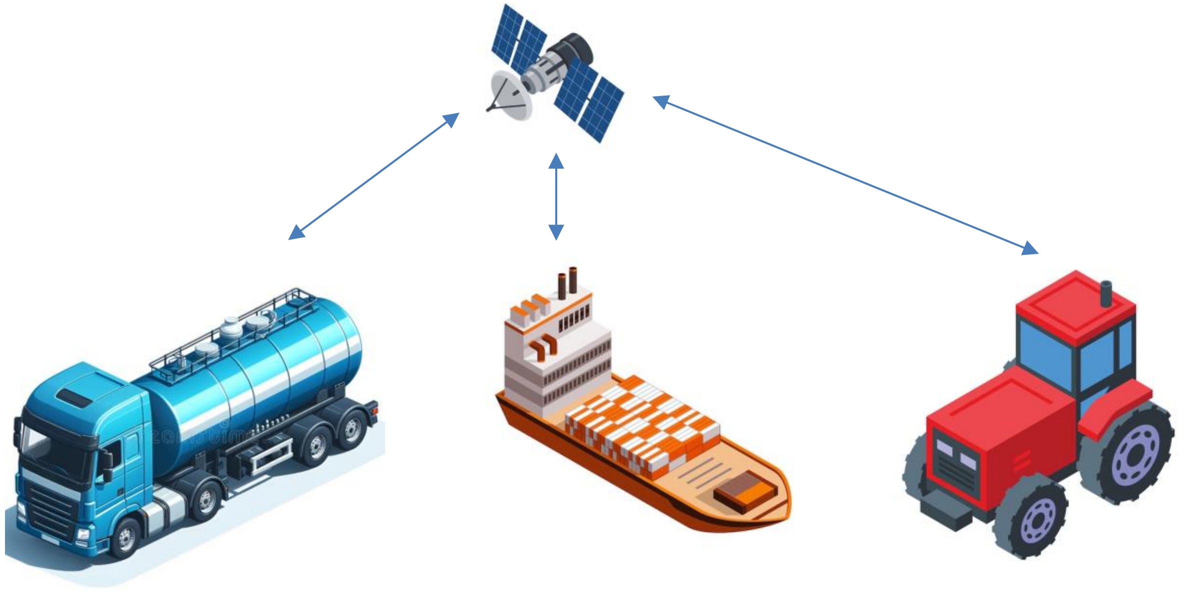
- Global connectivity
- Bridging connectivity gaps
- Reliable and continuous coverage
- Some applications:
  - Precision farming
  - Environmental monitoring
  - Maritime tracking


LEO
160 - 2000 Km
Lower Launch Cost
MEO
200 - 34000 Km
Path Loss > LEO
GEO
~36000 Km
Constant View

Parameters	LEO Satellites	GEO Satellites
Weight	<10 kg	< 10,000 kg
Size	Nanosatellites	Traditional satellites
Distance from Earth	500-1500 km	~36,000 km
Orbital Period	10-40 minutes (orbit the earth multiple times in a day)	24 hours
Satellite Life	Short	Long
Number of handoffs	High	Low
Path Loss	Low	High
Cost	Low	High
Coverage	Low	High
Latency	Low Latency	High

Satellite IoT Topology





IoT Aggregation

- Lower terminal density
- High Power – high data rates
- Suitable for localized deployments
- Usually IP protocol
- Examples: BGAN, VSATs

Direct to Satellite

- High terminal density
- Low Power – low data rates
- Suitable for wide area deployments
- Proprietary messaging protocols
- Examples: Inmarsat IDP, Iridium SBD, Globalstar, SmallSat IoT

Example: Starnote

- Satellite connectivity module for IoT
- $49, 18kB data included
- US, Canada, Western Europe coverage (Skylo)

https://blues.com/starnote/

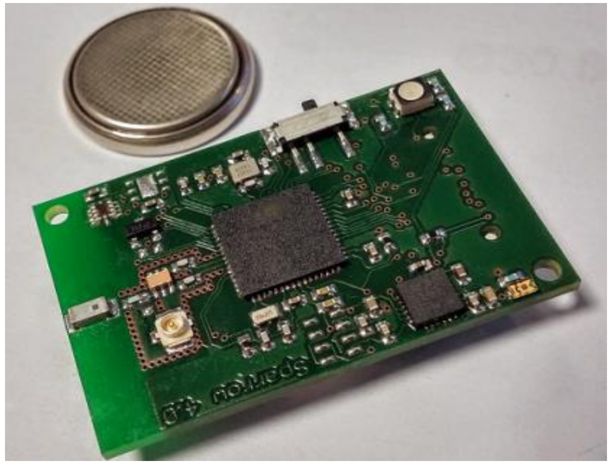
What's Next?

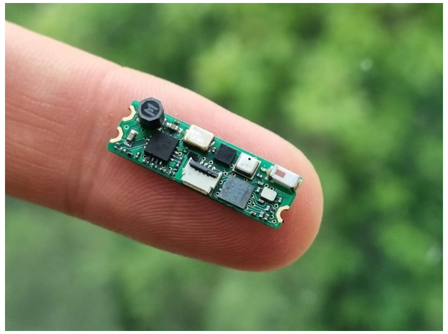
- Satellite & Cellular Convergence
- Growth & Global Connectivity
  - Most likely it's not going to be only satellites
- New Chipsets
  - Seamless transition between multiple protocols
- Scaling Costs & Pricing
  - Current costs are $80 - $350 per device and $10 - $35 for connectivity/month

IoT Research @ Politehnica

IoT Research @ UPB

- Sparrow - Wireless Sensor Network creată special pentru studiul energy harvesting
- Ultra Low-power
- Poate rula o multitudine de sisteme de operare și stive de protocol

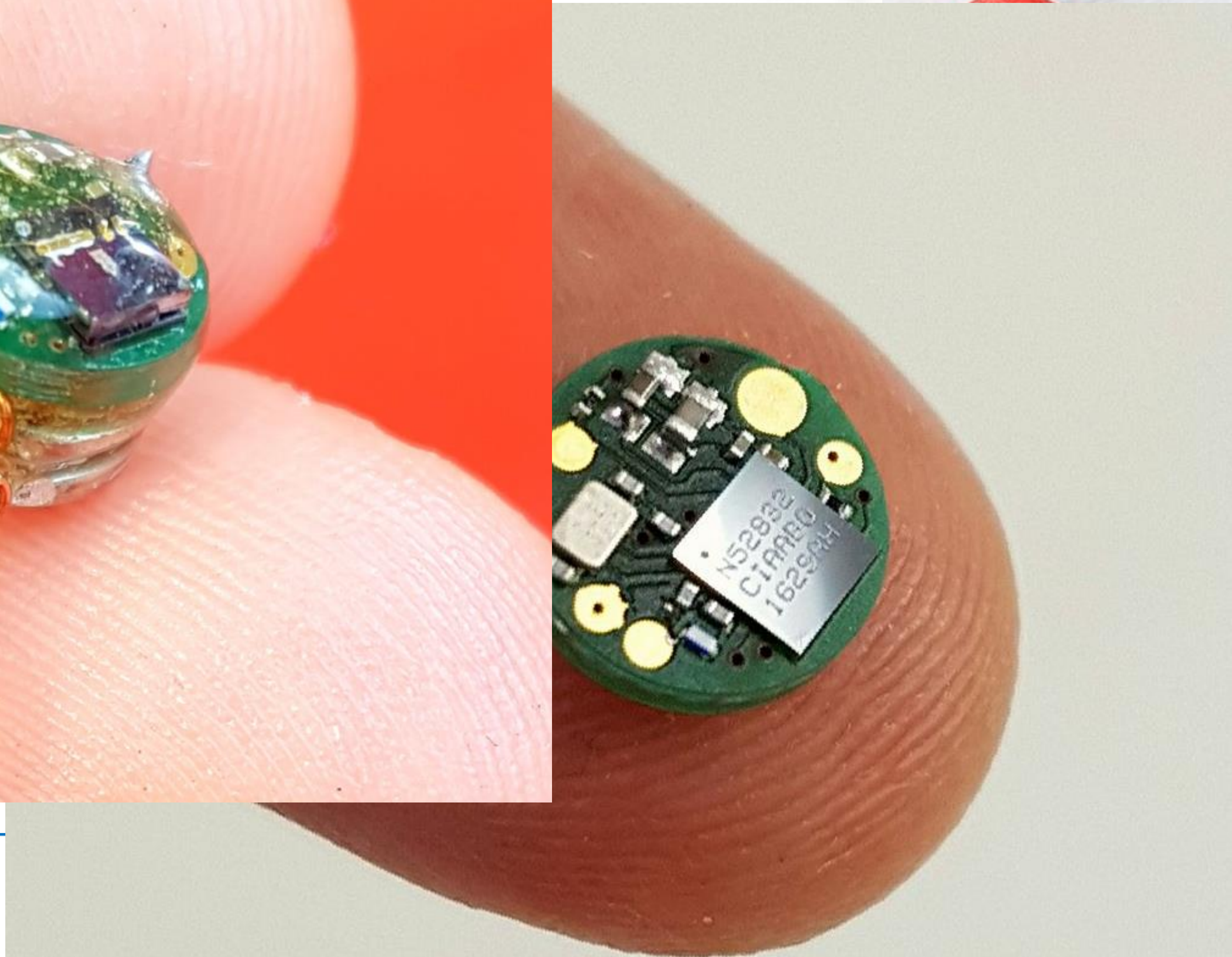


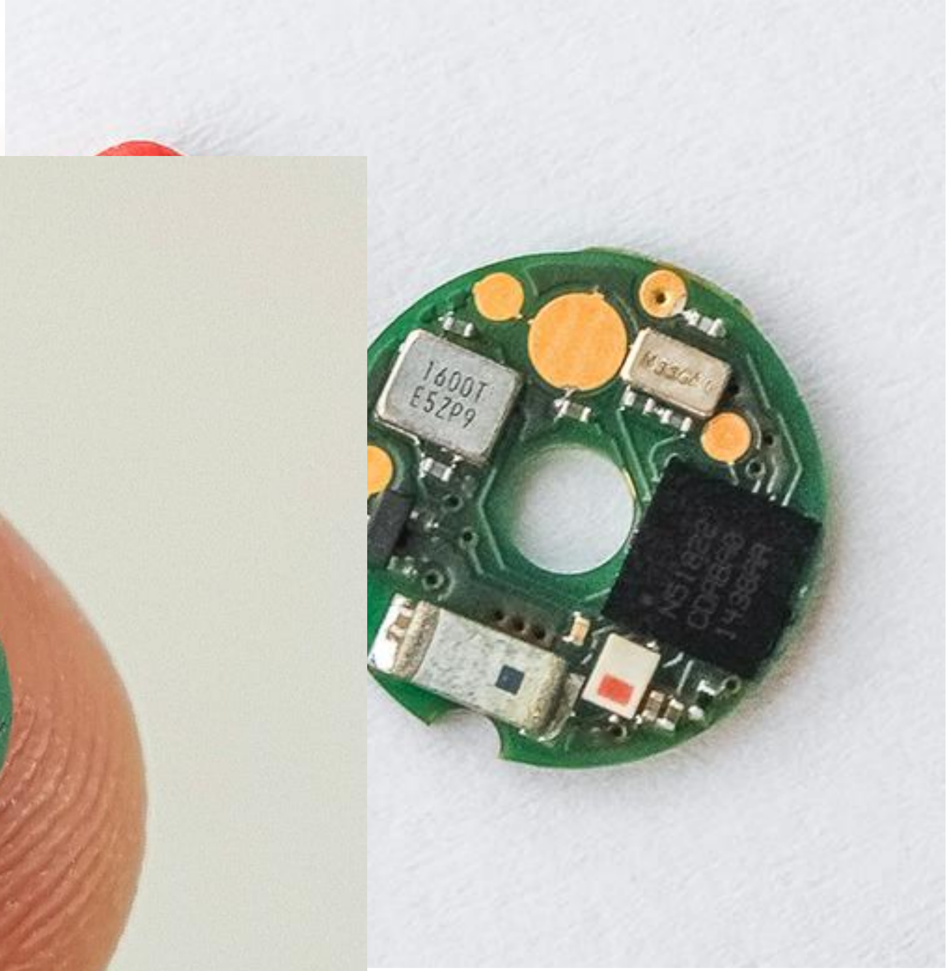


- Arduino compatible!
- Autonomie măsurată în ani de zile sau infinită

Microsal – Salivary Pacemaker

Embedded Systems Laboratory





TinySense

- Solar Energy Harvesting
- True battery-less operation
- Environmental sensors