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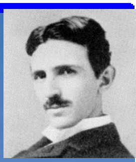
WCRG Wireless Communications Research Group



4COSC003W.2:
Trends in Computer Science
The Internet of Things (IoT)

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London W1W 6UW, UK

30 November 2022

THE INTERNET OF THINGS

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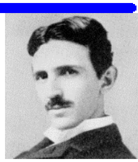

4COSC003W.2:
Trends in Computer Science
Topic: The Internet of Things (IoT)

Lecture Notes

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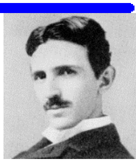

Module 4COSC003W.2: Trends in Computer Science

Topic: The Internet of Things (IoT)

- *Hi ! My name is Dr. Djuradj Budimir*
- *This lecture will consist of about 100+ slides*
- *I am in room 2.106/107, Tel extn. 65139*

My Web: https://www.westminster.ac.uk/about-us/our-people/directory/budimir-djuradj#about

Web-WCRG: https://www.westminster.ac.uk/research/groups-and-centres/wireless-communications-research-group

You Tube: http://www.youtube.com/watch?v=gTCSPtuO1Go

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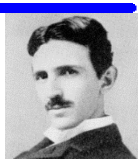

Content

1. Introduction to the Internet of Things (IoT)
   - What is the IoT?
   - Evolution of the IoT and IoT Impact
   - Elements/Components of an IoT
   - How an IoT system works?
   - IoT applications
2. IoT-Connectivity and Networks Technologies
   - Characteristics and Communications Criteria
     - Range: Short, Medium and Long Range
3. Real life IoT Examples:
4. IoT Security
5. Recommended Reading list

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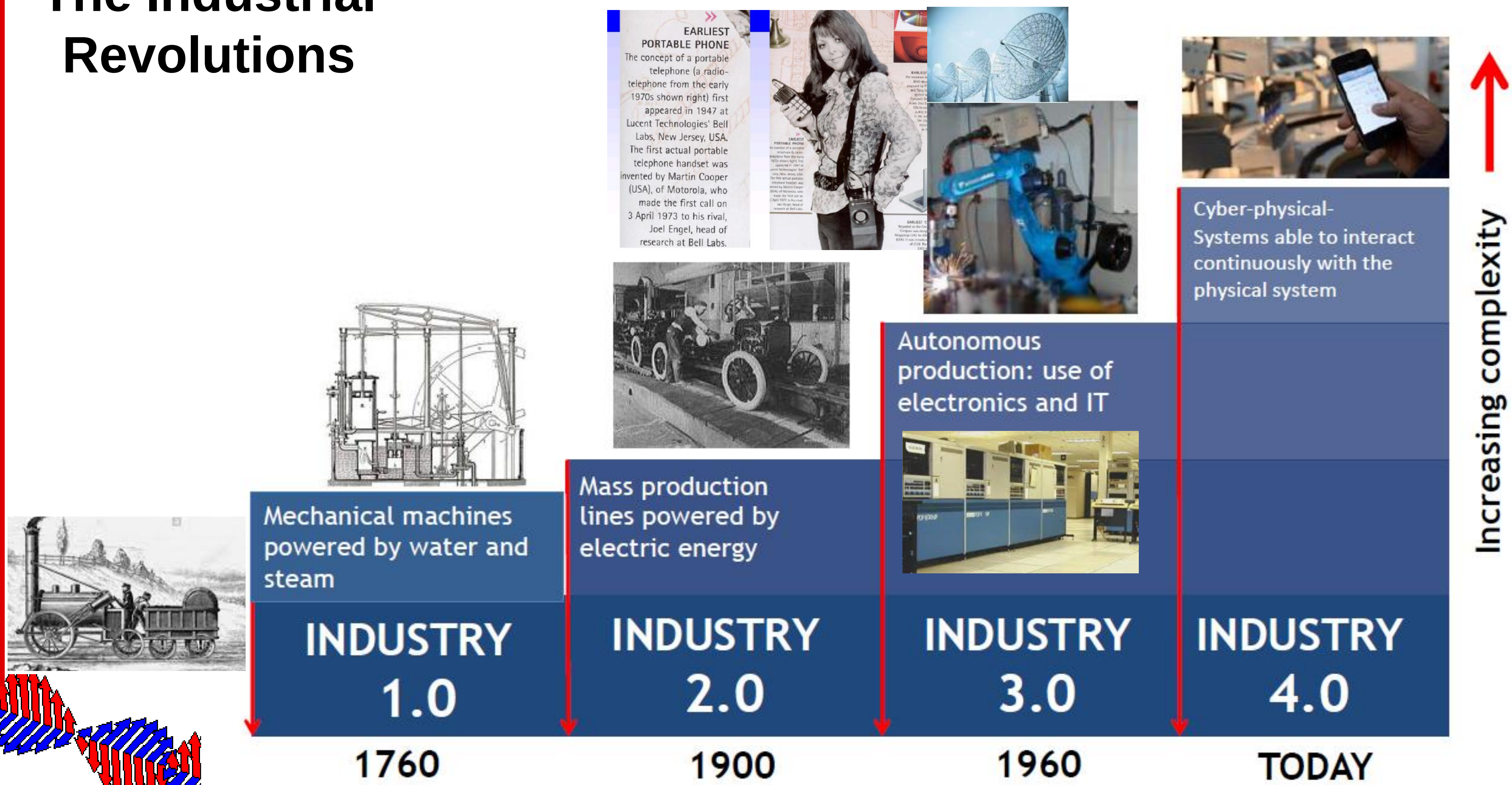
The Industrial Revolutions



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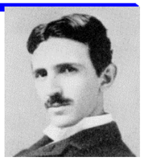
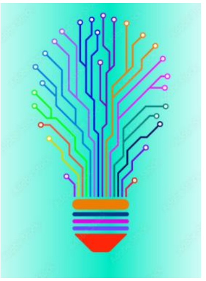
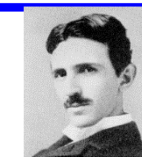


4th Industrial Revolution: Industry 4.0

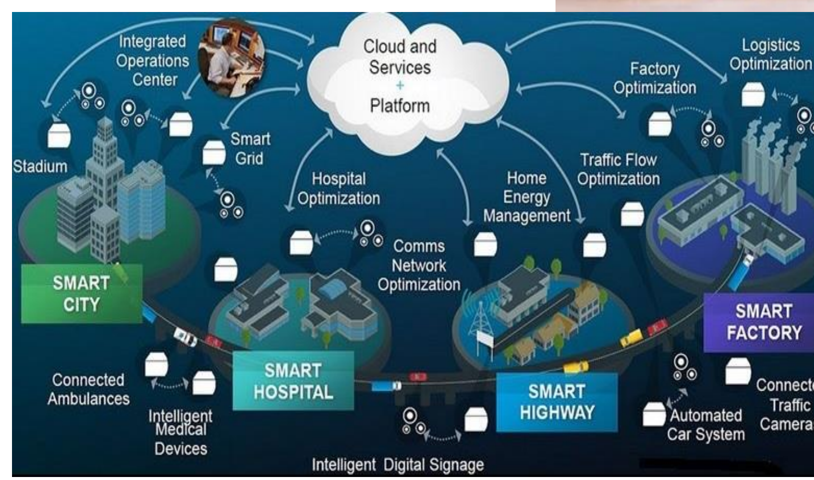


- It is a revolution happening now. We are experiencing it every day, and its magnitude is yet unknown
- Industry 4.0 started with the Internet (I became aware about it in 90s)
- Develops virtual reality worlds, allowing us to bend the laws of physics
- Ongoing automation of traditional manufacturing and industrial practices, using **modern smart technology**.



4^{th} Industrial Revolution: Industry 4.0

- Large-scale machine-to-machine communication (M2M) and the internet of things (IoT) are integrated for increased automation, improved communication and self-monitoring, and production of smart machines that can analyze and diagnose issues without the need for human intervention
- Creation of fully autonomous technical systems
- Cloud computing, cognitive computing, artificial intelligence
- Smart sensors, IoT and 5G (6G, 7G, 7G+) technologies



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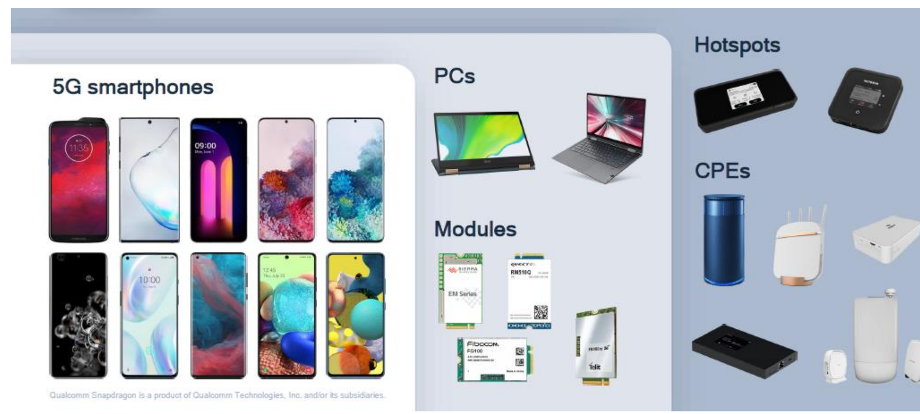
Historical Perspective

THE INTERNET OF THINGS

1890

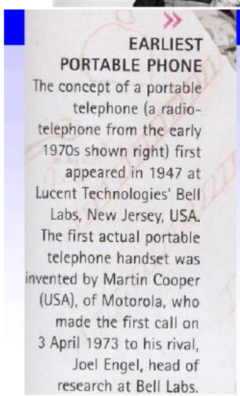
Now



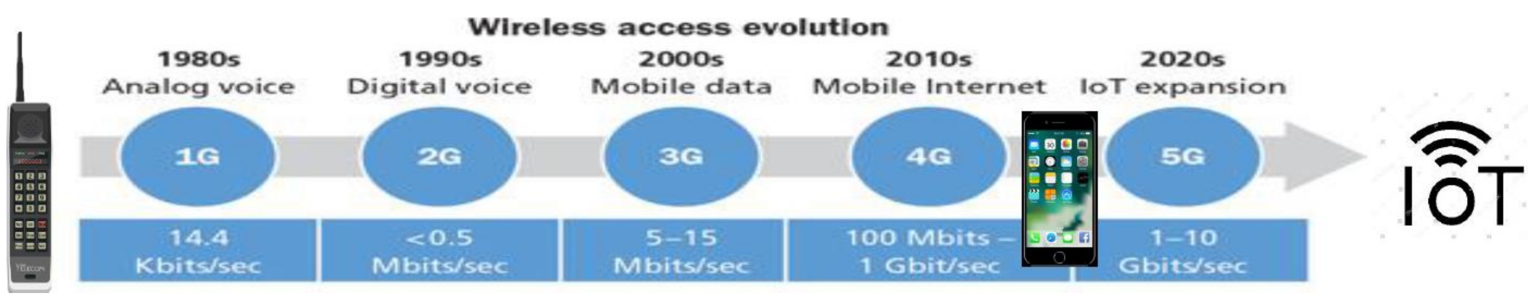
Historical Perspective of Wireless Networks

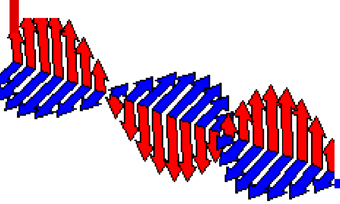
First Portable Telephone Call Made 50 years Ago

Posted 3 Apr 2013 | 4:51 GMT

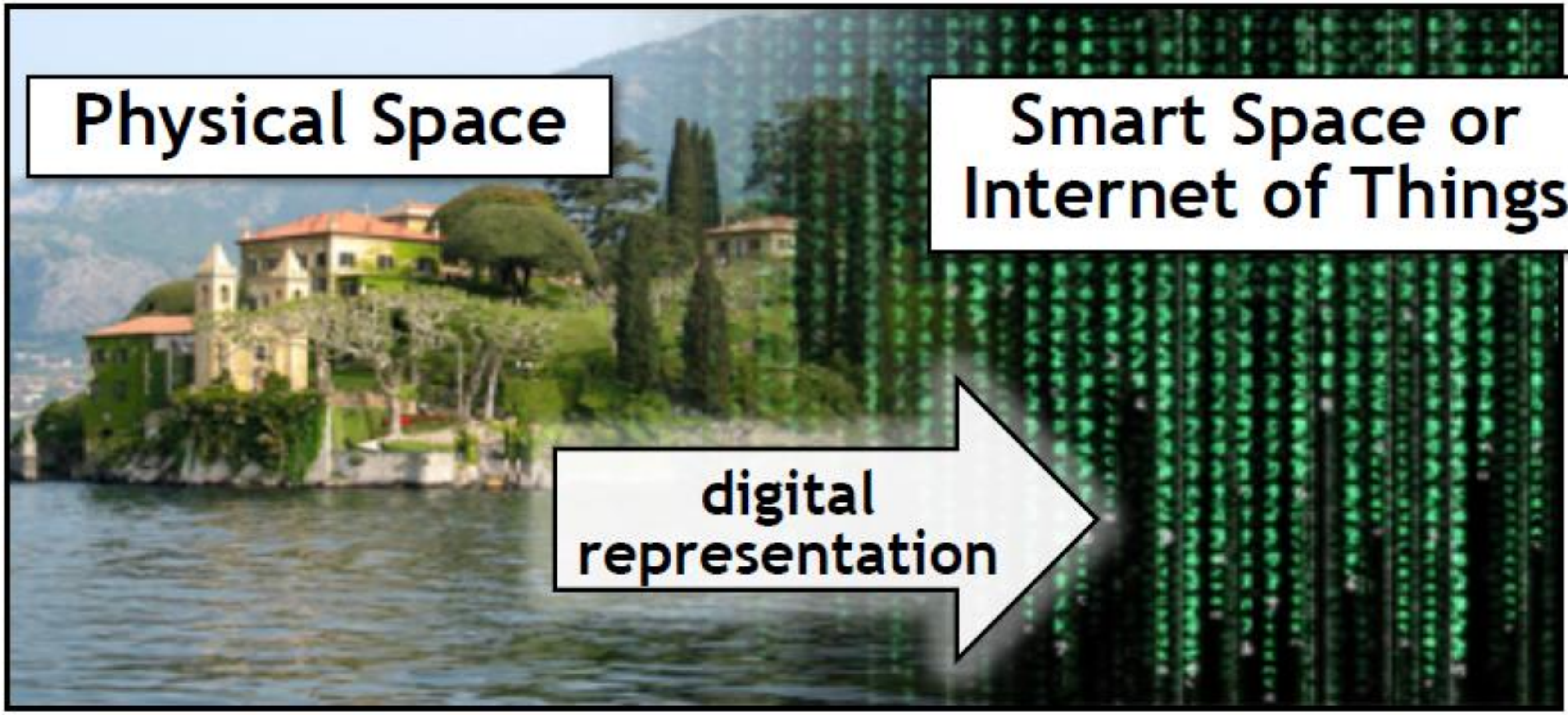


EARLIEST PORTABLE PHONE
The concept of a portable telephone (a radio-telephone from the early 1970s shown right) first appeared in 1947 at Lucent Technologies' Bell Labs, New Jersey, USA. The first actual portable telephone handset was invented by Martin Cooper (USA), of Motorola, who made the first call on 3 April 1973 to his rival, Joel Engel, head of research at Bell Labs.





The Vision: "Mapping" the Physical World into the Internet Physical World Web



Expected >50 billion devices!

- **Ambient intelligence**: almost unlimited applications

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Digitisation & Digitalisation & Digital Transformation

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DIGITIZATION
The process of making information available and accessible in a digital format.

DIGITALIZATION
The act of making processes more automated through the use of digital

DIGITAL TRANSFORMATION
The process of devising new business applications that integrate all the digitized data and digitalized applications.

Industry digitalisation

Example: Electricity digitalisation and smart energy systems in the UK. With the digitalisation of the energy sector seen as critical to meeting net-zero energy system of the future, including solar panels, electric vehicles, heat pumps, batteries and smart consumer devices.by 2050, end users should assess what is needed to deliver a transition to a smart, flexible energy system at the pace and scale needed.

Digitisation & Digitalisation

Digitisation is the conversion of changing the analogue to the digital Or convert something into digital format.

Example:
Changing the exam paper from a hand written document to a digital copy

Digitalisation is how this new digital world will impact people and work

Example:
Self service checkouts instead of a working cashier.

Introduction to the Internet of Things (IoT)

In recent years, IoT has developed into many areas of life including smart homes/offices/cities, agriculture, transportation, education, healthcare, industrial control, safety monitoring, environmental monitoring, and energy grids. Everyday physical items such as lights, locks and industrial machineries can now be part of the IoT ecosystem.

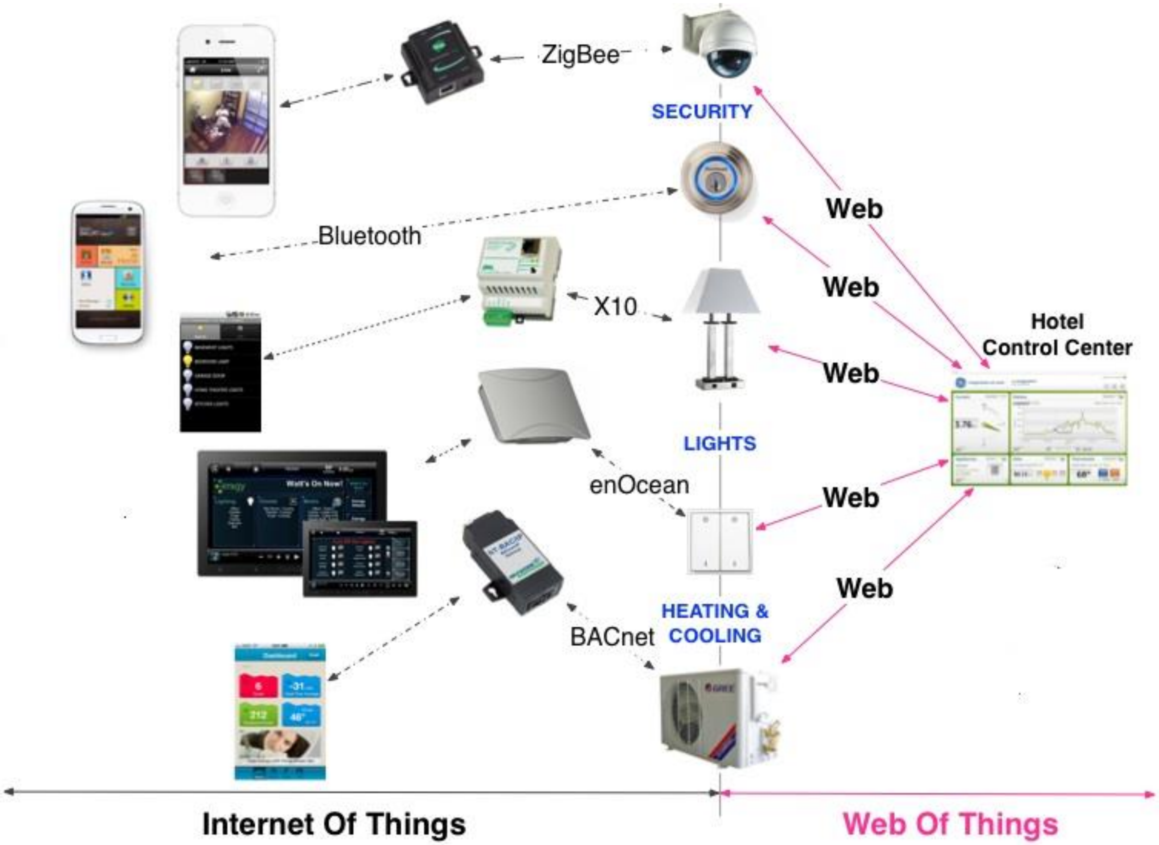
IoT is one of the most rapidly evolving technologies today

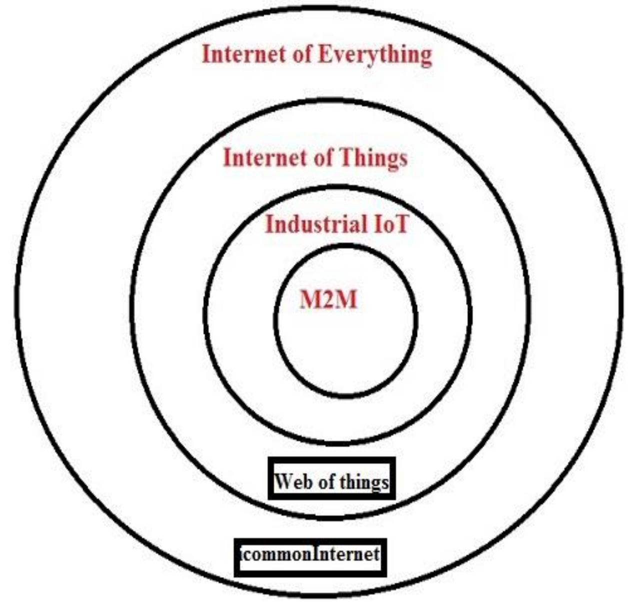
Introduction to IoT (cont.)

The main aim of the IoT is to make our lives more safe, efficient and comfortable. As a result, IoT technology is having a huge positive impact on our lives.

However, in addition to these positives, IoT systems have also attracted negative attention from malicious users who aim to infiltrate weaknesses within IoT systems for their own gain, referred to as **cyber security attacks**.

Introduction to IoT (cont.)





Introduction to IoT (cont.)

A number of IoT characteristics can be highlighted as:

1. IoT is a system that incorporates and connects `Things'
2. Things sense or monitor their environment
3. Things connect to the Internet to communicate
4. Things are uniquely identifiable
5. The system can potentially compute data, for example use, process, store or transmit data onward
6. The system should present information to a user or multiple users
7. The system responds to input from connected things and, or users
8. The basic premise and goal of IoT is to *connect the unconnected*.
9. Connecting Smart Objects

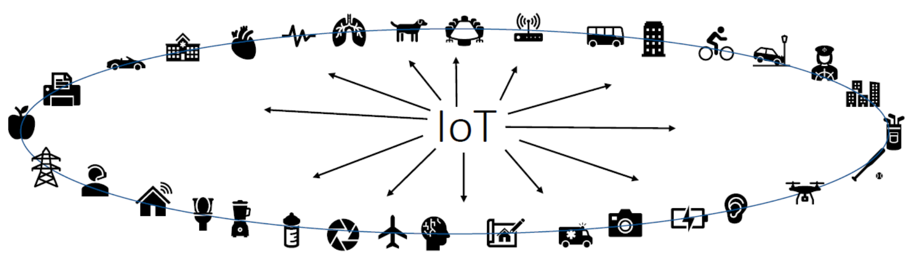
What is the IoT?

1. IoT is a technology transition in which devices will allow us to sense and control the physical world by making objects smarter and connecting them through an intelligent network.

2. To connect the unconnected means that objects that are not currently joined to a computer network, namely the Internet, will be connected so that they can communicate and interact with people and other objects.

What is the IoT?

3. The Internet of things (IoT) describes physical objects (or groups of such objects) with sensors, processing ability, software, and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks.



Source: WIKI

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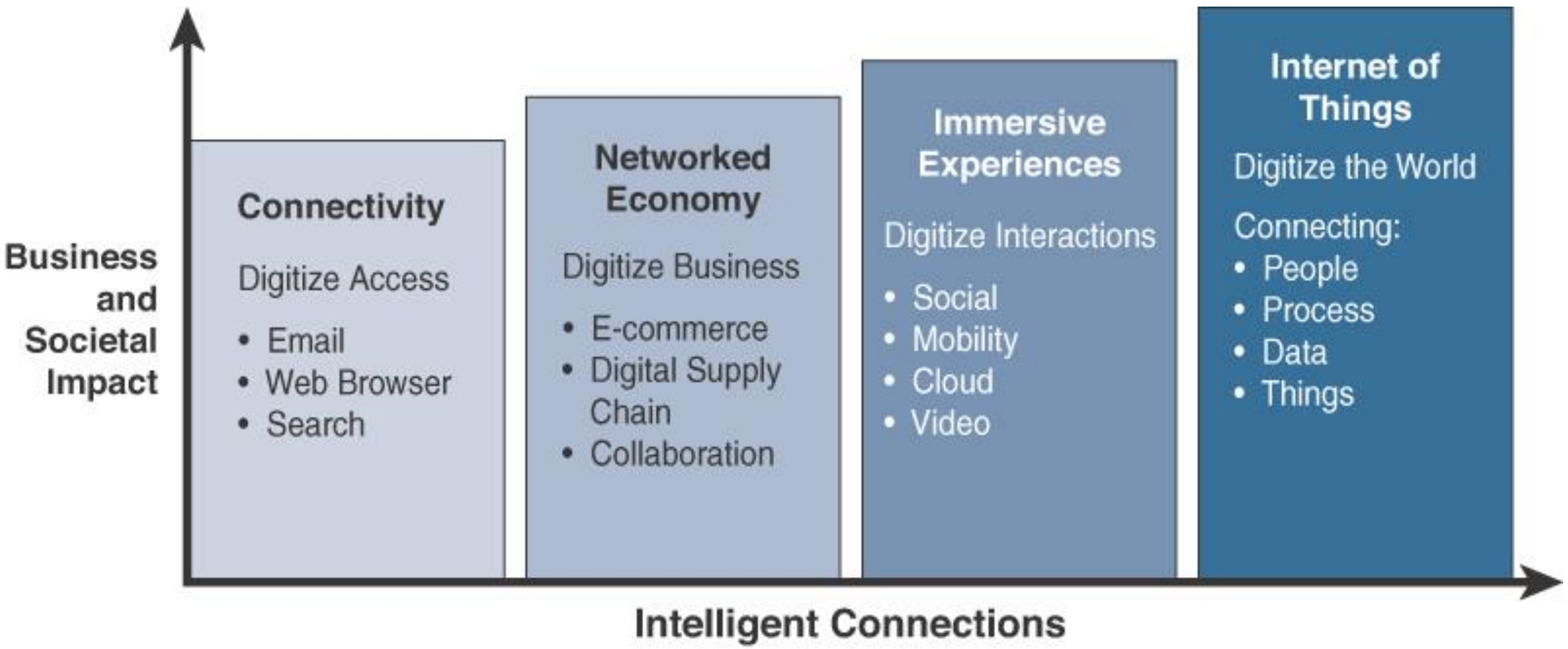
Evolutionary Phases of the Internet



Evolution of the IoT

1991
Birth of the World Wide Web

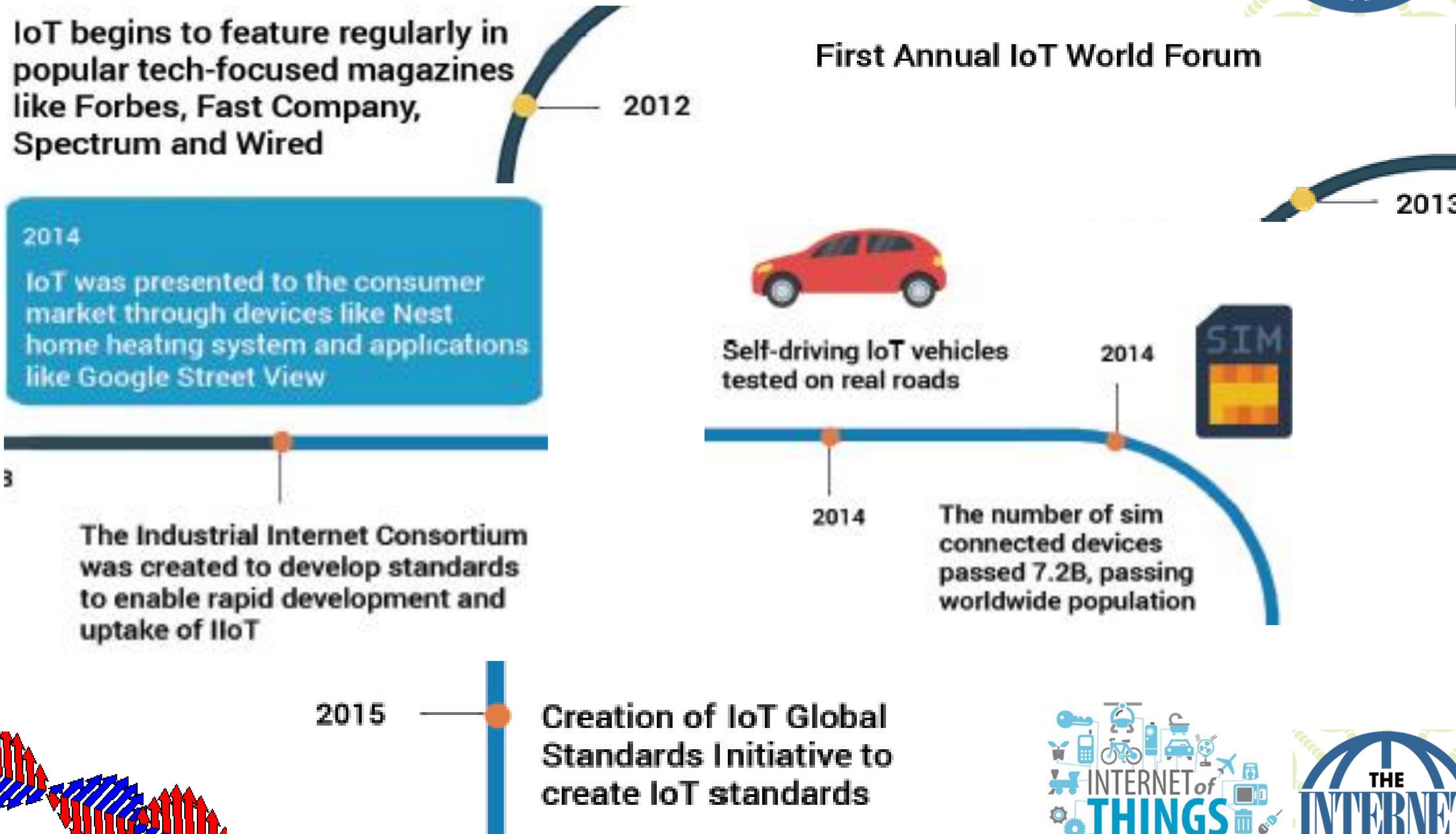
2006
IoT was formally recognised by the European Union

2008
Cisco announce "The Birth of IoT" with more connected Things than people

2008
A group of companies launched the IPSO Alliance to promote the use of Internet Protocol (IP) in networks of "smart objects" and to enable the Internet of Things

2010
China targets IoT as a technology sector for future investment

Evolution of the IoT (cont.)



Evolution of the IoT (cont.)

2015 — Creation of IoT Global Standards Initiative to create IoT standards

2017 — Worldwide, Governments start to consider IoT security threats resulting in development and implementation of security strategies and laws

2018 — Technologies AI, machine learning and blockchain start entering into IoT and IIoT solutions

2018 — Microsoft announce $5B investment over next 4 years in IoT

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IoT Impact

Projections on the potential impact of IoT are impressive. About 14 billion, or just 0.06%, of “things” are connected to the Internet today. Cisco Systems predicts that by 2020, this number will reach 50 billion. A UK government report speculates that this number could be even higher, in the range of 100 billion objects connected. Cisco further estimates that these new connections will lead to $19 trillion in profits and cost savings.

Some of the IoT Impacts:
Connected Factory, buildings and Roadways

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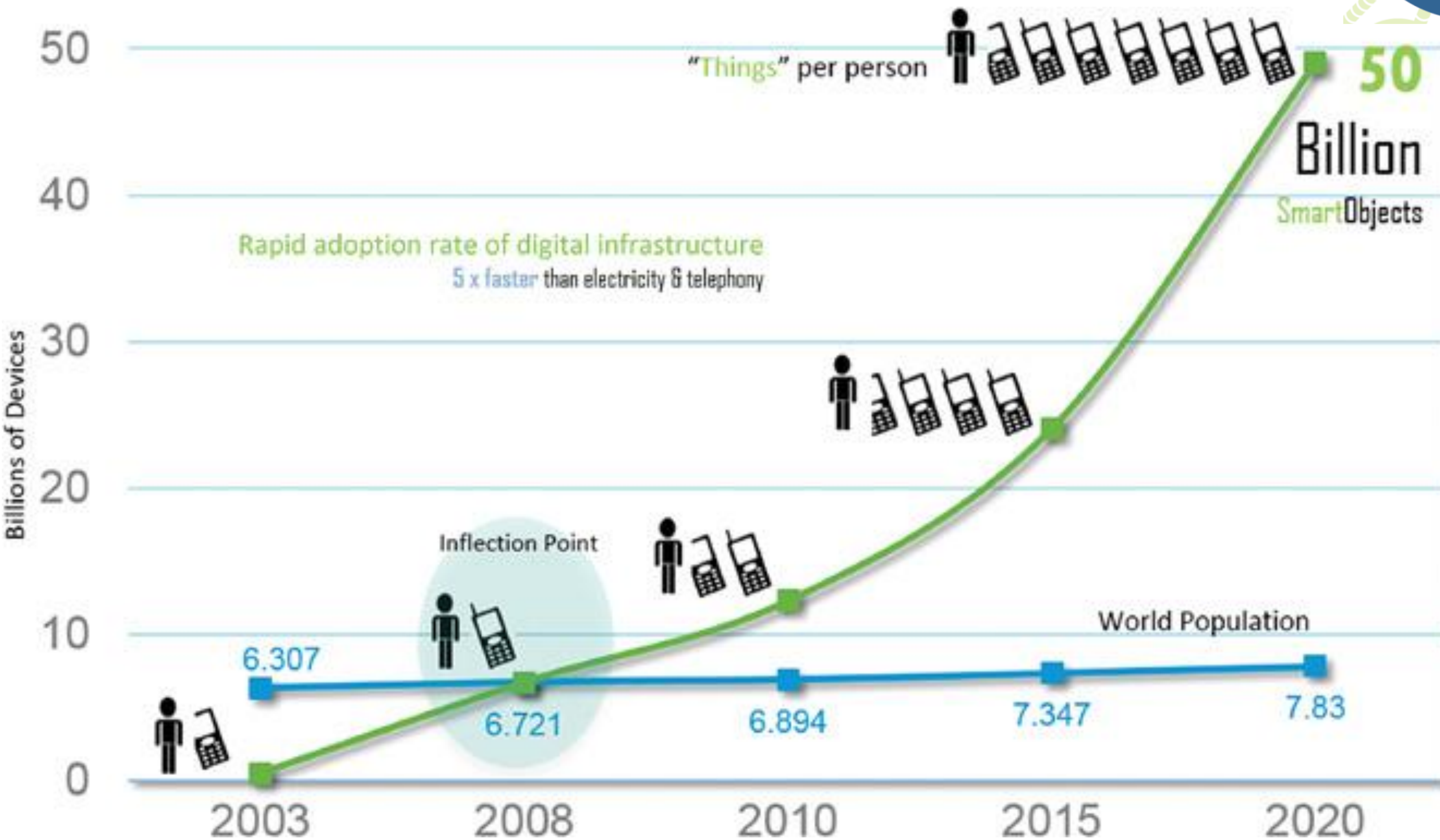
The Rapid Growth in the Number of Devices Connected to the Internet



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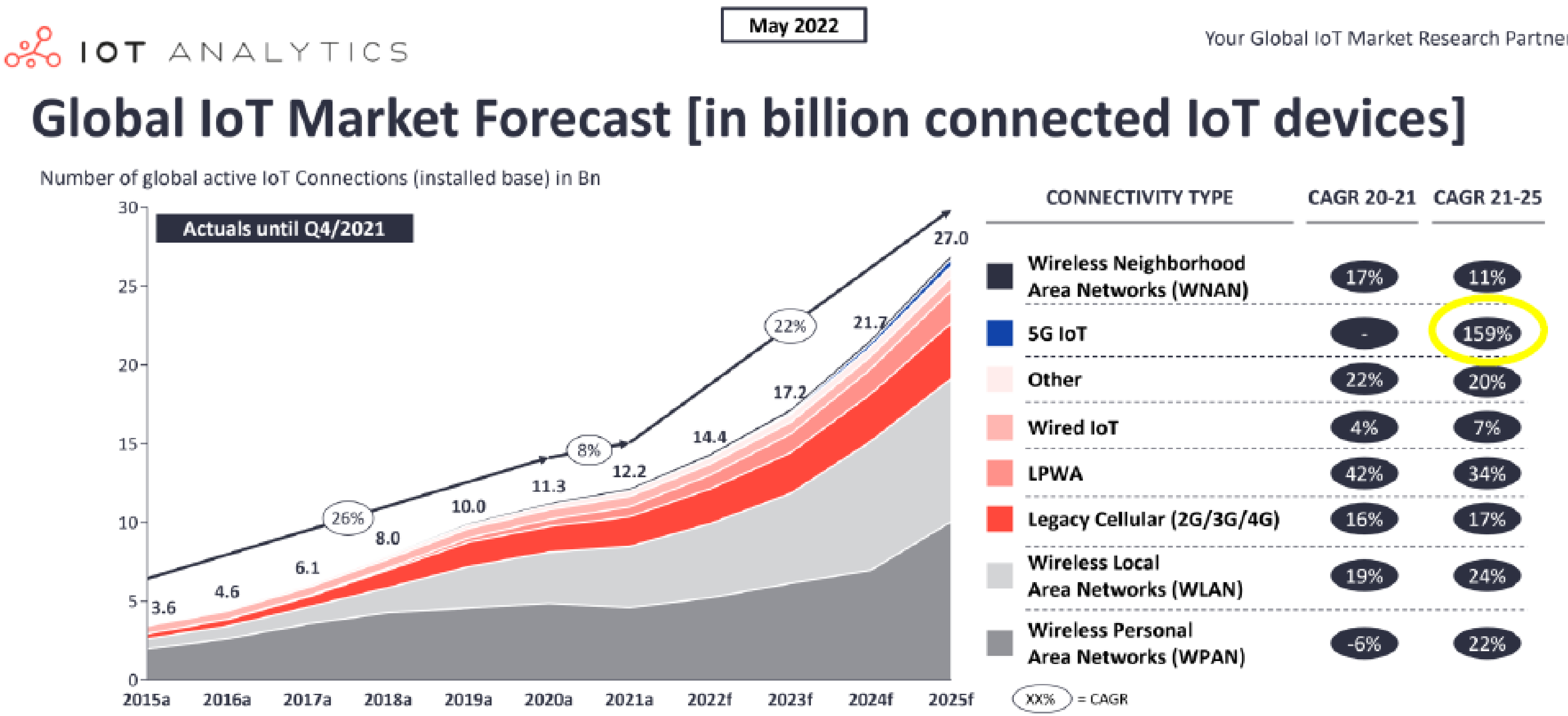
Global IoT Market



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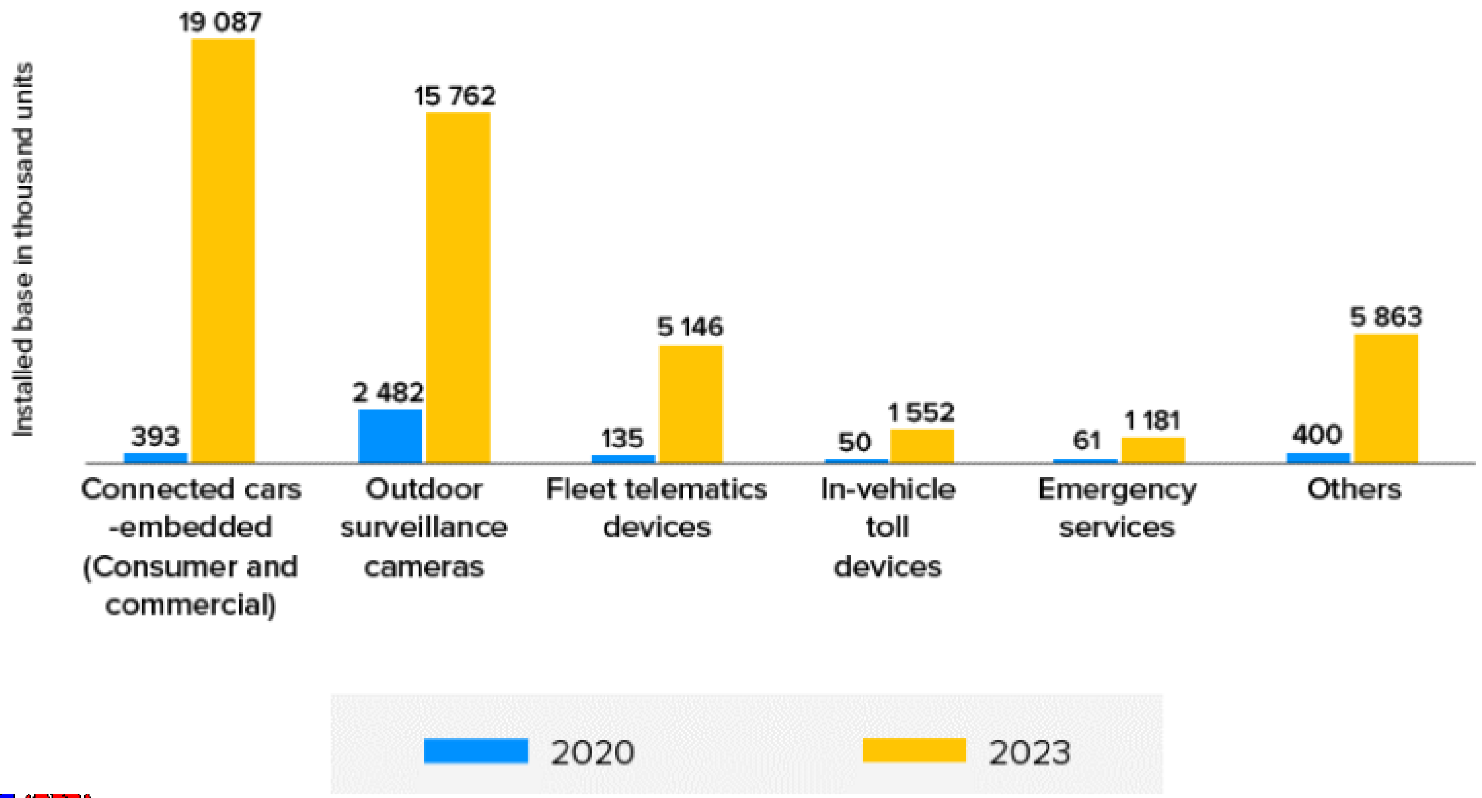
Connected Cars to be Largest segment of global IoT endpoint market



Source: Statista: May 2021

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5G IoT market

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Forecast for 2026

- **3.5 billion** 5G subscriptions covering 40% of all mobile subscriptions[1]
- NB-IOT and Cat-M are predicted to make up **45%** of all mobile IoT connections[5]
- Economic value between **$3.9 Trillion** and **$11.1 Trillion** a year[2]

IoT in 5G era

5G vision

5G's main application areas

5G implementations and features

Global 5G Deployments: 233

Forecast 2022: 311 Forecast 2024: 365

Global 5G IoT market size

to grow from **USD $0.7 billion** in 2020 to **USD $15.7 billion** by 2026

MarketWatch, 2021

$ 111.2 Billion globally by 2028 at 72.1% CAGR

Verified Market Research, 2022

IoT Connecting Smart Objects

IoT Wired Connectivity

Ethernet

Ethernet TSN

Power Line Communications (PLC)

Cellular IoT Technologies

EC-GSM-IoT

LTE-based cellular IoT technologies

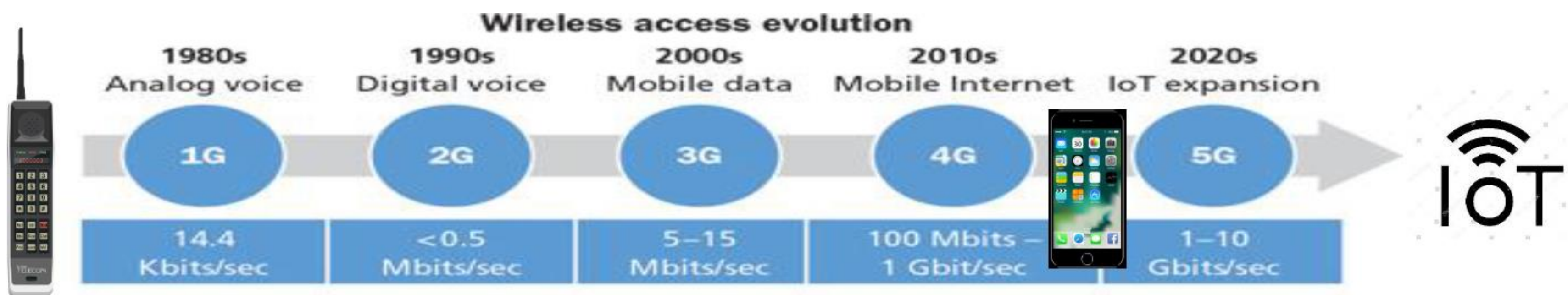
Unlicensed-band wireless IoT

Zigbee wireless network

BLE wireless network

WiFi wireless network

LoRaWAN wireless wide area network

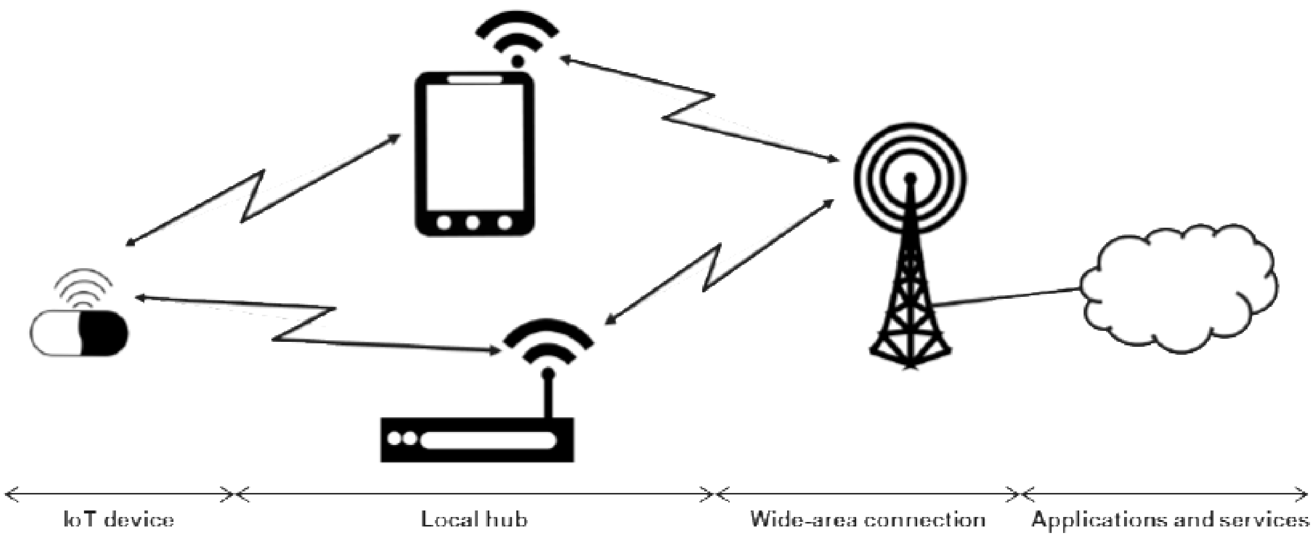


Historical Perspective

Internet of Things (IoT) Elements

The Internet of Things (IoTs) consists of sensors and smart things/objects that are connected to the Internet anytime, anywhere. Acted as a perception layer of IoTs, the wireless sensor networks play an important role by detecting events and collecting surrounding context and environment information.

IoT architecture with a local hub



Internet of Things (IoT) Elements

IoT Elements		Samples
Identification	Naming	EPC, uCode
	Addressing	IPv4, IPv6
Sensing		Smart Sensors, Wearable sensing devices, Embedded sensors, Actuators, RFID tag
Communication		RFID, NFC, UWB, Bluetooth, BLE, IEEE 802.15.4, Z-Wave, WiFi, WiFiDirect, , LTE-A

Computation	Hardware	SmartThings, Arduino, Phidgets, Intel Galileo, Raspberry Pi, Gadgeteer, BeagleBone, Cubieboard, Smart Phones
	Software	OS (Contiki, TinyOS, LiteOS, Riot OS, Android); Cloud (Nimbits, Hadoop, etc.)
Service		Identity-related (shipping), Information Aggregation (smart grid), Collaborative-Aware (smart home), Ubiquitous (smart city)
Semantic		RDF, OWL, EXI

The IoT Elements

Sensing

The IoT sensing means gathering data from related objects within the network and sending it back to a data warehouse, database, or cloud. The collected data is analysed to take specific actions based on required services.

The IoT sensors can be smart sensors, actuators or wearable sensing devices.

Internet of Things (IoT) Elements

Sensors and sensor nodes

Sensing Components and Devices

Sensor modules, nodes and systems

Example of an IoT system

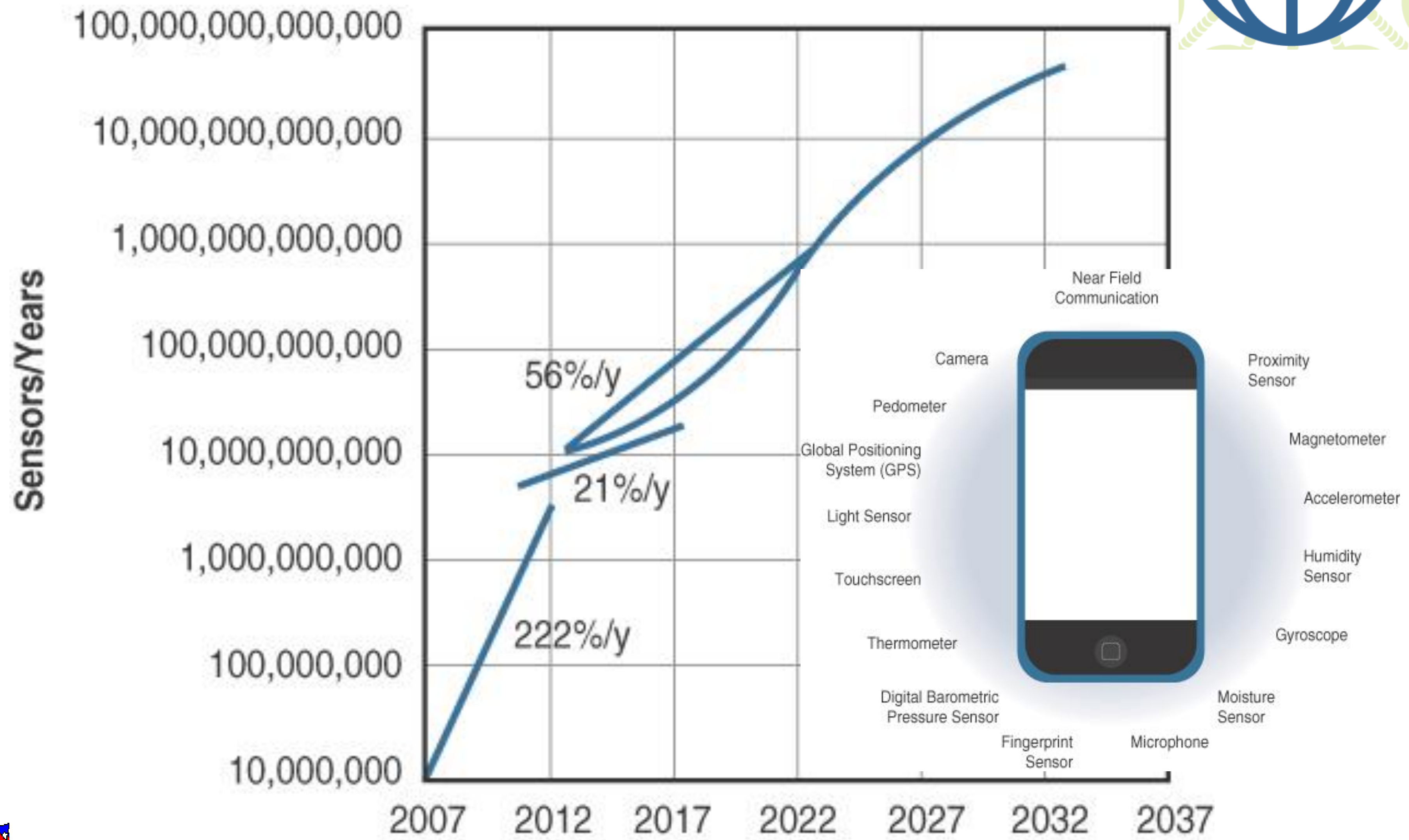
Example: Sensors

“System” Sensors

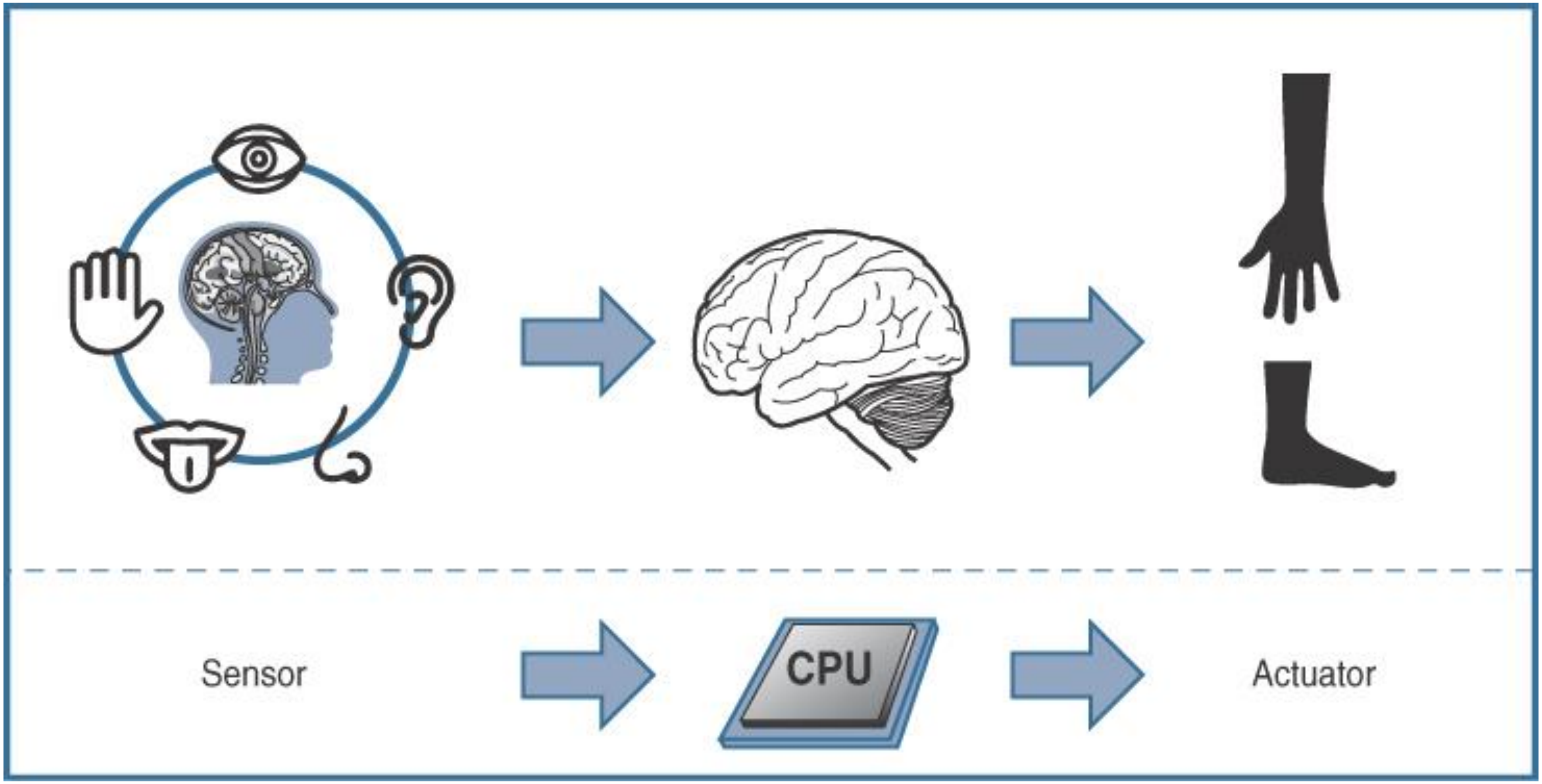
Human Sensors

Example: Sensors in a Smart Phone

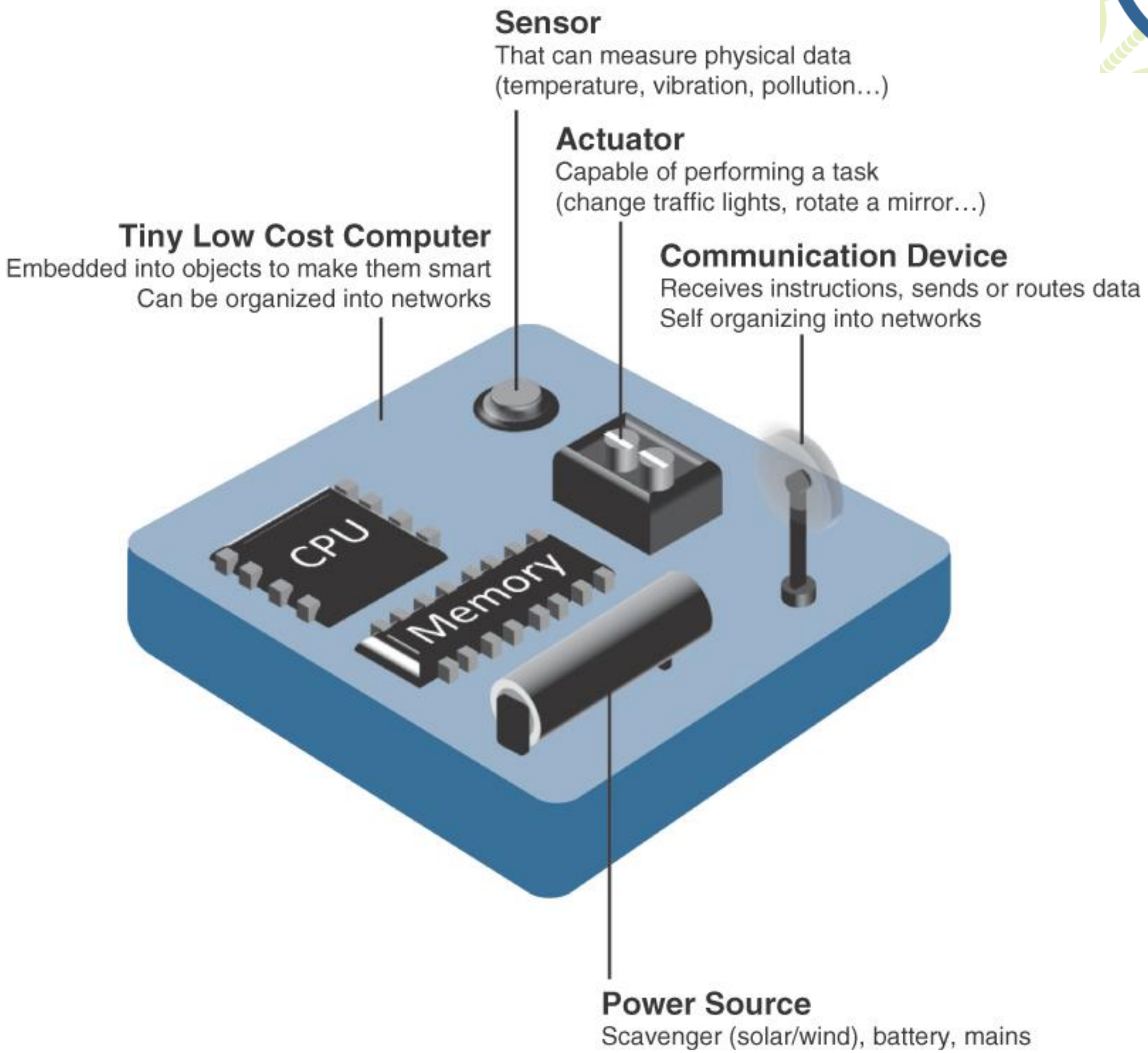
Growth and Prediction in the Number of Sensors



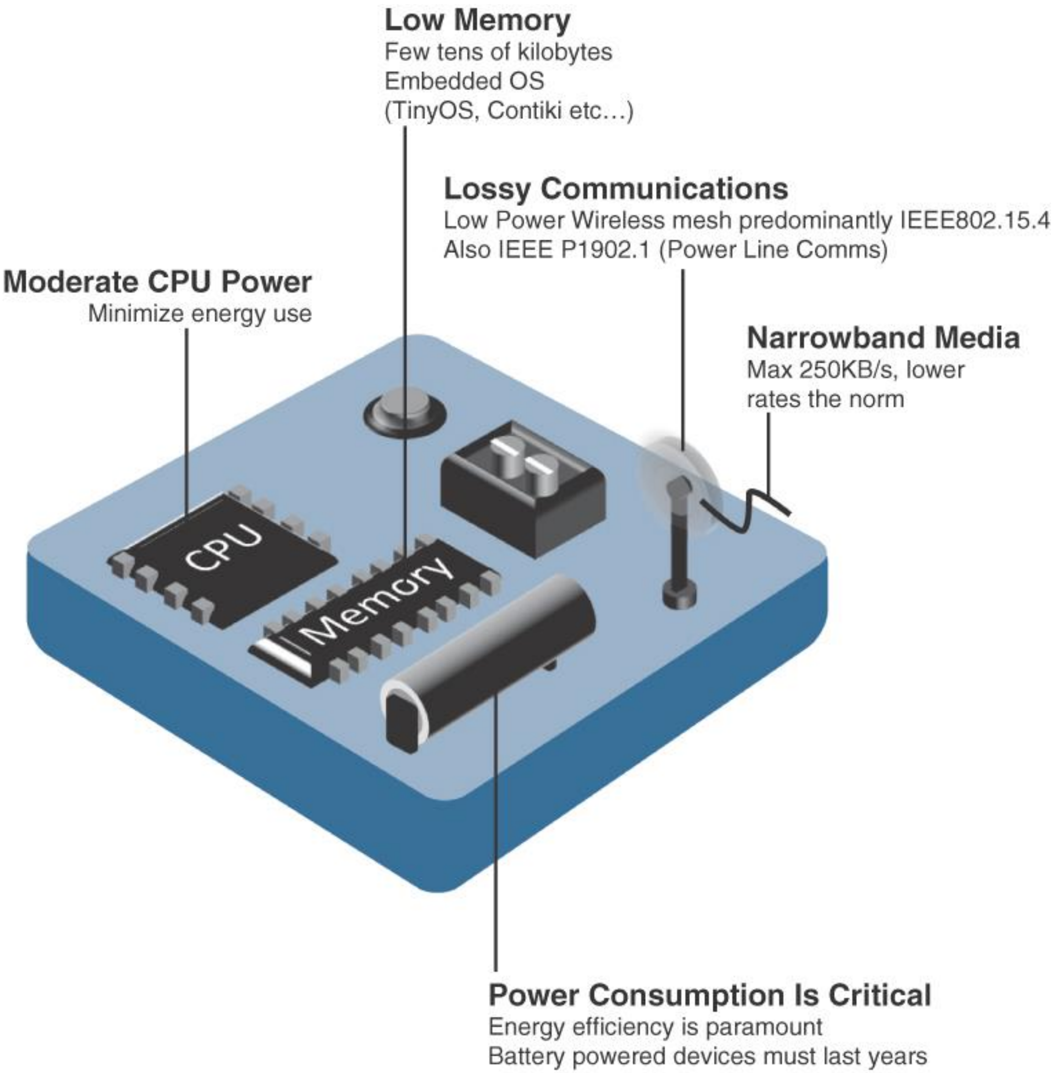
Comparison of Sensors and Actuator Functionality with Humans



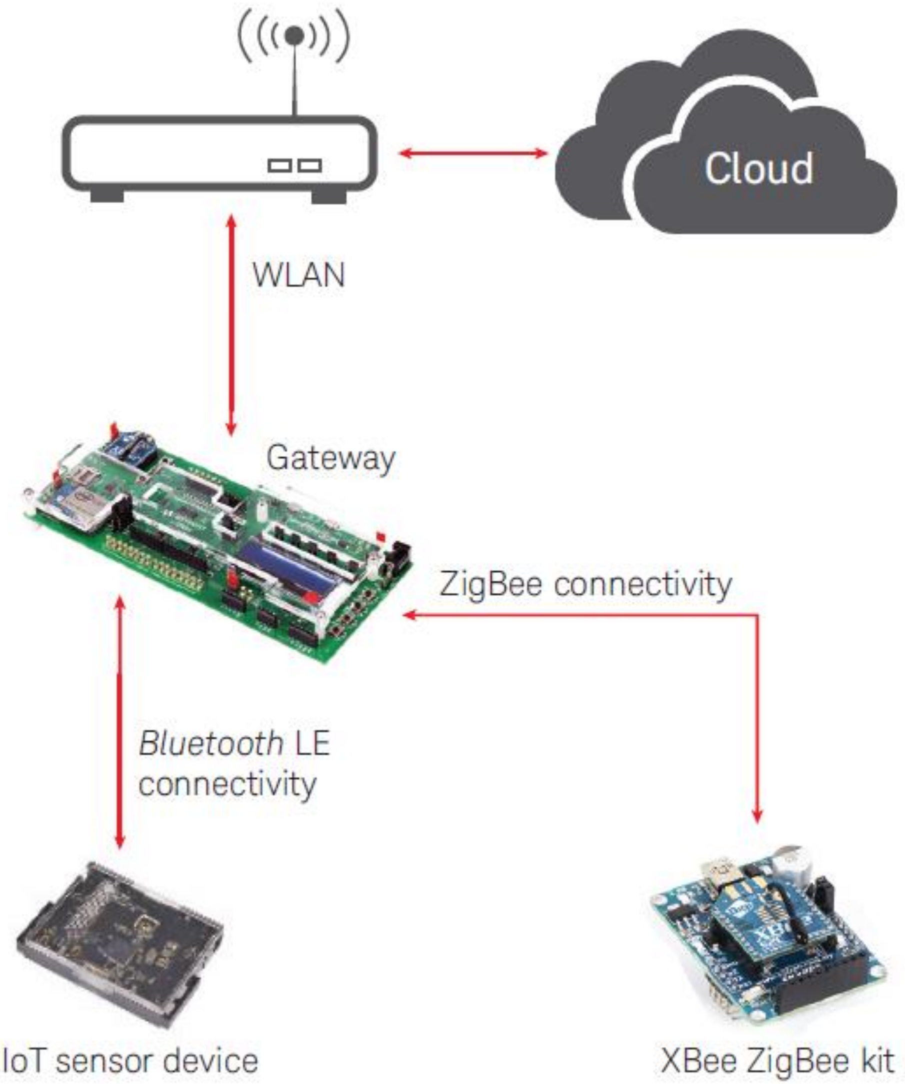
Example: Characteristics of a Smart Object



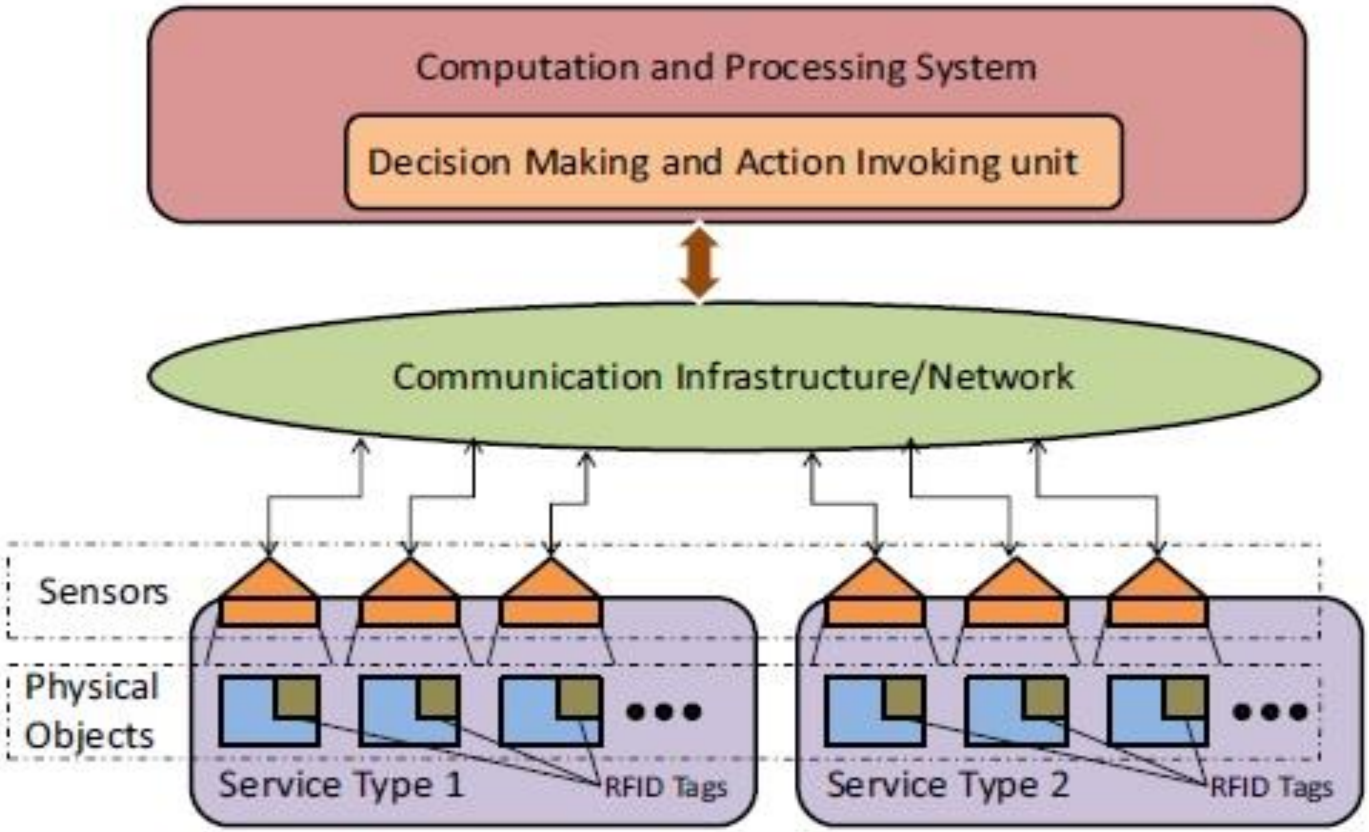
Example: Design Constrains for Wireless Smart Objects



Example: Internet of Things (IoT) Elements

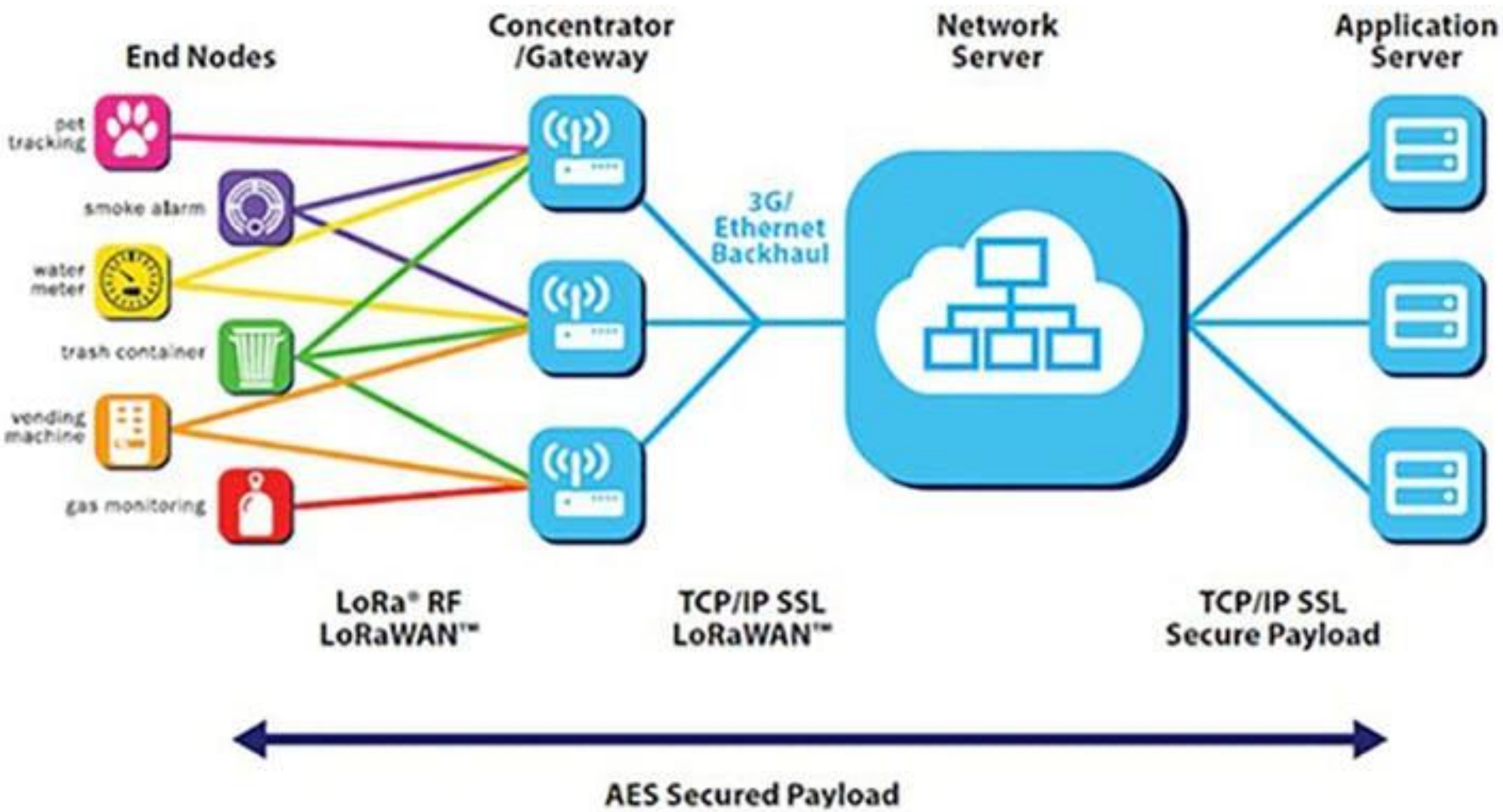


How an IoT system works

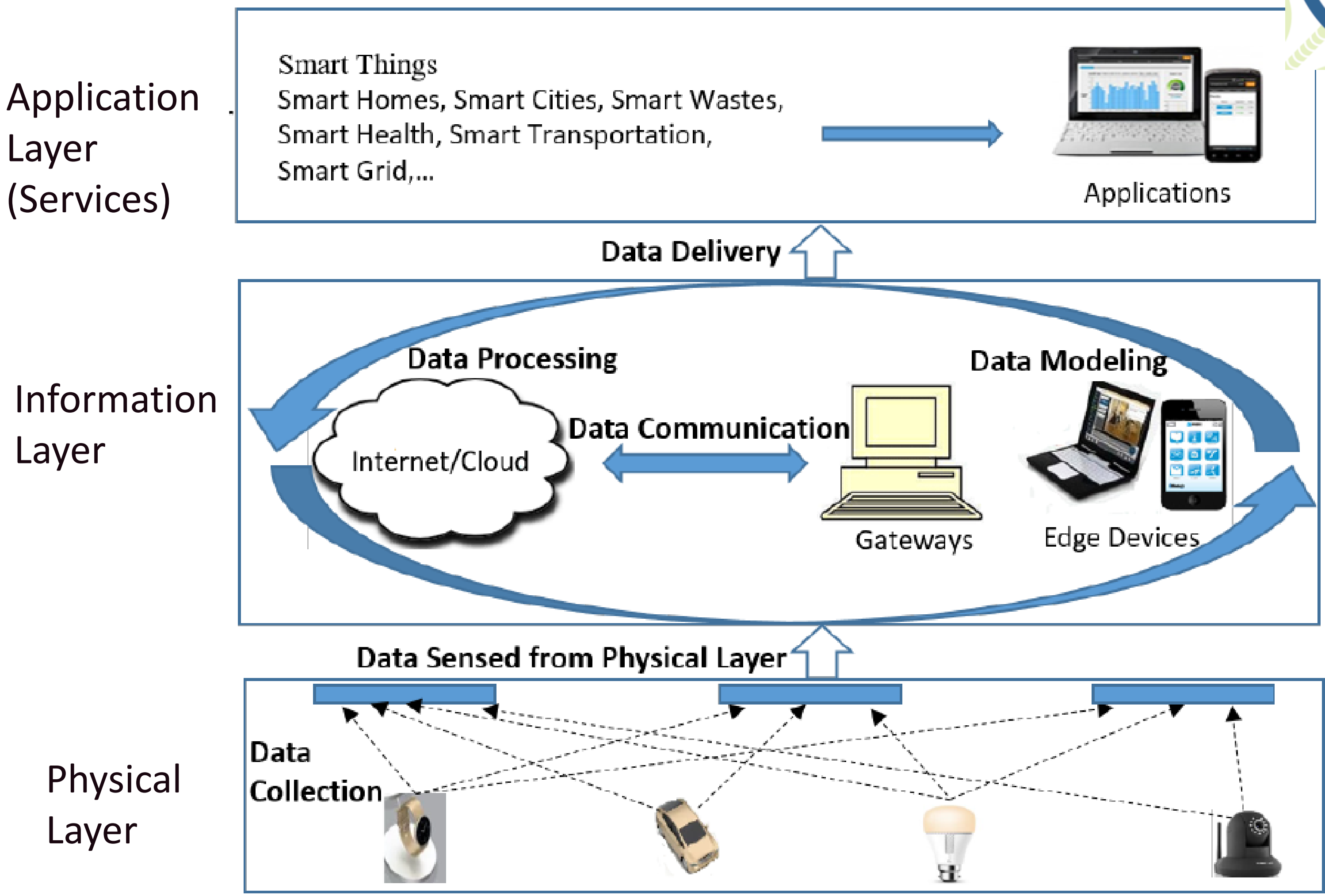


Basic IoT system.

How an IoT system works (cont.)



How an IoT system works (cont.)



A Generic Architecture of IoT Systems.

How an IoT system works (cont.)

Equation for the internet of things

Physical Objects
+
Controller, Sensor and Actuator
+
Internet
=
Internet of Things

Example: LoRa:
The IoT network has 4 distinct elements:
End nodes (IoT devices) gather sensor data from their environment and transmit/receive data.

Gateway (local hub)

Network server gathers data from the gateways and decides which gateway should respond to end node messages.

Application Server collects data from end-nodes and controls the actions of the end-node devices.

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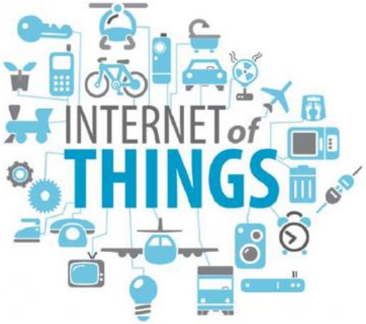
Internet of Things (IoT) Applications

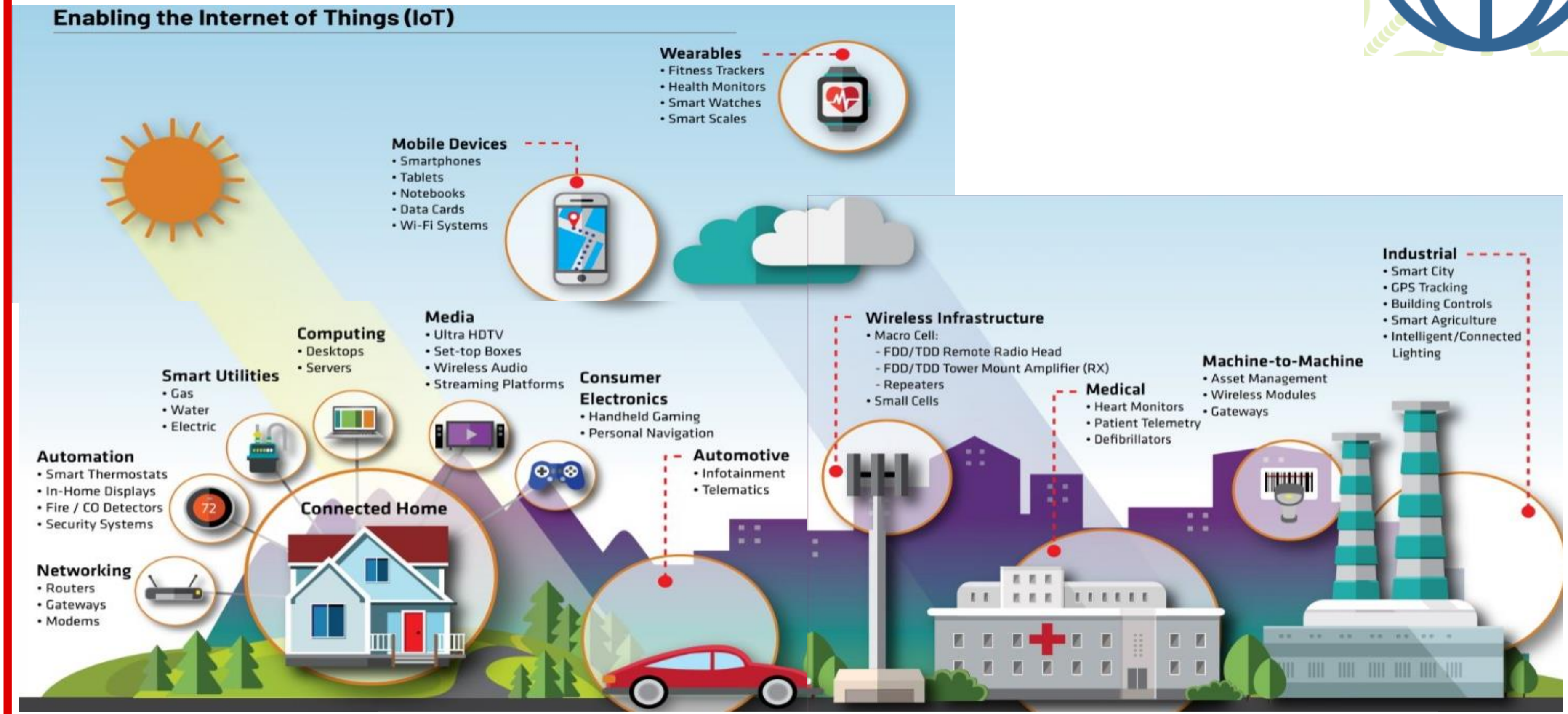
There are already a number of competing technologies that may be suitable for the many and various IoT applications, however they will need to meet the

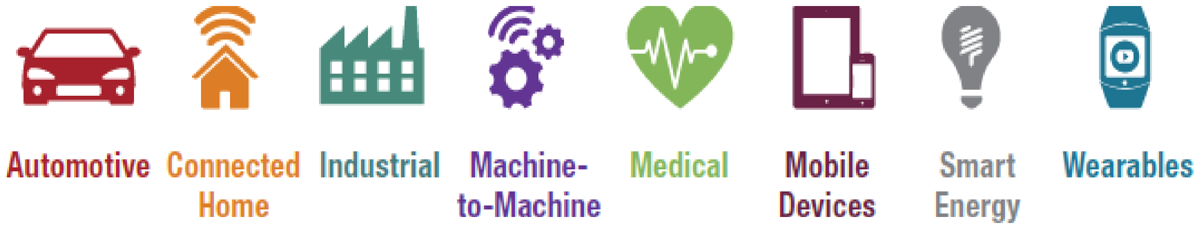
low power;
low cost;
short- and long-range requirements

of a typical IoT service.

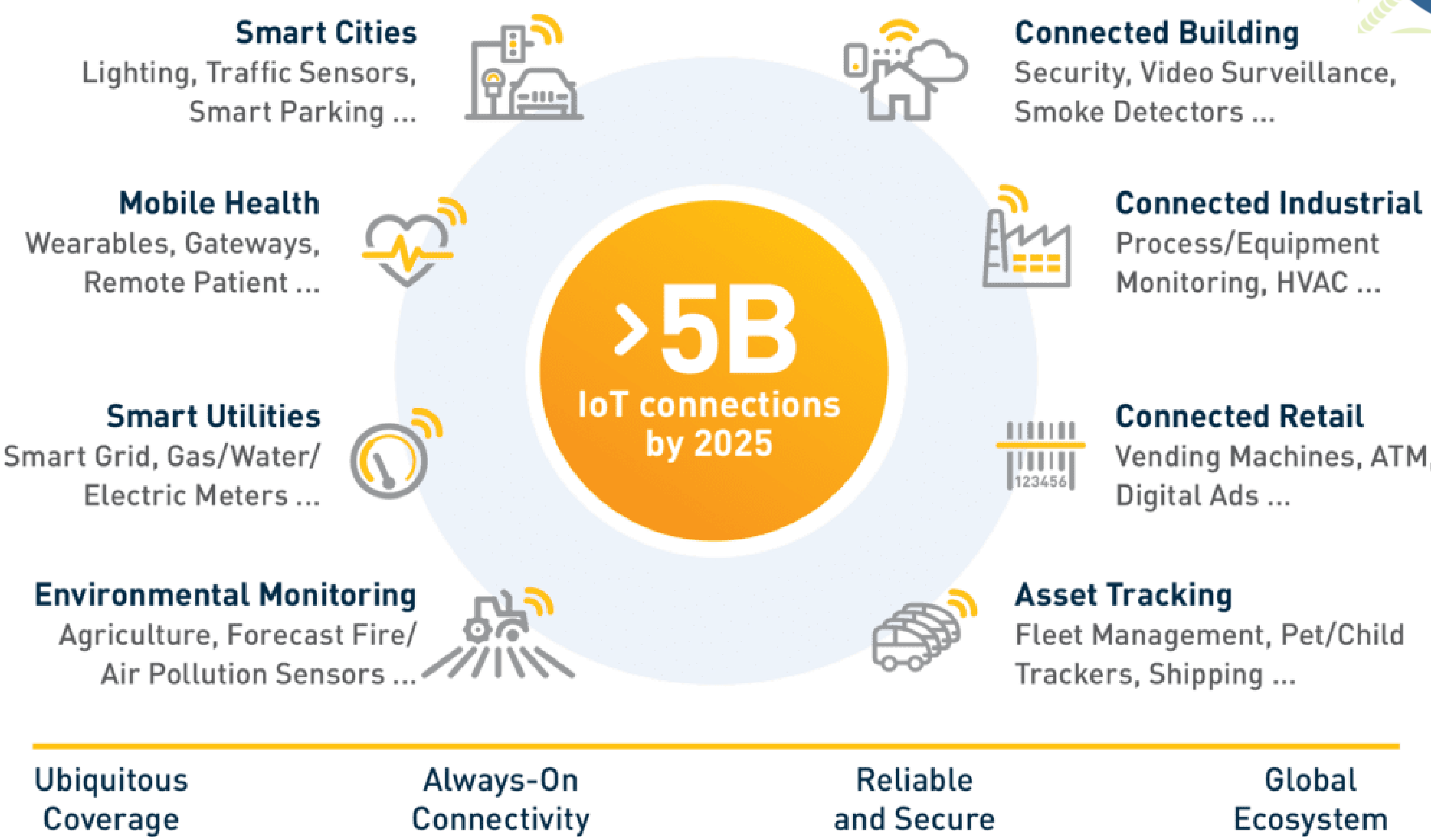


Internet of Things (IoT) Applications





IoT Applications (cont.)



Mobile IoT/Cellular IoT addresses a variety of applications and services

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IoT-Connectivity and Networks Technologies

IoT Connectivity/ Communication

The sensors/devices can be connected to the cloud through a variety of methods including:

cellular, satellite, WiFi, Bluetooth, low-power wide-area networks (LPWAN), connecting via a gateway/router or connecting directly to the internet via ethernet.

Each option has tradeoffs between power consumption, range, and bandwidth. Choosing which connectivity option is best comes down to the specific IoT application, but they all accomplish the same task: getting data to the cloud.

IoT Network Technologies

Characteristics and Communications Criteria

IoT Range/Distance

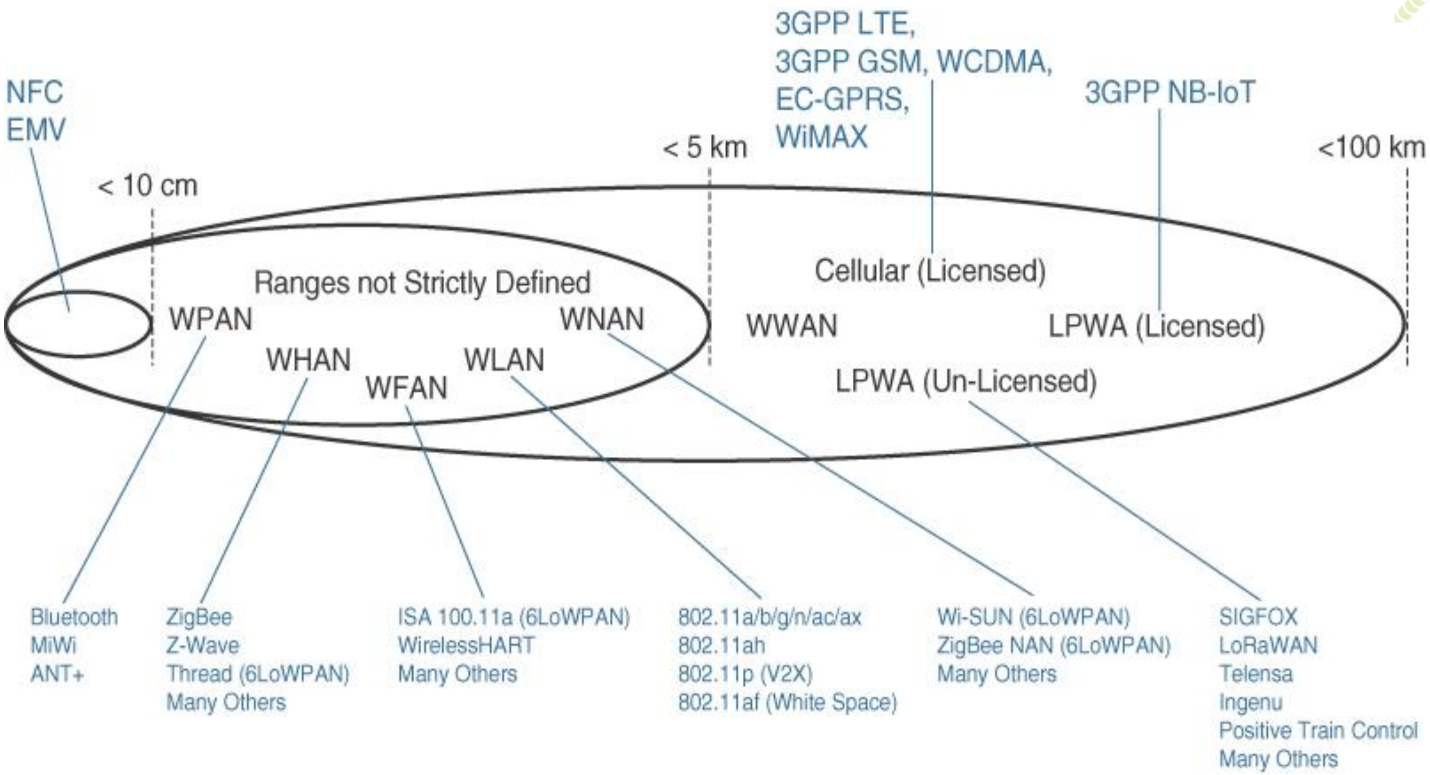
IoT Frequency Bands/Spectrum

IoT Range

Range estimates are grouped by category names that illustrate the environment or the vertical where data collection over that range is expected. The following common groups are:

PAN (personal area network): Scale of a few meters.
HAN (home area network): Scale of a few tens of meters.
NAN (neighborhood area network): Scale of a few hundreds of meters.
FAN (field area network): Scale of several tens of meters to several hundred meters.
LAN (local area network): Scale of up to 100 m.

Access Technologies and Distances



WPAN: Wireless Personal Area Network
WHAN: Wireless Home Area Network
WFAN: Wireless Field (or Factory) Area Network
WLAN: Wireless Local Area Network

WNAN: Wireless Neighborhood Area Network
WWAN: Wireless Wide Area Network
LPWA: Low Power Wide Area

Access Technologies and Distances

■ : > Billion units/year now
■ : Emerging

WPAN: Wireless Personal Area Network
WHAN: Wireless Home Area Network
WFAN: Wireless Field (or Factory) Area Network
WLAN: Wireless Local Area Network

WNAN: Wireless Neighborhood Area Network
WWAN: Wireless Wide Area Network
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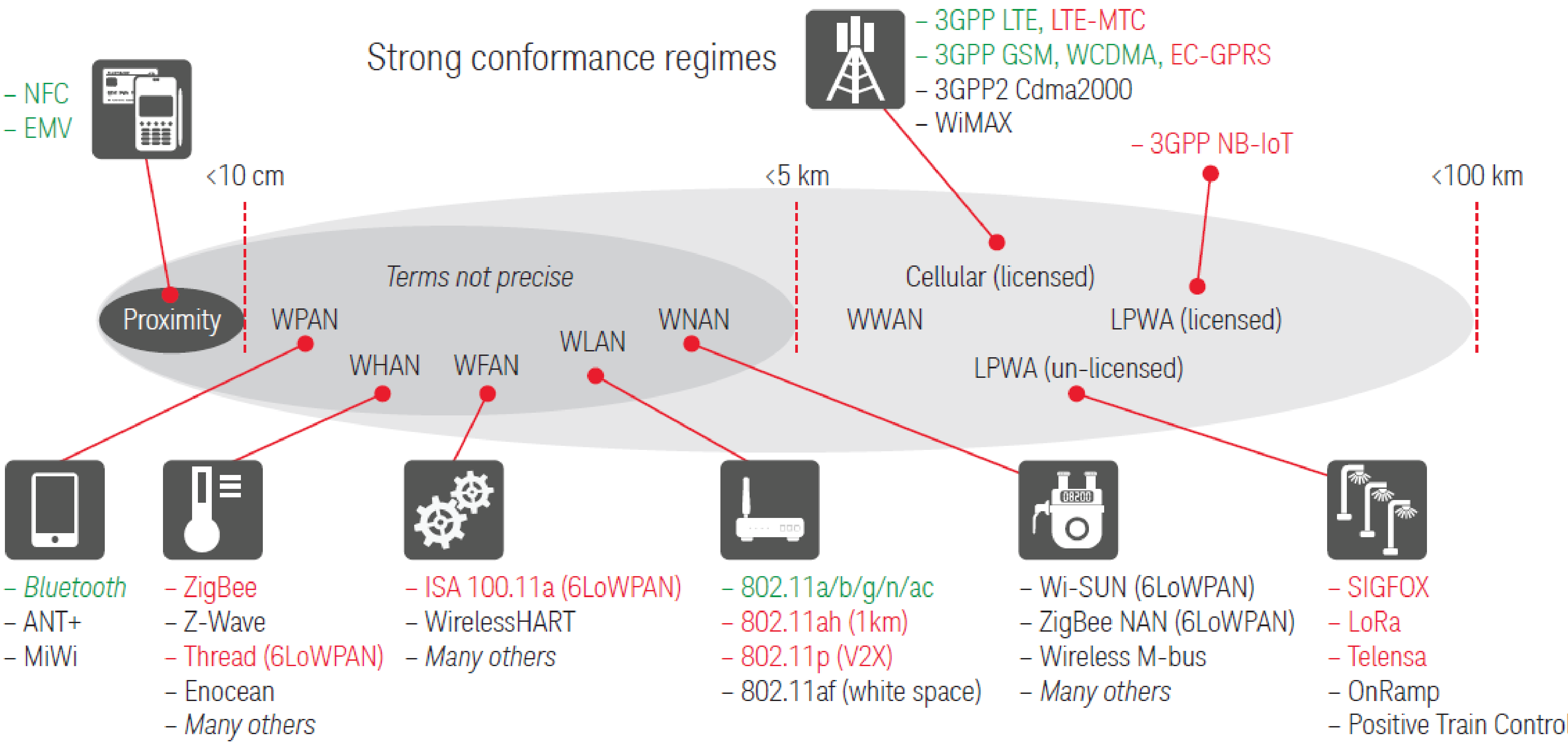
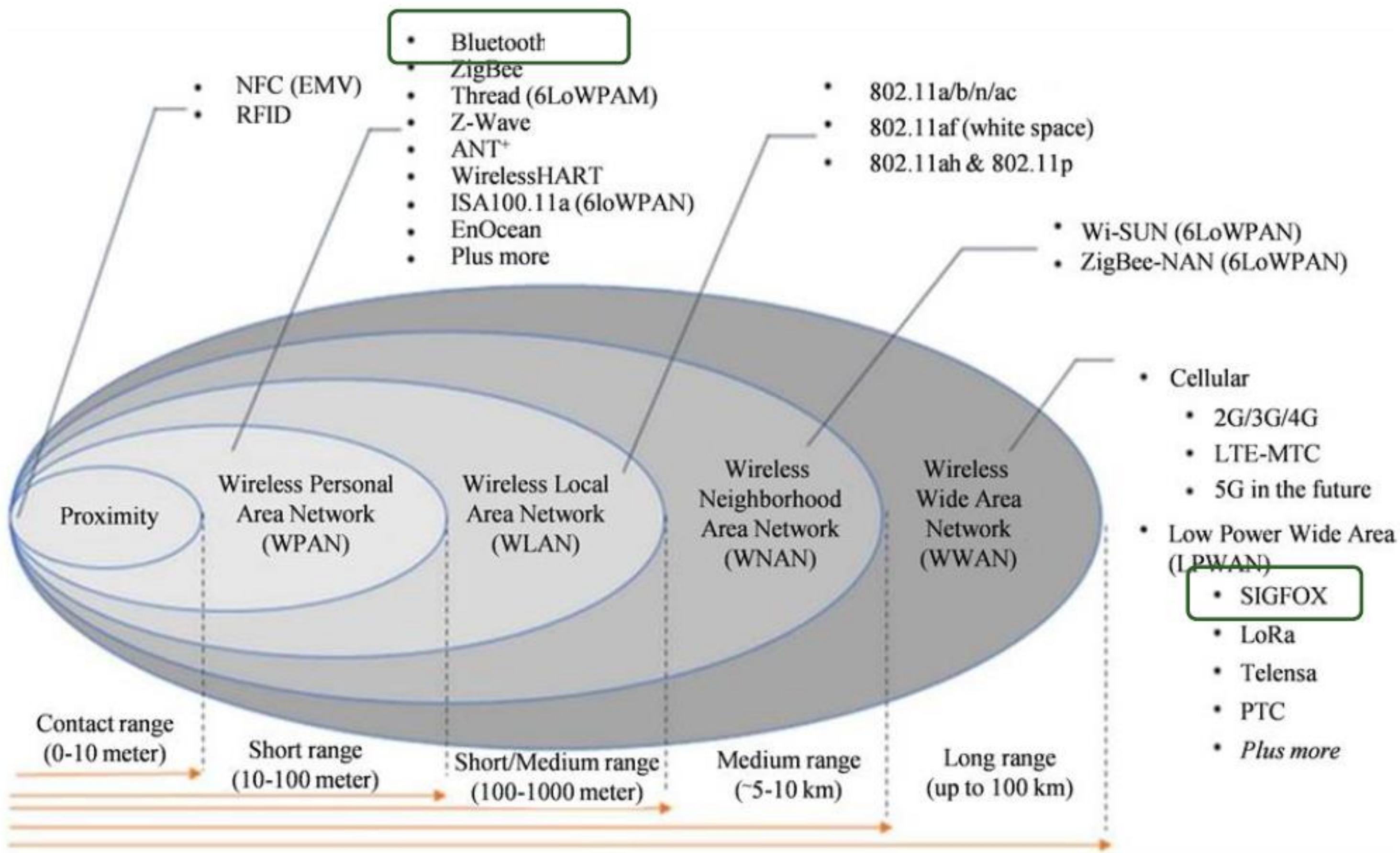


Expected operating range has a direct relation to the available choices of connection technologies.

Access Technologies and Distances



Example of Mapping the Different Protocols to Different Area Networks

IoT Range/Distance

Short range:

- The classical wired example is a serial cable.
- Wireless short-range technologies

(tens of meters of maximum distance between two devices)

Examples:

IEEE 802.15.1 Bluetooth

Medium range:

x100 m and up to 1.6 km the max distance between two devices.

Examples:

Wireless medium-range technologies

IEEE 802.11 Wi-Fi, IEEE 802.15.4, and IEEE 802.15.4g WPAN.

Wired technologies:

IEEE 802.3 Ethernet and

IEEE 1901.2 Narrowband Power Line Communications (PLC)

Long range:

Distances greater than 1 mile between two devices require long-range technologies.

Examples:

Wireless long-range technologies:

Cellular (2G, 3G, 4G) and

some applications of outdoor IEEE 802.11 Wi-Fi and low-Power Wide-Area (LPWA) technologies.

LPWA communications have the ability to communicate over a large area without consuming much power. These technologies are therefore ideal for battery-powered IoT sensors.

IEEE 802.3 over optical fiber

and

IEEE 1901 Broadband Power Line Communications are classified as long range but are not really considered IoT access technologies.

IoT Range

Short-range wireless IoT standards such as:

6LoWPan, Zigbee and Z-wave.

Long-range IoT standards such as:

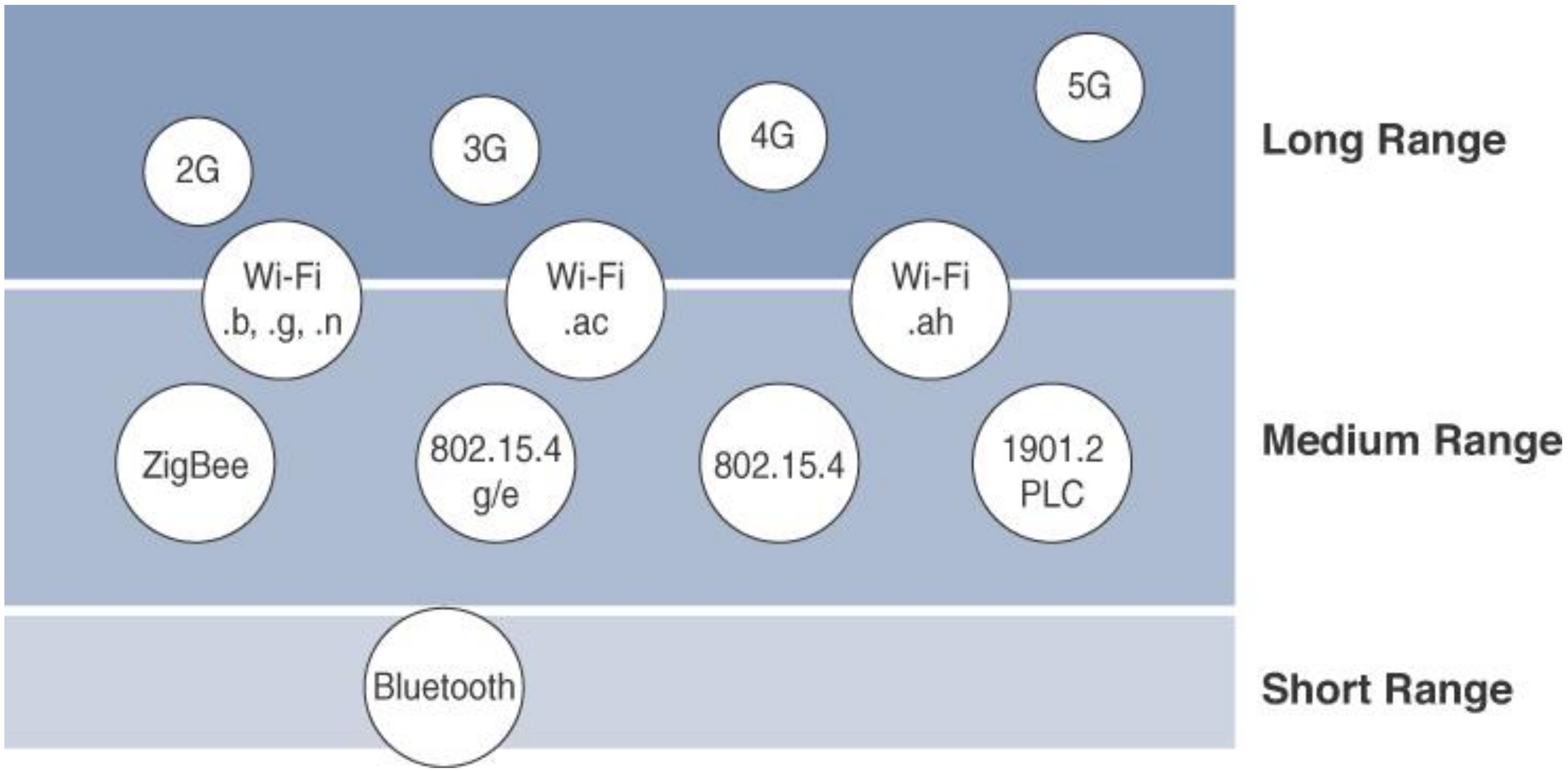
Low power Long Range (LoRa);

Low-power, Wide-Area wireless technology (LPWA)

and cellular offerings such as Narrowband Internet of Things (NB-IoT);

5G IoT Networks.

Wireless Access Landscape



Wireless Access Landscape (cont.)

	Short Range	Local Area	Wide Area
Range (typical)	<10m/30ft	<100m/300ft	Outdoor (km/miles)
Content distribution Focus on high data rates	Bluetooth	DIRECT WiFi, WiFi, 6	GSM, Lte, 5G
Sense and control Low/energy long battery life	Bluetooth SMART	.11ah: HaLow, zigbee, THREAD	NB-IoT, GPRS
Proprietary solutions	ANT+	Sub GHz, Z-WAVE, enocean	LoRa, sigfox, INGENU, WEIGHTLESS
Typical applications	Personal appliances (wristband, smart watch, step counter, keyboard, mouse, pointer, etc.)	Indoor networks (internet, email, phone, security, energy management, home monitoring, etc.)	Outdoor networks (phone, chat, internet, smart city, industry 4.0, agriculture, smart logistics, etc.)

Wireless

Bluetooth® Classic BLE	Wi-Fi®	802.15.4 (SubGHz & 2.4GHz)	LoRa®	LTE-M NB-IoT (*)
Bluetooth	WiFi	zigbee, MiWi	LoRa, LoRaWAN	NB-IoT, LTE-M

www.microchip.com/bluetooth
www.microchip.com/wifi
www.microchip.com/802-15-4
www.microchip.com/lora

IoT Access Technologies

IEEE 802.15.4

IEEE 802.15.4g and IEEE 802.15.4e

IEEE 1901.2a

IEEE 802.11ah

LoRaWAN

NB-IoT and other LTE variations

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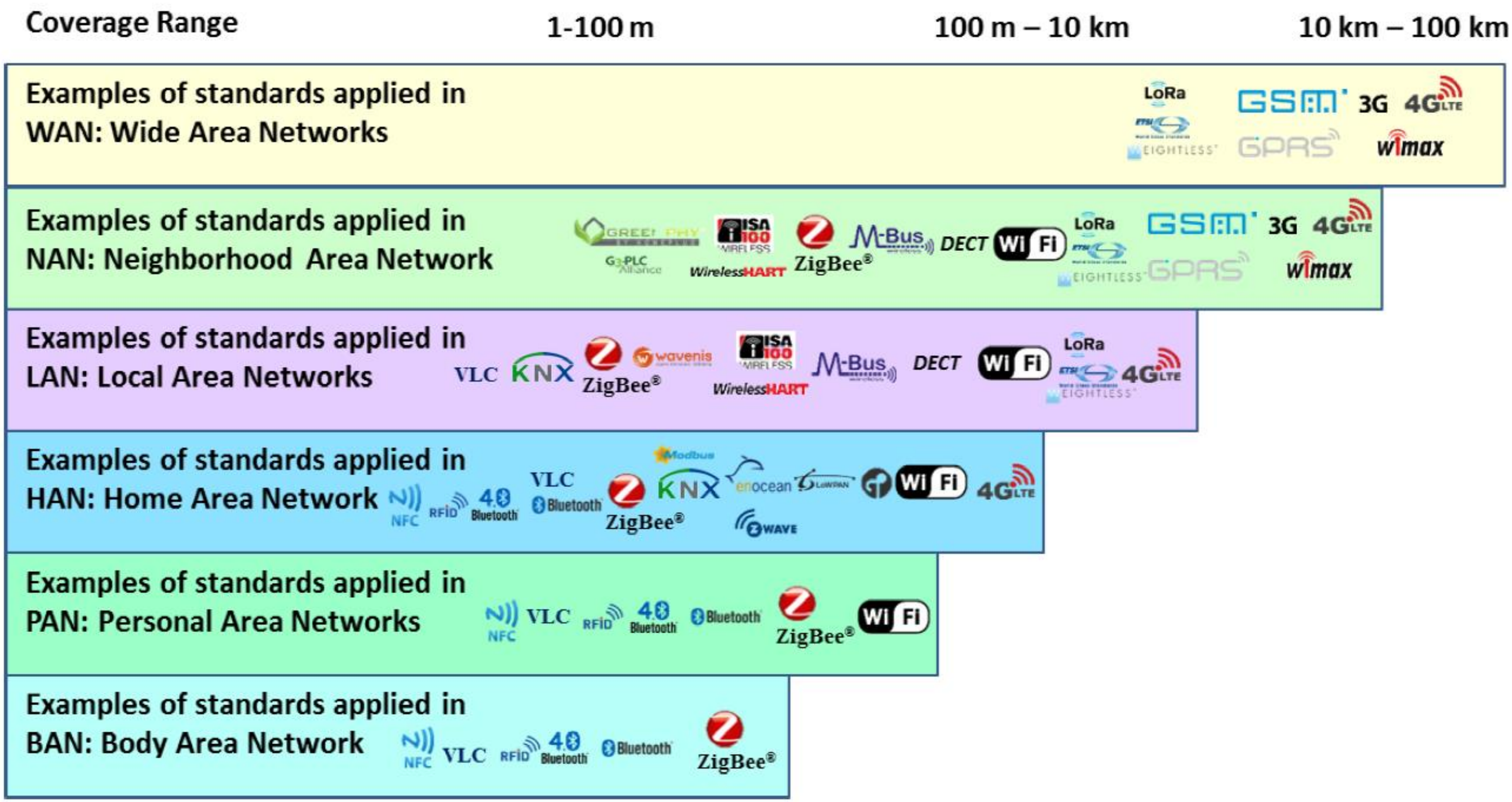
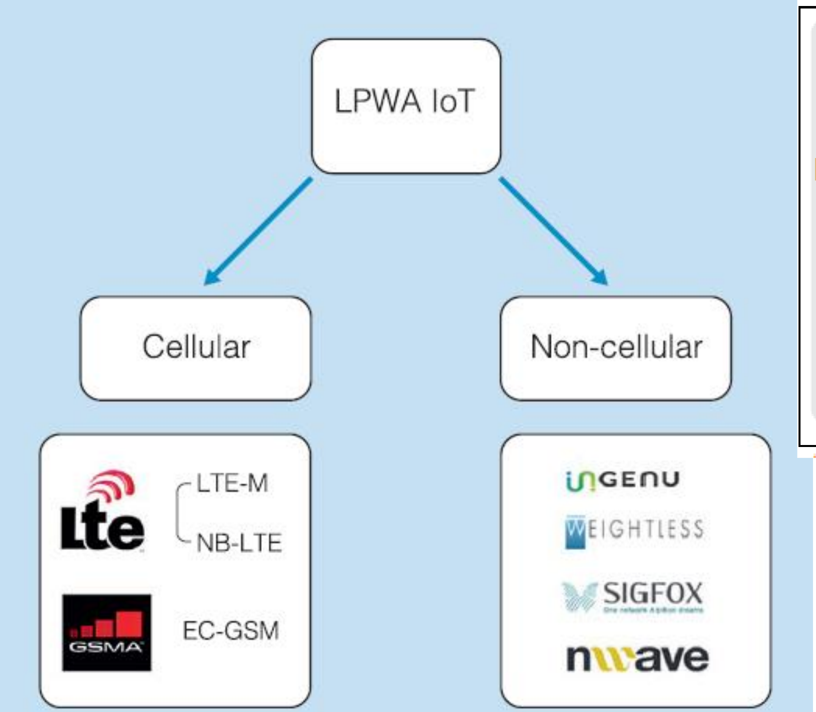
Map of IoT technologies over operating ranges



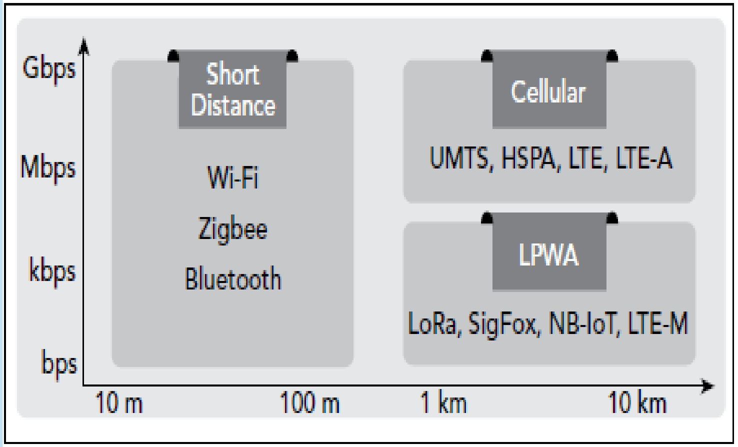
Example of Mapping the Different Protocols to Different Area Networks

Map of IoT technologies over operating ranges

Protocols Range	> Billion units/year now	Emerging
Proximity <10 cm	NFC	-
Middle range < 5 km	Bluetooth; 802.11a/b/g/n/ac	Thread (6LowPAN); 802.11ah (1km); 802.11p (V2X)
5 km < Long range <100 km	3GPP LTE; 3GPP GSM; 3GPP WCDMA	Sigfox; LoRa; Telensa; 3GPP NB-IoT; 3GPP LTE-MTC; Extended Coverage (EC)-GPRS



LPWA IoT standards



Universe of networking technologies

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Short-range IoT

BLE	
Frequency	2.4 Ghz
Bandwidth	1 MHz
Data Rate	1 Mbps
Modulation	GFSK
Range	50 m
Network	WPAN
Applications	Automotive, healthcare, security, and home entertainment

Thread (802.15.4)	
Frequency	800, 900, 2400 MHz
Bandwidth	2 MHz
Data Rate	40 kbps to 250 kbps
Modulation	BFSK, FSK, OQPSK
Range	10 m
Network	WPAN
Applications	Mesh network for home and support 6LoWPAN

ZigBee	
Frequency	800, 900, 2400 MHz
Bandwidth	2 MHz
Data Rate	40 kbps to 250 kbps
Modulation	BPSK OQPSK
Range	10 m
Network	WPAN
Applications	Home automation, smart grid. and remote control

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Short-range IoT (cont.)

802.11ah	
Frequency	Sub GHz
Bandwidth	1 to 16 MHz
Data Rate	150 kbps to 78 Mbps
Modulation	OFDM
Range	1000 m
Network	WLAN
Applications	Target for IoT, wearable devices or extended range

Wi-Sun	
Frequency	800, 900, 2400 MHz
Bandwidth	200 kHz to 1.2 MHz
Data Rate	50 kbps to 1 Mbps
Modulation	FSK, OFDM, OQPSK
Range	1000 m
Network	WNAN
Applications	FAN and HAN Smart Utility Networks, Smart Grid, and Smart Metering

Long-range IoT

NB-IoT	
Frequency	GSM/LTE band
Bandwidth	180 kHz
Data Rate	Up to 250 kbps
Modulation	BPSK, QPSK, opt 16QAM
Range	10's of km
Network	WAN
Applications	Critical infrastructure and agriculture

LTE-M Catagory 0/1 (LTE Rel. 12/13)	
Frequency	LTE bands
Bandwidth	1.4 MHz
Data Rate	200 kbps ~ 1Mbps
Modulation	OFDM
Range	1000 m
Network	WAN
Applications	Lower speed and power versions of LTE in 3GPP Release 12/13. Cat-M1 is expected to be used on machine-to-machine (M2M) applications for industrial IoT.

LoRa	
Frequency	Sub GHz
Bandwidth	125 kHz
Data Rate	0.3 to 50 kbps
Modulation	GFSK, CSS
Range	32 Km
Network	WAN
Applications	Critical infrastructure and agriculture

SigFox	
Frequency	Sub GHz
Bandwidth	600 Hz
Data Rate	Up to 500 kbps
Modulation	BPSK, GFSK
Range	10's of km
Network	WAN
Applications	Critical infrastructure and agriculture

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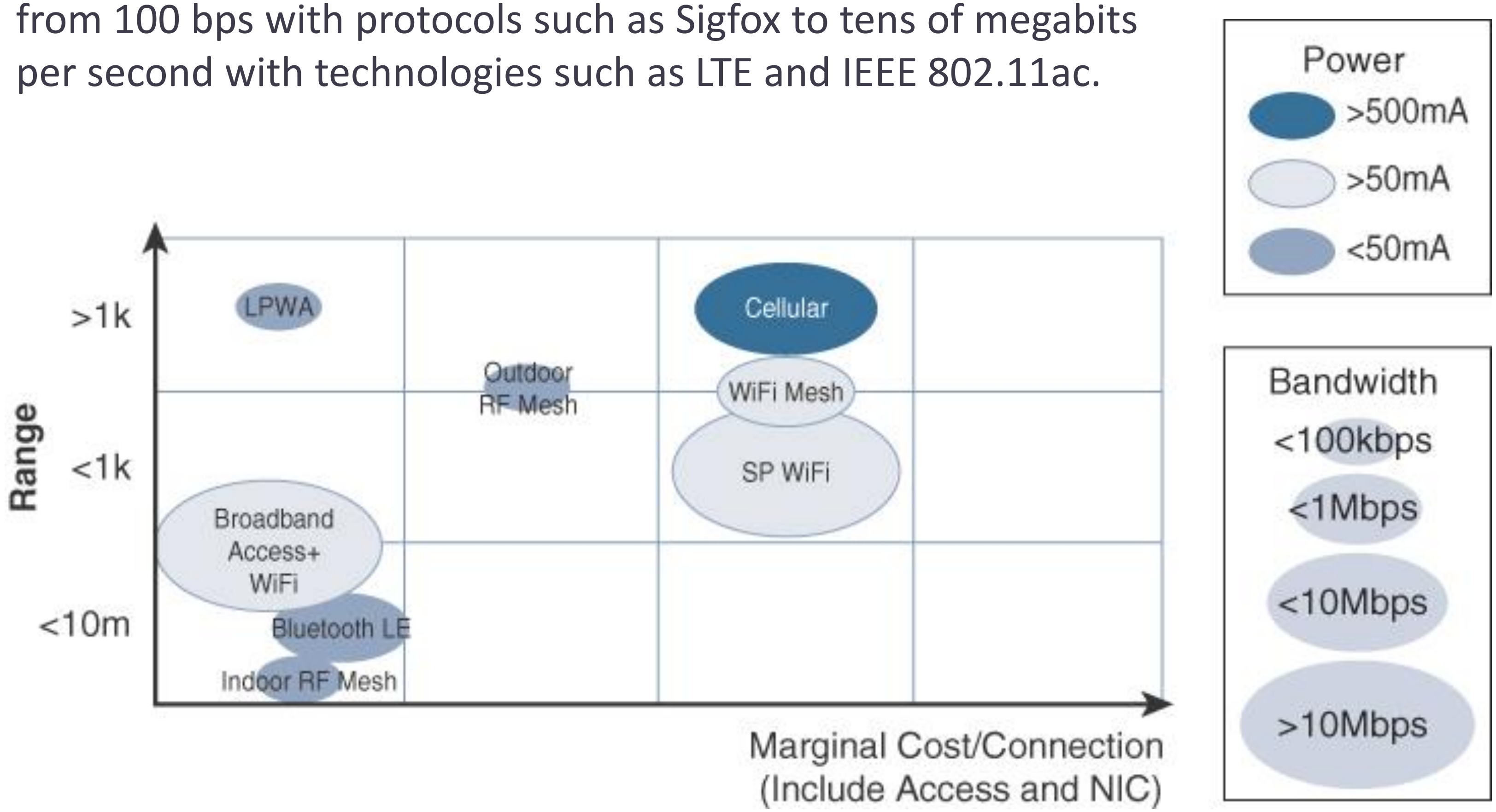
Comparison Between Common Last-Mile Technologies in Terms of Data rate, Range Versus Cost, Power, and Bandwidth

The data rates available from IoT access technologies range from 100 bps with protocols such as Sigfox to tens of megabits per second with technologies such as LTE and IEEE 802.11ac.



Range, Data Rate and Throughput

Technology and Data Rate

Technology	Data rate	Spectrum	Standardisation approach	Comments
eMTC (also known as LTE-M or LTE Cat-M1)	1 Mbps	Licensed	Standardised by 3GPP	Expected to be more expensive than other LPWA technologies, but offers higher data rate
NB-IoT (also known as LTE Cat-NB1)	20-60 kbps	Licensed	Standardised by 3GPP	Expected to be a software upgrade to existing infrastructure, and cheaper than other LPWA technologies
EC-GSM	10 kbps	Licensed	Standardised by 3GPP	Expected to be a software upgrade to existing infrastructure, but will lose out to NB-IoT in most markets
LoRaWAN	250 bps to 50 kbps	Licence-exempt	Developed by Semtech, the on-going standardisation by the LoRa Alliance	A growing ecosystem of certified devices

eMTC – enhanced machine type communication
also called LTE-M or LTE Cat-M1
NB-IoT or LPWA
Extended Coverage GSM – EC-GSM

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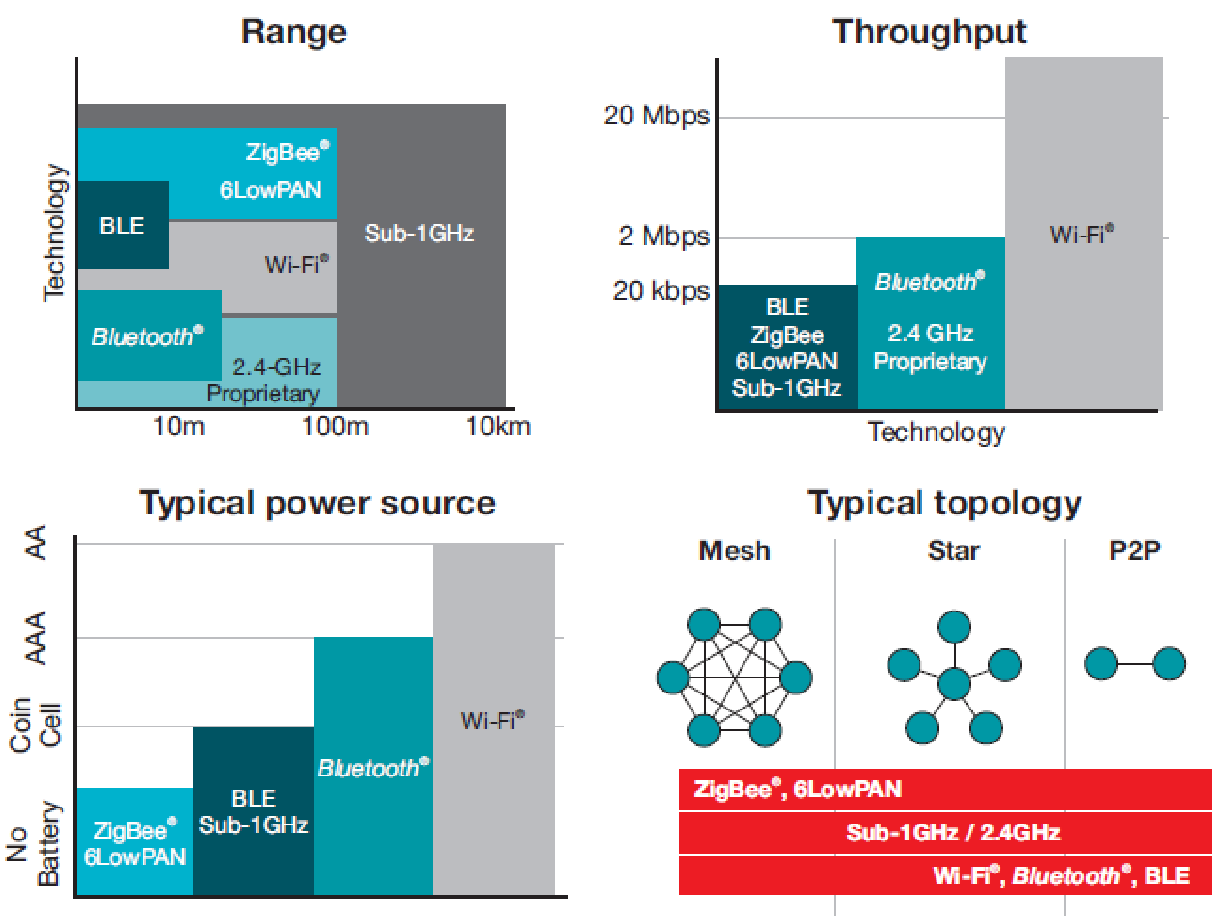
Range, Data Rate and Throughput

IoT WIRELESS TECHNOLOGIES

Technologies	Standards & Organizations	Network Type	Frequency (US)	Max Range	Max Data Rate	Max Power	Encryption
WiFi	IEEE 802.11 (a,b,g,n,ac,ad, and etc)	WLAN	2.4,3.6,5,60 GHz	100 m	"6-780 Mb/s 6.75 Gb/s @ 60 GHz"	1 W	WEP, WPA, WPA2
Z-Wave	Z-Wave	Mesh	908.42 MHz	30 m	100 kb/s	1 mW	Triple DES
Bluetooth	Bluetooth (formerly IEEE 802.15.1)	WPAN	2400-2483.5 MHz	100 m	1-3 Mb/s	1 W	56/128-bit
Bluetooth Smart (BLE)	IoT Interconnect	WPAN	2400-2483.5 MHz	100 m	1 Mb/s	10-500 mW	128-bit AES
Zigbee	IEEE 802.15.4	Mesh	2400-2483.5 MHz	10 m	250 kb/s	1 mW	128-bit
THREAD	IEEE 802.15.4 + 6LoWPAN	Mesh	2400-2483.5 MHz	11 m	251 kb/s	2 mW	128-bit AES
RFID	Many	P2P	13.56 MHz, etc.	1 m	423 kb/s	~1 mW	possible
NFC	ISO/IEC 13157 & etc	P2P	13.56 MHz	0.1 m	424 kb/s	1-2 mW	possible
GPRS (2G)	3GPP	GERAN	GSM 850/1900 MHz	25 km / 10 km	171 kb/s	2 W / 1 W	GEA2/GEA3/GEA4
EDGE (2G)	3GPP	GERAN	GSM 850/1900 MHz	26 km / 10 km	384 kb/s	3 W / 1 W	A5/4, A5/3
UMTS (3G) HSDPA/HSUPA	3GPP	UTRAN	850/1700/1900 MHz	27 km / 10 km	0.73-56 Mb/s	4 W / 1 W	USIM
LTE (4G)	3GPP	GERAN/UTRAN	700-2600 MHz	28 km / 10 km	0.1-1 Gb/s	5 W / 1 W	SNOW 3G Stream Cipher
ANT+	ANT+ Alliance	WSN	2.4 GHz	100 m	1 Mb/s	1 mW	AES-128
Cognitive Radio	IEEE 802.22 WG	WRAN	54-862 MHz	100 km	24 Mb/s	1 W	AES-GCM
Weightless-N/W	Weightless SIG	LPWAN	700/900 MHz	5 km	0.001-10 Mb/s	40 mW / 4 W	128-bit

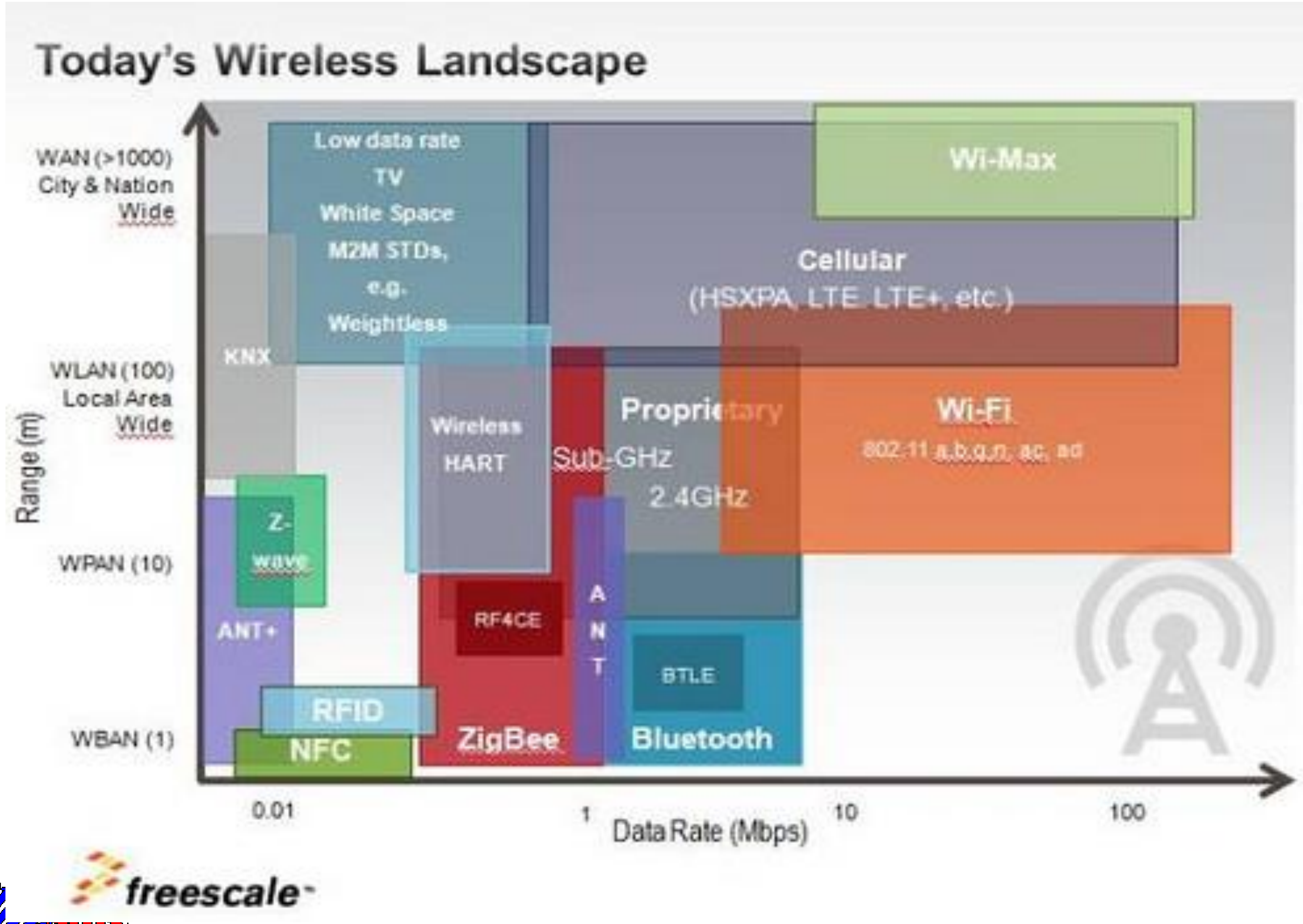
Range, Topology and Throughput



Summary of wireless technology parameters

IoT technologies: *Bluetooth's evolution to BT low energy; WLAN evolution (IEEE 802.11x) (2.4/5/60 GHz);* and new radio access technologies including *NFC, Zigbee and Z-wave*, 6LowPAN Sub-1GHz (500 - 950 MHz and peak data rate >200 Mbps)

Range and Data Rate



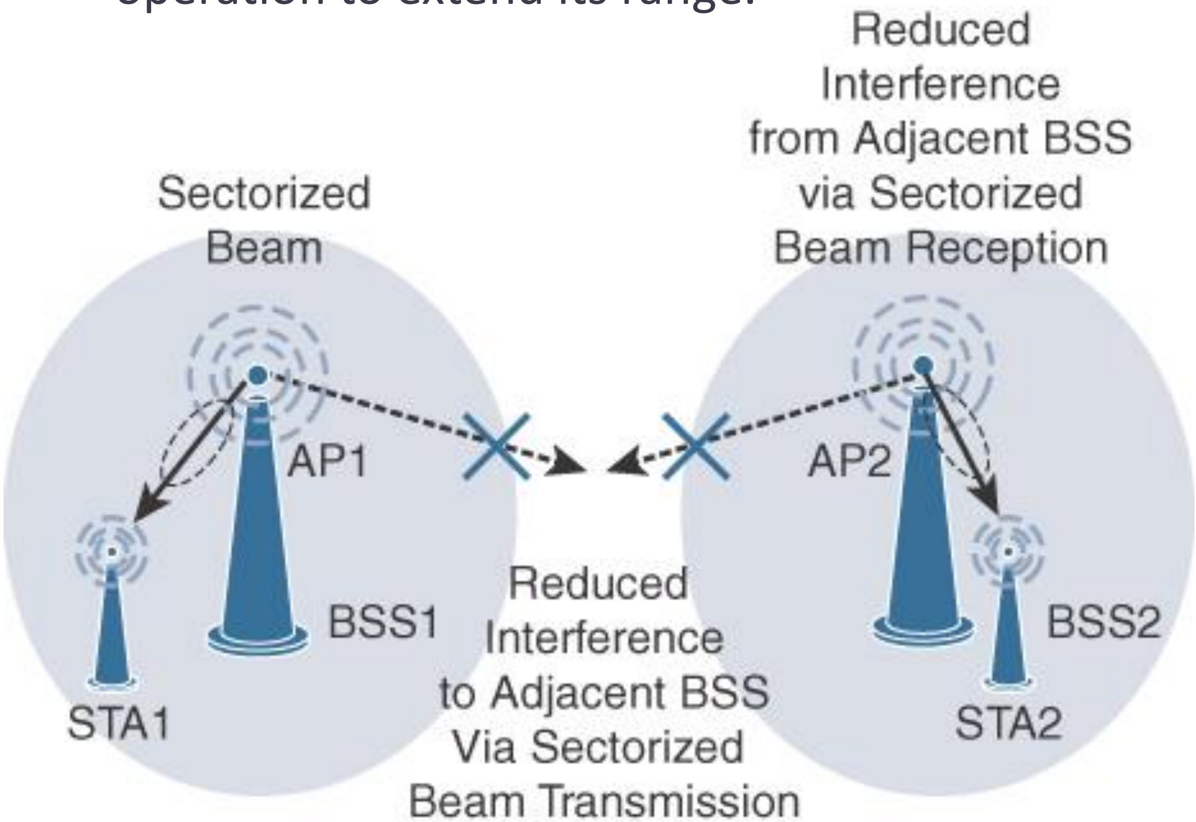
Main Characteristics of IoT Access Technologies

Characteristic	IEEE 802.15.4	IEEE 802.15.4g and IEEE 802.15.4e	IEEE 1901.2a	IEEE 802.11ah	LoRaWAN	NB-IoT
Wired or wireless	Wireless	Wireless	Wired	Wireless	Wireless	Wireless
Frequency bands	Unlicensed 2.4 GHz and sub-GHz	Unlicensed 2.4 GHz and sub-GHz	Unlicensed CENELEC A and B, FCC, ARIB	Unlicensed sub-GHz	Unlicensed sub-GHz	Licensed
Topology	Star, mesh	Star, mesh	Mesh	Star	Star	Star
Range	Medium	Medium	Medium	Medium	Long	Long
Data rate	Low	Low	Low	Low–high	Low	Low

Topology, Range, and Data Rate

IEEE 802.11ah Topology

The IEEE 802.11 Wi-Fi is certainly the most successfully deployed wireless technology. While IEEE 802.11ah is deployed as a star topology, it includes a simple hops relay operation to extend its range.



IEEE 802.11ah Sectorization

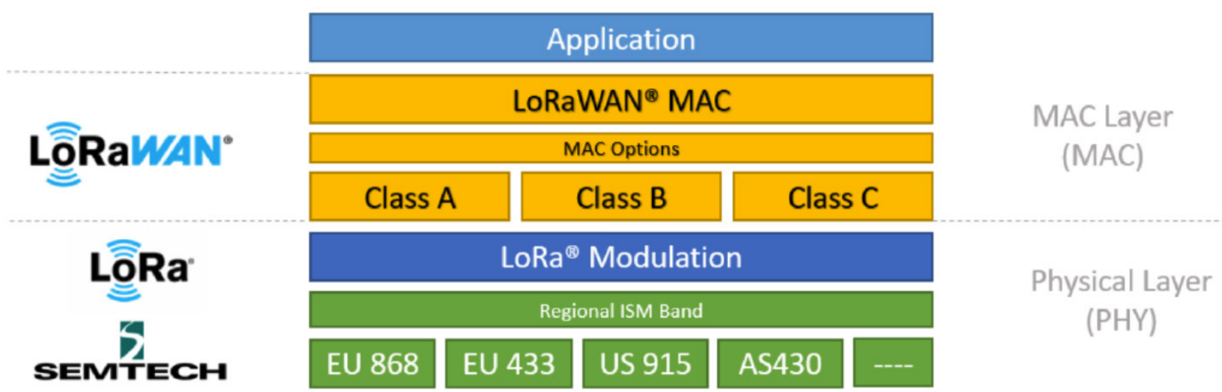
LoRa IoT

What is LoRa?

LoRaWAN is a high capacity, Long Range, open, Low Power Wide Area Network (LPWAN) standard designed for LoRa Powered IoT Solutions by the LoRa Alliance. LoRa is an RF modulation technology for LPWANs. The name is a reference to the extremely long-range data links that this technology enables. Designed to wirelessly connect battery operated things to the internet in regional, national or global networks.

How LoRaWAN operates?

LoRa is the physical (PHY) layer, which means it is the wireless modulation used to create the long-range communication link. As the data layer, LoRaWAN is an open networking protocol that delivers secure bi-directional communication, mobility, and localization services standardized and maintained by the LoRa Alliance.



Main Characteristics of LoRa

Long Range

Deep Indoor coverage

Topology, star network design

Long Battery Life

Low power

Up to 10 years life

High Capacity

Millions of messages per base station/gateway

Multi-tenant interoperability

Low Cost

Minimal Infrastructure

Low-Cost end node

Geolocation

Indoor/Outdoor

Accurate without need for GPS

FUOTA

Firmware updates over the air for applications

Roaming

Seamless handovers

Security

Embedded end to end AES-128 encryption

Unique ID

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Maximise IoT Device Life

Avoid early IoT device failure

Problem: Battery Life

Long Battery Life

Low power

Up to 10 years life

Potential Solution:

Smart Passive Sensors (SPS) Energy Harvesting Wireless Sensing

Smart

Stimuli Detector

Adaptable RF front end

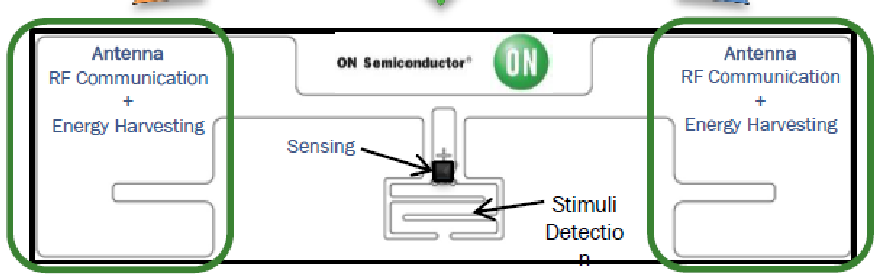
Passive

No Batteries

Energy Harvesting

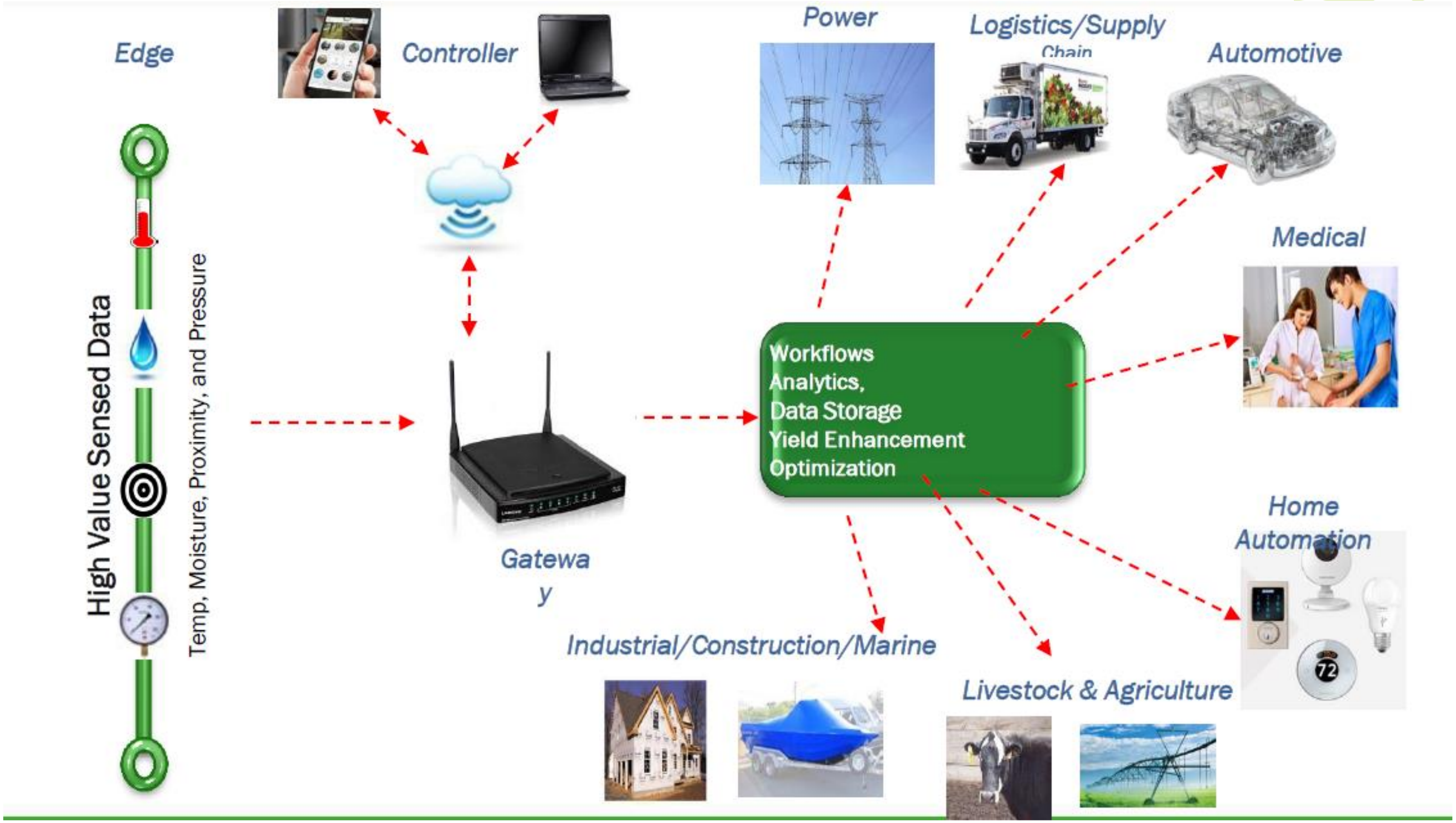
Sensors

Temperature, Pressure, Moisture, Proximity



Battery Free, MCU Free, Sensor Tag

SPS: Multi market Benefits



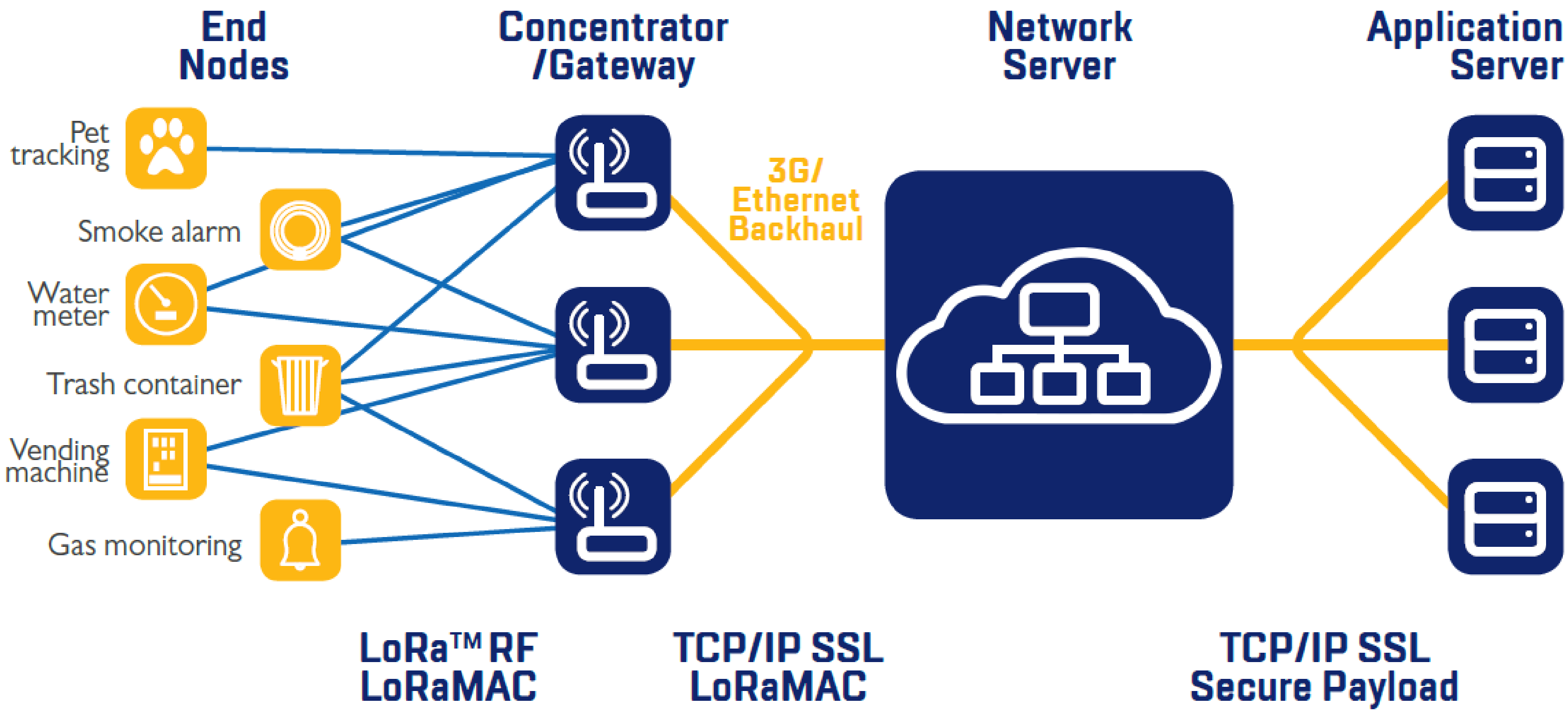
LoRaWAN Topology

LoRaWAN topology is often described as a “star of stars” Topology.

Long Range

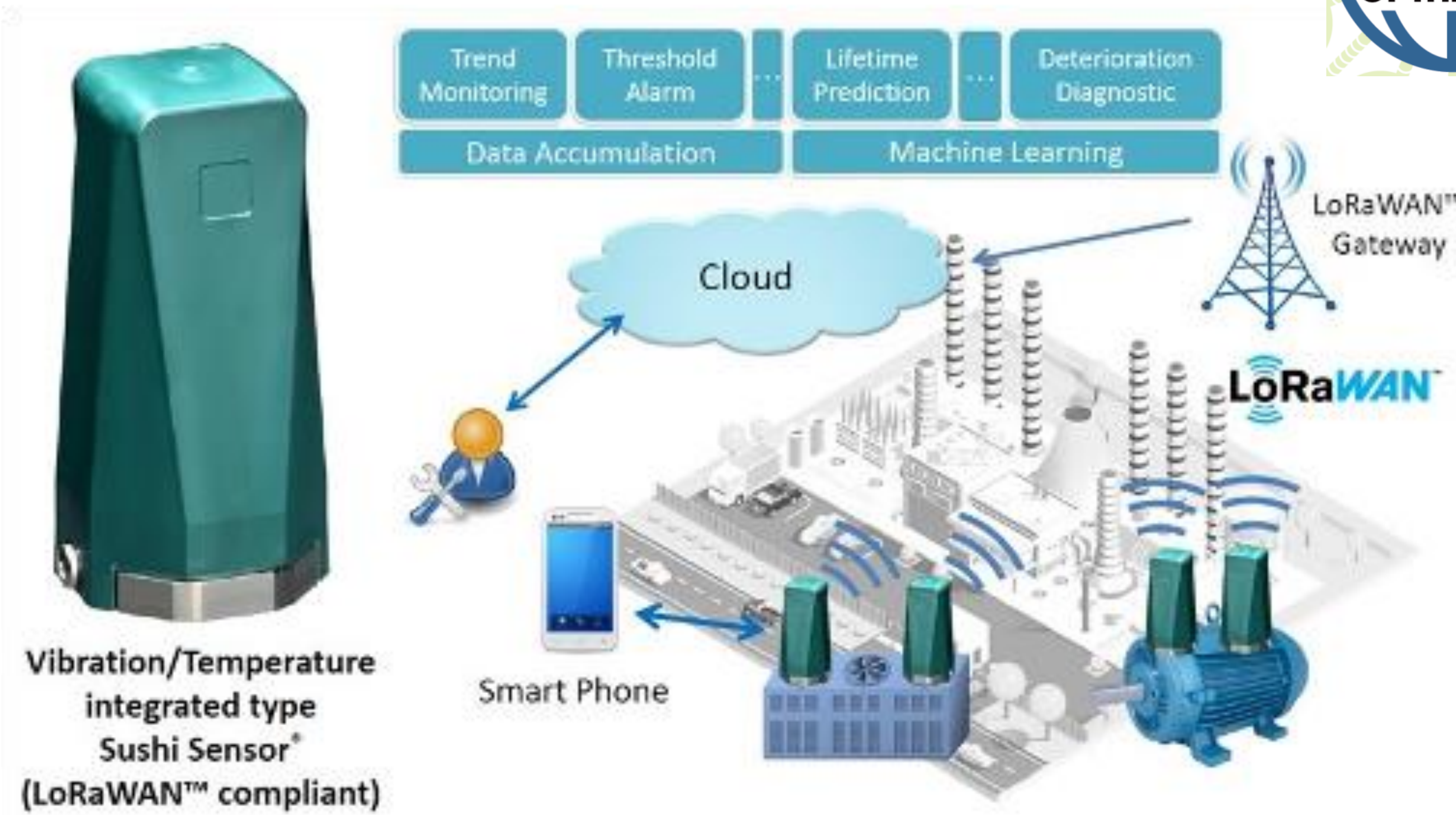
Deep Indoor coverage

Topology, star network design



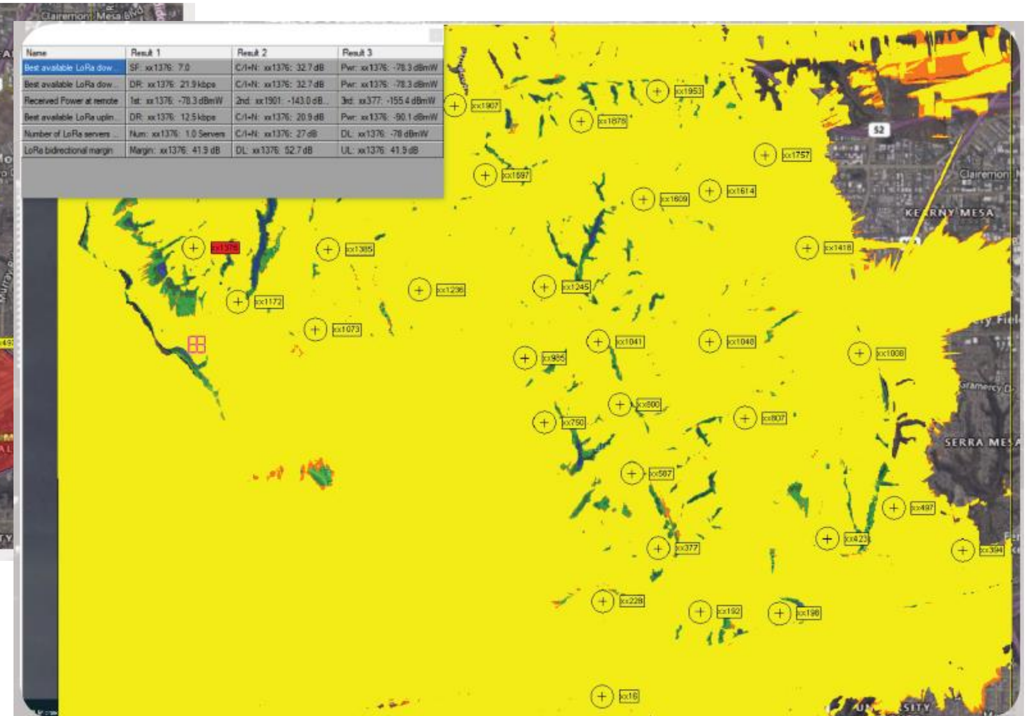
Typical LoRaWAN Network Architecture:
LoRaWAN uses the star network as opposed to Mesh.

LoRaWAN



Trend Monitoring
Threshold Alarm
Lifetime Prediction
Deterioration Diagnostic
Data Accumulation
Machine Learning
Cloud
LoRaWAN™ Gateway
LoRaWAN
Vibration/Temperature integrated type Sushi Sensor® (LoRaWAN™ compliant)
Smart Phone

Example: Coverage Map and Associated Data Rate



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Unlicensed LPWA Technology Comparison

THE INTERNET OF THINGS

Characteristic	LoRaWAN	Sigfox	Ingenu Onramp
Frequency bands	433 MHz, 868 MHz, 902–928 MHz	433 MHz, 868 MHz, 902–928 MHz	2.4 GHz
Modulation	Chirp spread spectrum	Ultra-narrowband	DSSS
Topology	Star of stars	Star	Star; tree supported with an RPMA extender
Data rate	250 bps–50 kbps (868 MHz) 980 bps–21.9 kbps (915 MHz)	100 bps (868 MHz) 600 bps (915 MHz)	6 kbps
Adaptive data rate	Yes	No	No
Payload	59–230 bytes (868 MHz) 19–250 bytes (915 MHz)	12 bytes	6 bytes–10 KB
Two-way communications	Yes	Partial	Yes
Geolocation	Yes (LoRa GW version 2 reference design)	No	No
Roaming	Yes (LoRaWAN 1.1)	No	Yes
Specifications	LoRA Alliance	Proprietary	Proprietary

NB-IoT and Other LTE Variations

Existing cellular technologies, such as GPRS, Edge, 3G, and 4G/LTE, are not particularly well adapted to battery-powered devices and small objects specifically developed for the Internet of Things.

LTE Cat 0

The first enhancements to better support IoT devices in 3GPP occurred in LTE Release 12.

LTE-M

Following LTE Cat 0, the next step in making the licensed spectrum more supportive of IoT devices was the introduction of the LTE-M category for 3GPP LTE Release 13.

NB-IoT

Recognizing that the definition of new LTE device categories was not sufficient to support LPWA IoT requirement, 3GPP specified Narrowband IoT (NB-IoT).

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THE INTERNET OF THINGS

Key 3GPP Release 16 Features

- eMBB enhancement
- Vehicular communications
- Industrial IoT
- mMTC
- NW architectural evolution

Key 3GPP Release 17 Features

- NR support on 52.6 – 71 GHz
- RedCap device (Reduced Capable UE)
- NR over NTN / IoT over NTN
- Positioning enhancement
- NR coverage enhancement
- Further MIMO enhancement
- URLLC/IIoT enhancement
- XR Study
- NR multicast

Cellular IoT Wireless Technologies

Various 3GPP formats enabling cellular and LPWAN communication in IoT applications.

	3GPP Rel 12	3GPP Rel 13		
	MTC Cat 0	eMTC Cat M*	EC-GPRS	NB-IoT*
	3GPP Rel 12	3GPP Rel 13	3GPP Rel 13	3GPP Rel 13
Heritage	LTE	LTE	GSM	Clean-slate
Bandwidth (downlink)	20 MHz	1.4 MHz	200 kHz	180 kHz (12 by 15 kHz)
Bandwidth (uplink)	20 MHz	1.4 MHz	200 kHz	Single-tone (180 kHz by 3.75 kHz or 15 kHz) or multi-tone (180 kHz by 15 kHz)
Multiple access (down-link)	OFDMA	OFDMA	TDMA	OFDMA
Multiple access (uplink)	SC-FDMA	SC-FDMA	TDMA	Single-tone FDMA or multi-tone SC-FDMA
Modulation (downlink)	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM	GMSK	BPSK, QPSK, optional 16QAM
Modulation (uplink)	QPSK, 16QAM	QPSK, 16QAM	GMSK	BPSK, QPSK, 8PSK optional 16QAM
Peak data rate	1 Mbps	1 Mbps	10 kbps	DL 128 kbps, UL single tone 48 kbps 64 kbps multi-tone
Coverage (link budget)	~141 dB	~156 dB	~164 dB	~164 dB
Mobility	Full	Full	Full	Nomadic

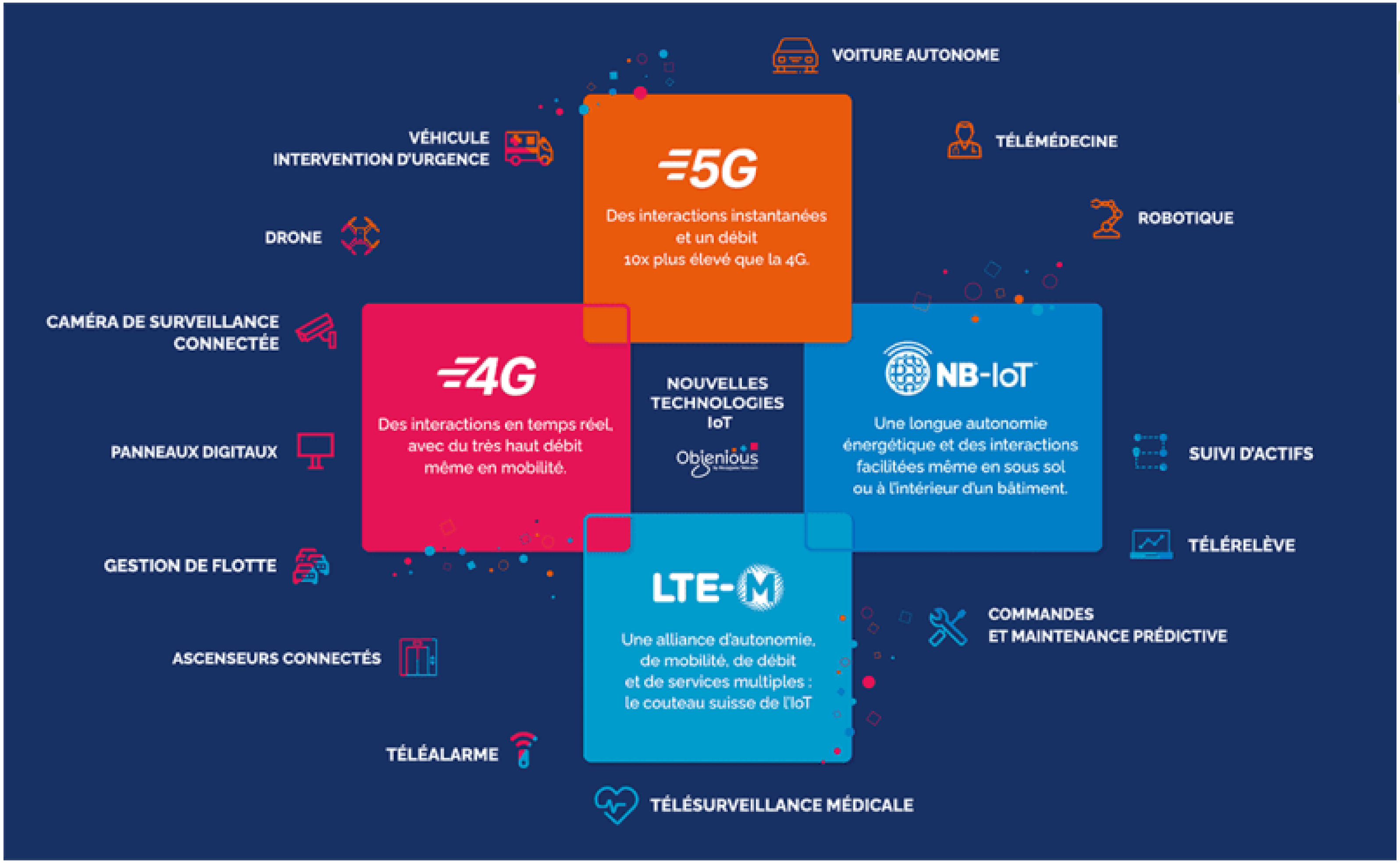
Note * Cat M also currently referred to as Cat M1, NB-IoT also referred to as Cat M2. Details for NB-IoT are subject to change as 3GPP drafting continues

Main Characteristics of Access Technologies

Characteristic	IEEE 802.15.4	IEEE 802.15.4g and IEEE 802.15.4e	IEEE 1901.2a	IEEE 802.11ah	LoRaWAN	NB-IoT
Wired or wireless	Wireless	Wireless	Wired	Wireless	Wireless	Wireless
Frequency bands	Unlicensed 2.4 GHz and sub-GHz	Unlicensed 2.4 GHz and sub-GHz	Unlicensed CENELEC A and B, FCC, ARIB	Unlicensed sub-GHz	Unlicensed sub-GHz	Licensed
Topology	Star, mesh	Star, mesh	Mesh	Star	Star	Star
Range	Medium	Medium	Medium	Medium	Long	Long
Data rate	Low	Low	Low	Low–high	Low	Low

Topology, Range and Data Rate

Example: The new Objenious portfolio for IoT



Objenious, a Bouygues Telecom brand dedicated to the Internet of Things, supports all companies, communities, and institutions in their digital transformation through offerings and services based on LoRaWAN®, 2G, 3G, 4G, LTE-M networks and 5G. Objenious experts support companies in their decision-making and in the implementation of their IoT project.

Bouygues Telecom made clear the late rise of cellular IoT – with mobile operators finally getting to grips with pricing and roaming, and rolling out NB-IoT and LTE-M in earnest – informed its decision to step away from non-cellular LoRaWAN. The firm's IoT subsidiary Objenious, a long-time member of the LoRa Alliance, expects to have more than half of its connections on NB-IoT and LTE-M by the end of 2022 ("by 2023"), and will switch off its LoRaWAN network completely by the end of 2024, it said.

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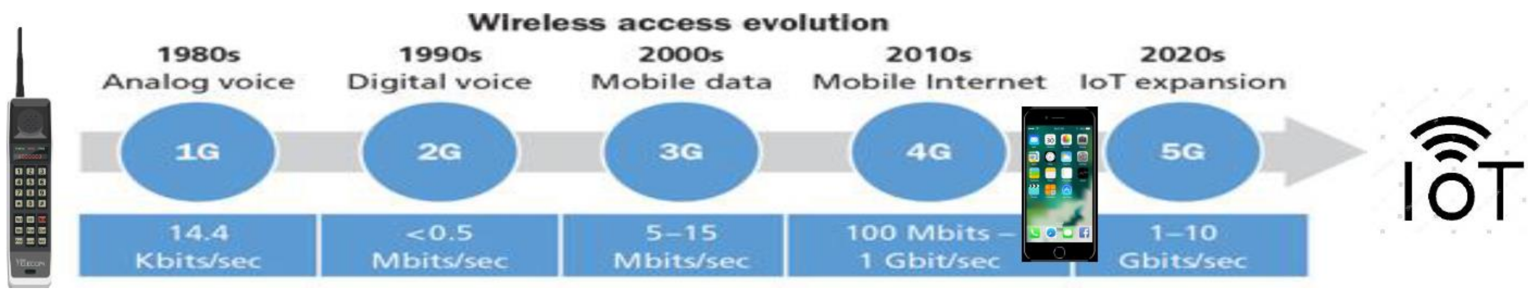
5G Today
- Slightly better than LTE
- Extremely limited footprint, devices

5G As Marketed
- “Gbps speeds”
- “Low latency”
- Massive IoT
- Cost/bit savings

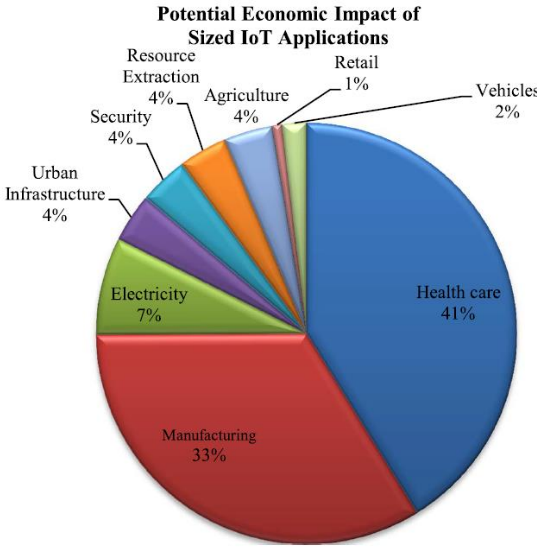
Frequency range designation	Corresponding frequency range
FR1	410 MHz – 7125 MHz
FR2	24250 MHz – 52600 MHz



Internet of Things (IoT) Applications: Real Examples

The IoT is relevant to almost all verticals:

- Education/Schools
- Healthcare
- Agriculture/Farming
- Smart homes/cities
- Vehicles/Automotive
- Transportation
- Industry/Industrial Control
- Markets
- Manufacturing



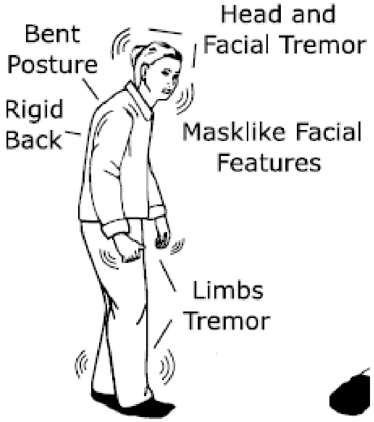
Projected market share of dominant IoT applications by 2025.

The overall picture of IoT emphasizing the vertical markets and the horizontal integration between them.

IoT for Healthcare (HIoT): Example Applications

Some common HIoT management applications:

Blood Glucose Monitoring
Cardiac Monitoring
Respiration Monitoring
Sleep Monitoring
Blood Pressure Monitoring
Stress Monitoring
Parkinson's Disease Monitoring



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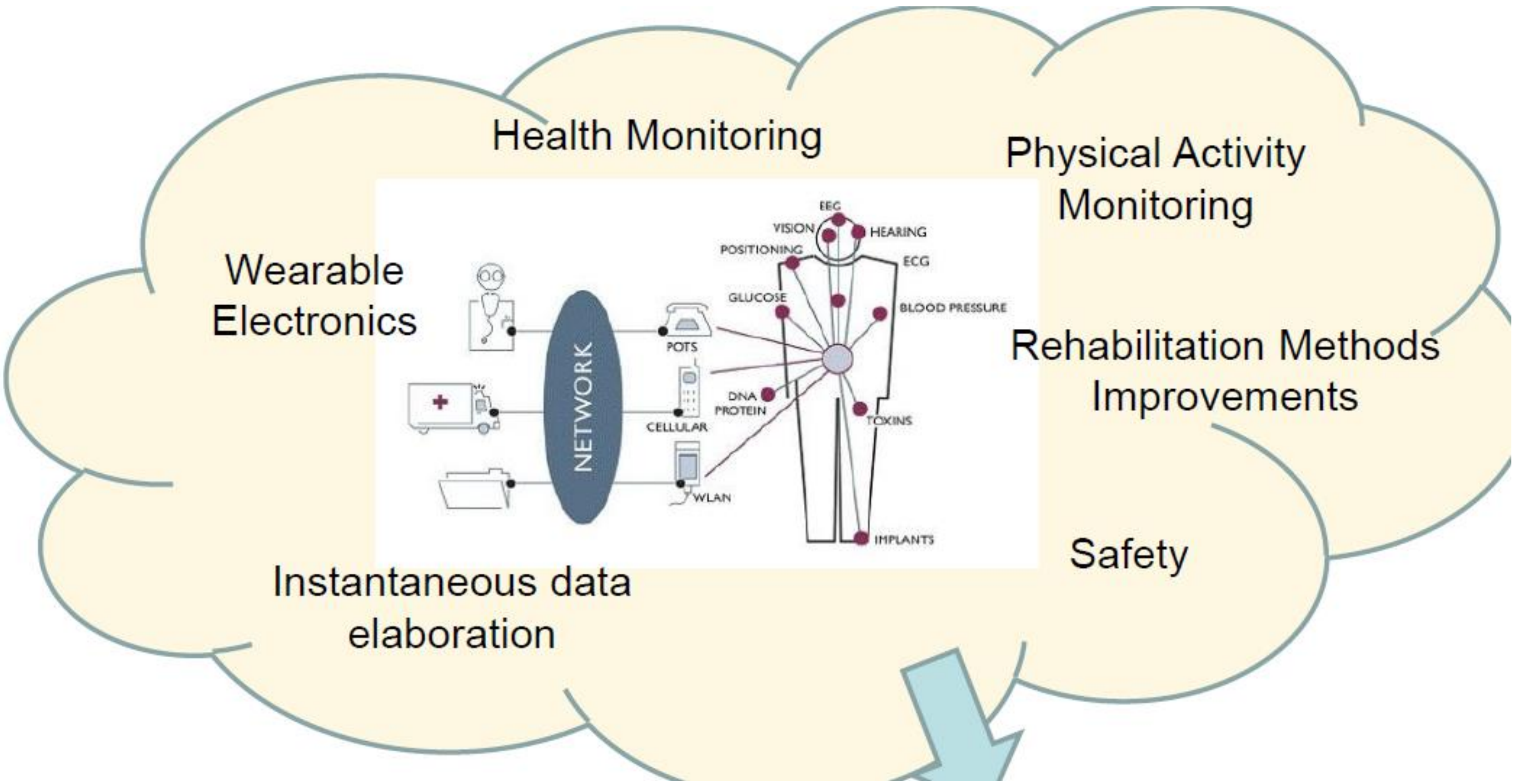
IoT for Healthcare (HIoT): Example Applications

Medical Profiles

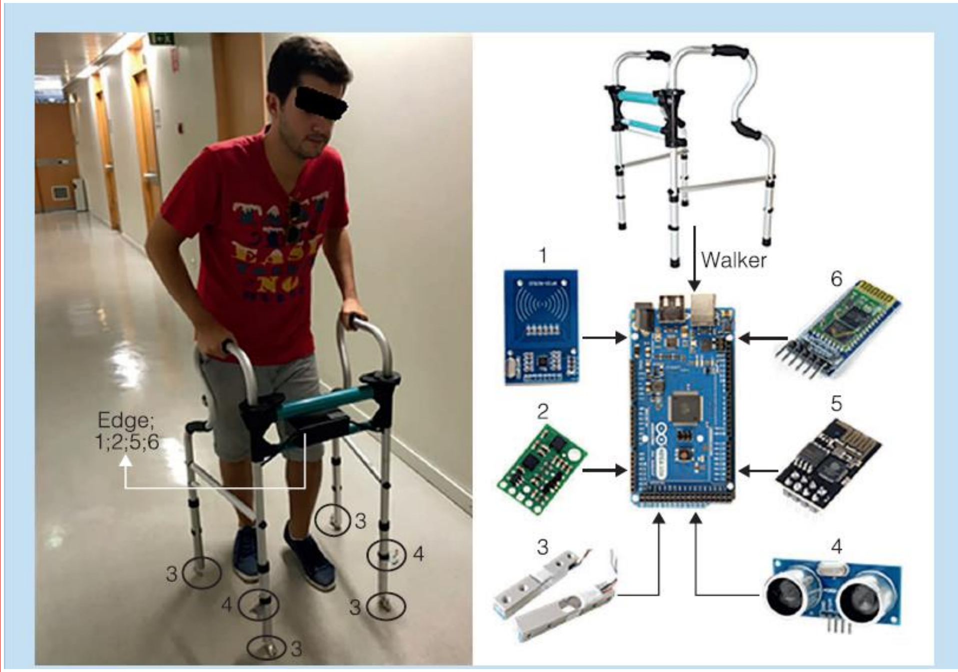
A FEW EXAMPLES

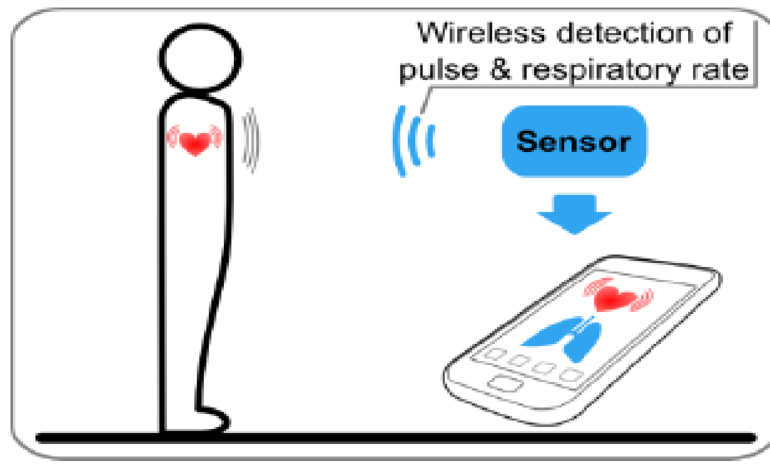
- Blood Pressure
- Continuous Glucose Monitoring
- Health Thermometer
- Insulin Delivery
- Pulse Oximeter

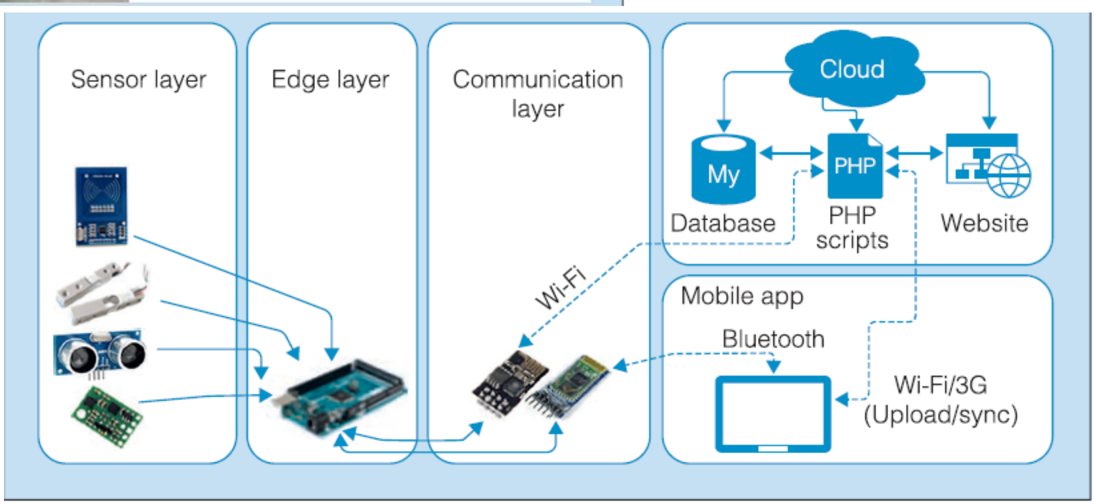
IoT for Healthcare (HIoT)



IoT for Healthcare (HIoT)

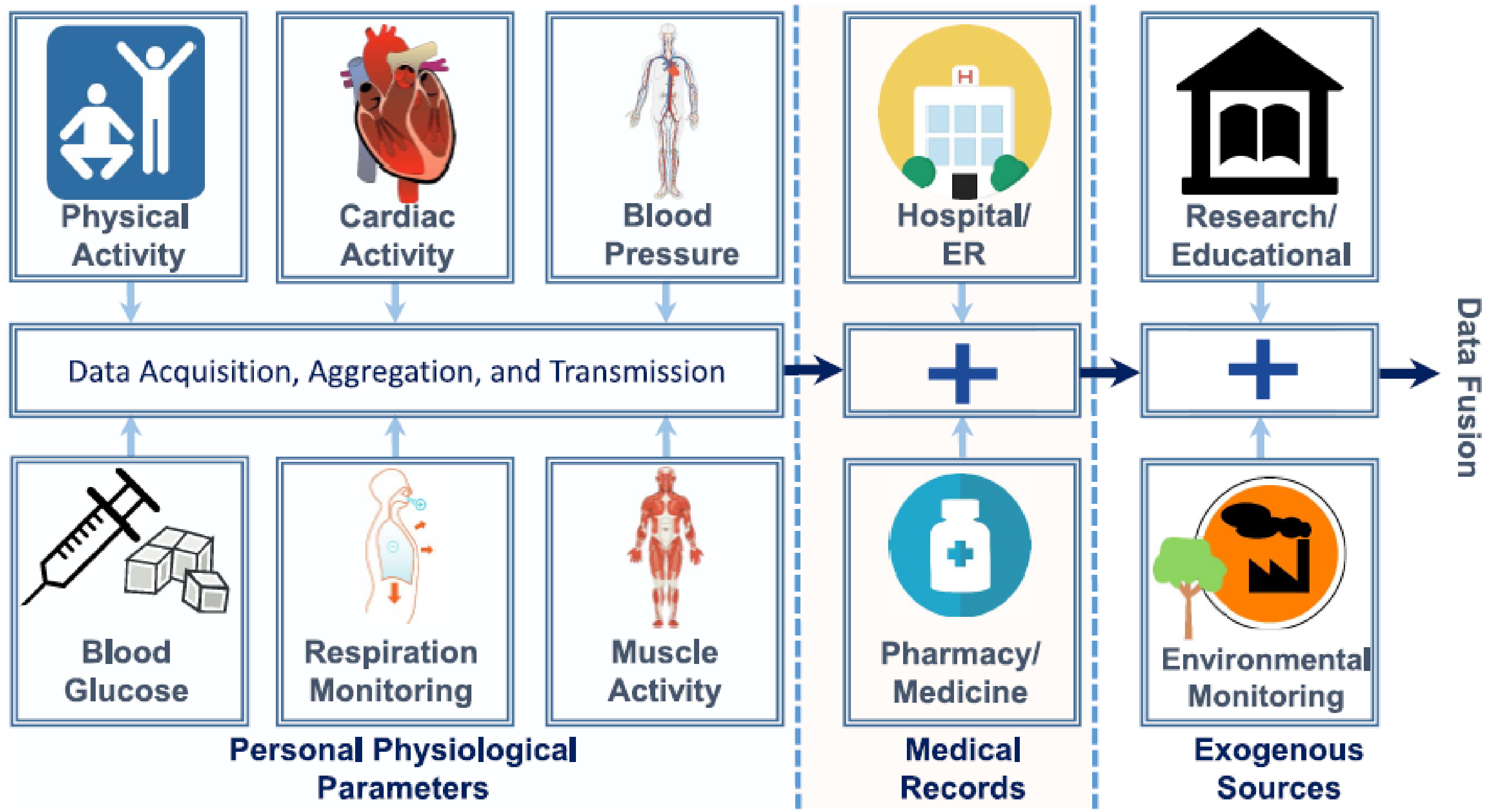






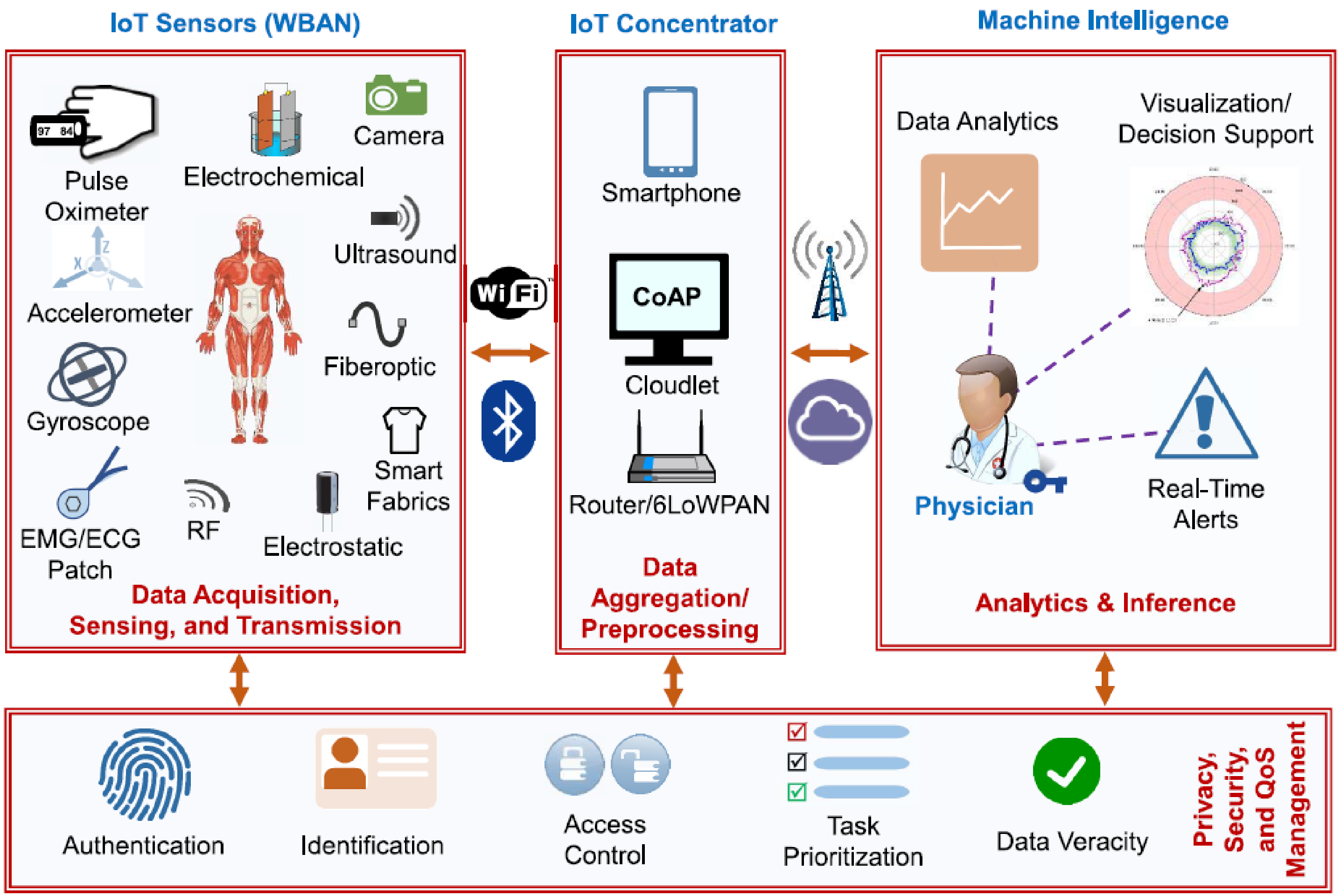
Smart walker IoT for physical rehabilitation architecture.

Modern smart healthcare applications



System Architecture:

The general architecture of the typical HIoT systems



High-level system architecture illustrating HIoT integration into clinical healthcare.

System Architecture

- Data Acquisition, Sensing, and Transmission

The first HIoT component is data acquisition, where IoT devices and sensors measure physiological and environmental signals. These devices are connected to a WBAN (WiFi, Bluetooth, or ZigBee Standard), generally through an intermediate data aggregator such as a smartphone. The primary function of the sensors is to sense and gather data, but many are also now able to preprocess data before transmission.

- Data Aggregation/Pre-processing Cloudlet:

- Cloud Processing and Storage:

- Privacy, Security, and Quality of Service (QoS) Management:

IoT sensors record measurements for a range of physiological and health-related physical attributes.

The data is communicated over the network and aggregated in the cloud by IoT concentrators.

Cloud-based analytics and inference algorithms operating on the data provide decision support to physicians via visualization interfaces, dashboards, and real-time alerts to individual users.

Security and privacy solutions must be implemented to include other components, ensuring data protection from acquisition to storage.

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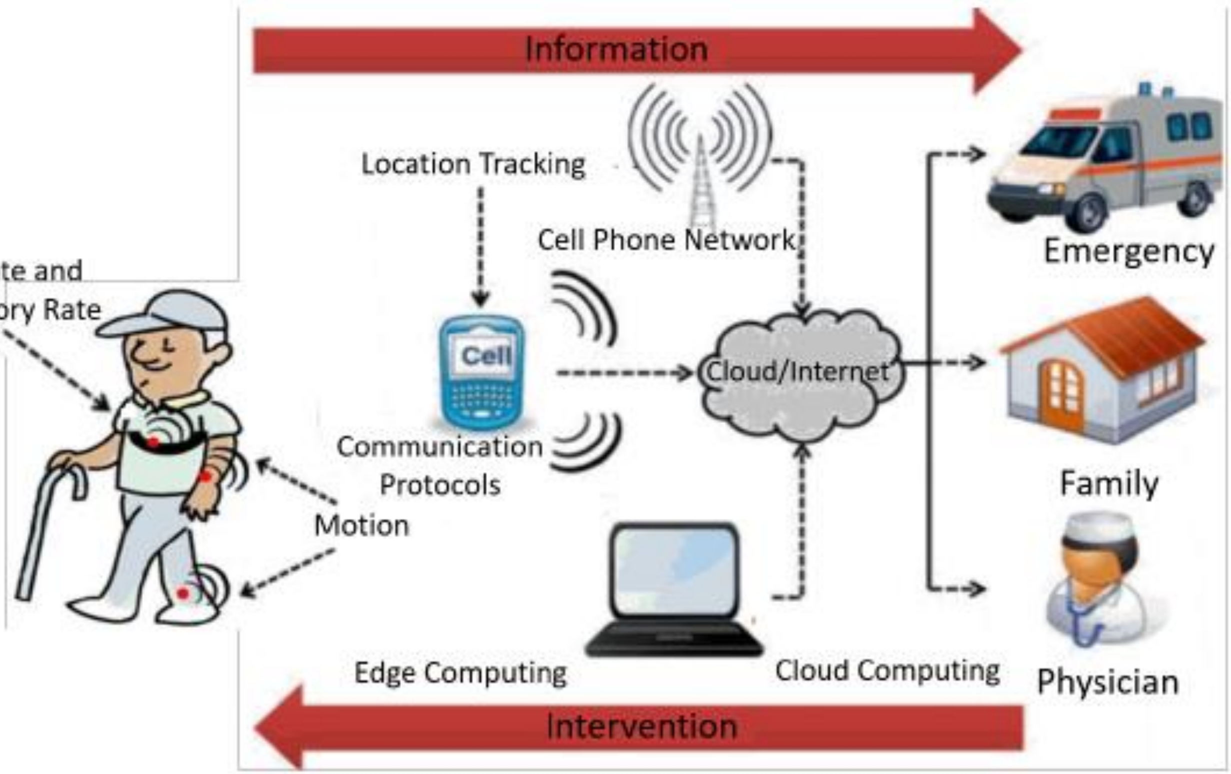
Smart Personal Healthcare Architecture.

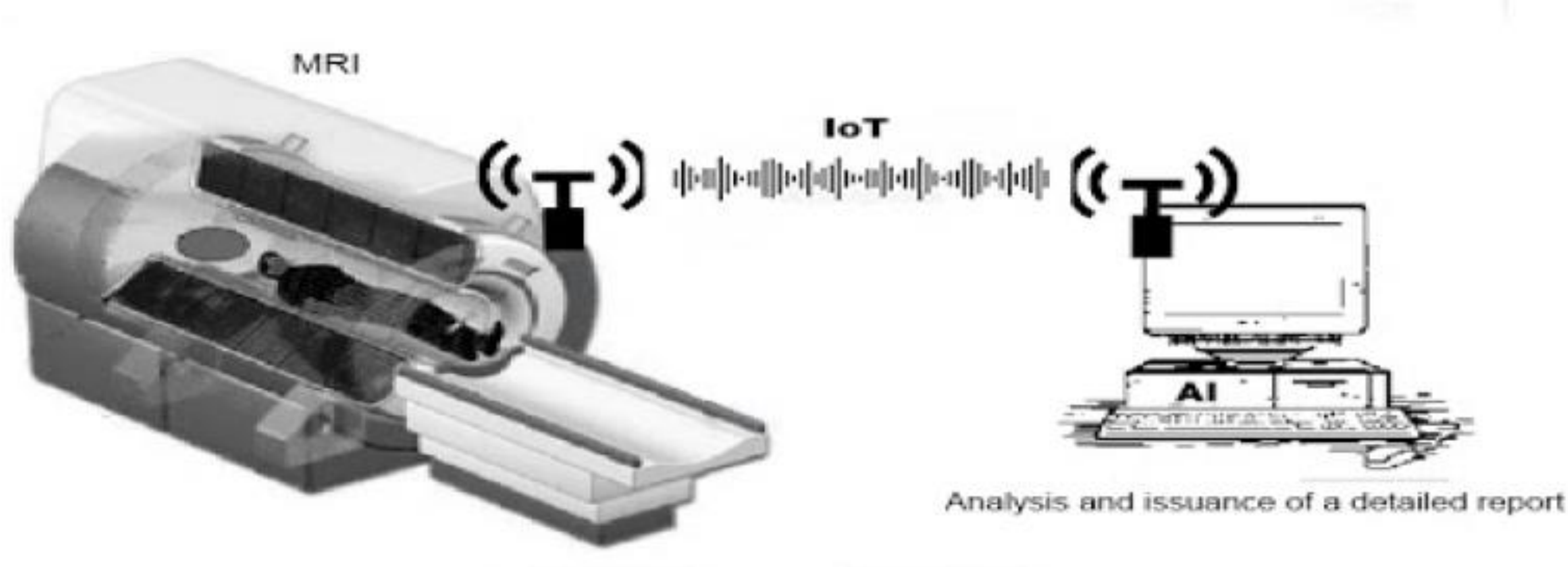


List of commonly used sensors in various clinical HIoT applications

Application	Sensor	Characteristics
Activity Detection	Wearable & Environment IMU	✓ Inexpensive ✗ Obtrusive
	RF	✓ Unobtrusive ✗ Low Accuracy
	Camera	✓ Easy-to-Setup ✗ LoS Limitation ✗ Privacy Concerns
Respiration Detection	Accelerometer & Piezoelectric Materials	✓ Low Power ✓ Accurate ✗ Obtrusive
	Camera	✓ Inexpensive ✗ Low Accuracy ✗ Noise Sensitivity
Heartbeat Monitoring	Wearable ECG Electrodes	✓ No Skin Contact ✗ Low Accuracy
	Accelerometers (BCG)	✓ Inexpensive ✗ Noise Sensitivity
	Accelerometer, Fiber Optics, & Microphone (PCG)	✓ Unobtrusive ✗ Noise Sensitivity
	Pulse Oximeter	✓ Versatile ✗ Obtrusive
Blood Pressure Monitoring	In-Vivo	✓ Unobtrusive ✗ Invasive
	PWV and PTT Sensors	✓ Non-Invasive ✗ Noise Sensitivity
Blood Glucose Monitoring	Electro-Chemical Sensors	✓ Accurate ✗ Invasive
	Optical Sensors	✓ Non-Invasive ✗ Low Accuracy

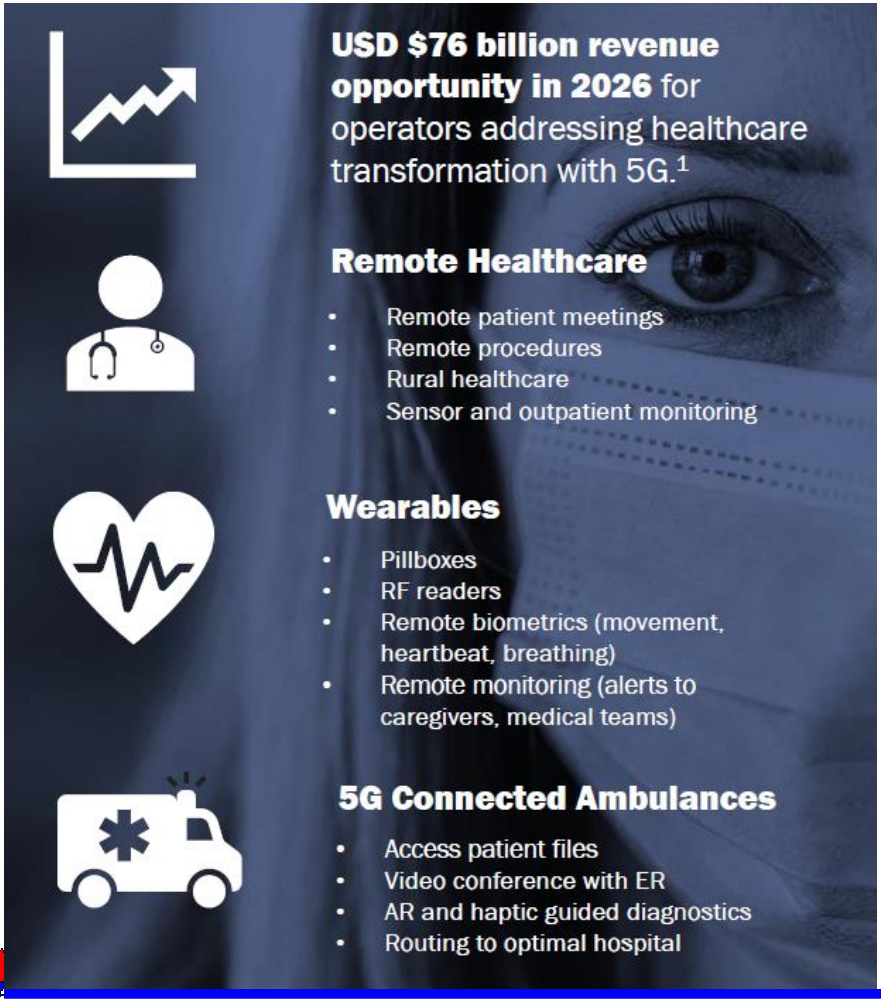
In the last two decades, IoT and Sensor Networks have been applied for various e-Health applications and thus improve diagnostic tools, such as magnetic resonance imaging, and epigenetic and neuropsychological tests.

Example: PhD Research project
IoT in the Development of Medical Radiology /Magnetic Resonance Imaging)



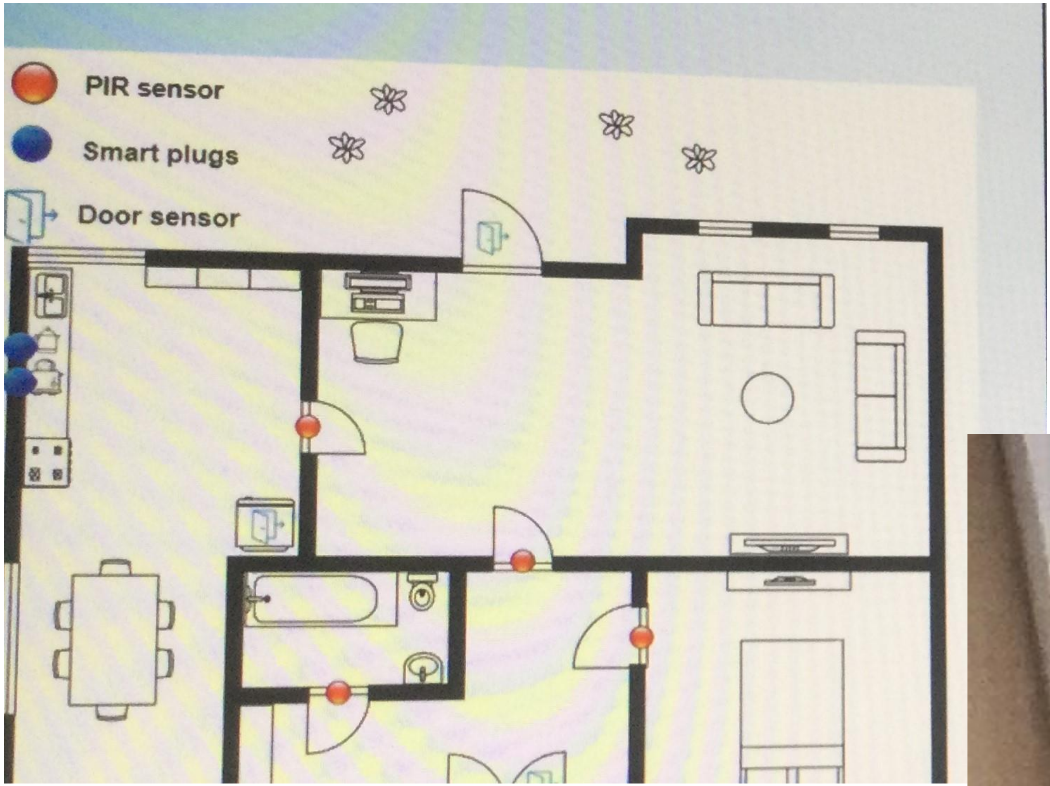
The process of receiving, analysing and comparing the image and taking all measurements as the human brain but without omitting any single pixel of the image

5G offers a wide range of use cases for IoT: Healthcare

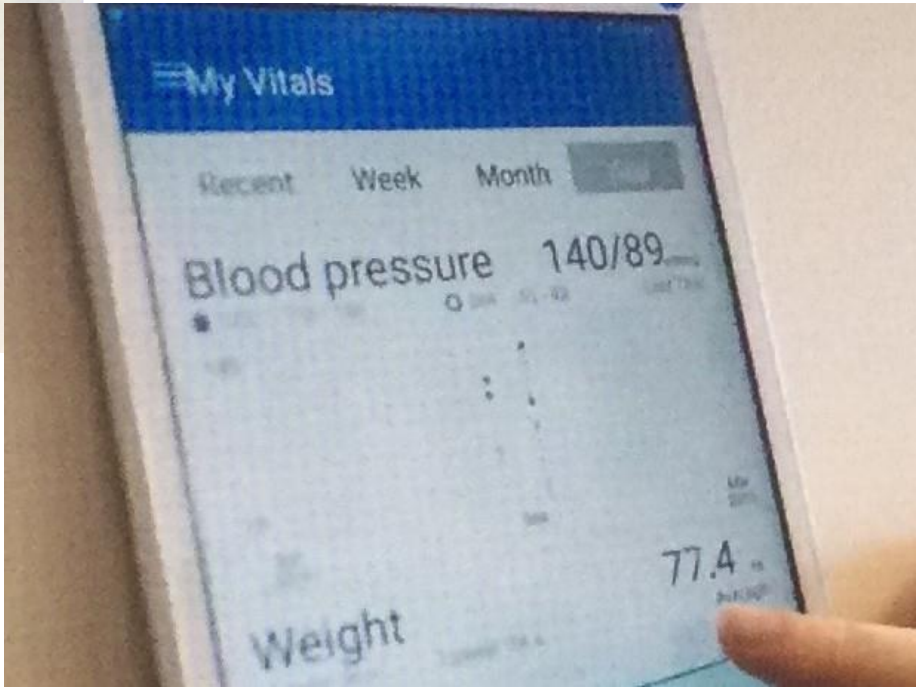


HEALTHCARE COULD BE A HOT AREA FOR 5G & IOT USE CASES

Example: Healthy home concept and the state of the art

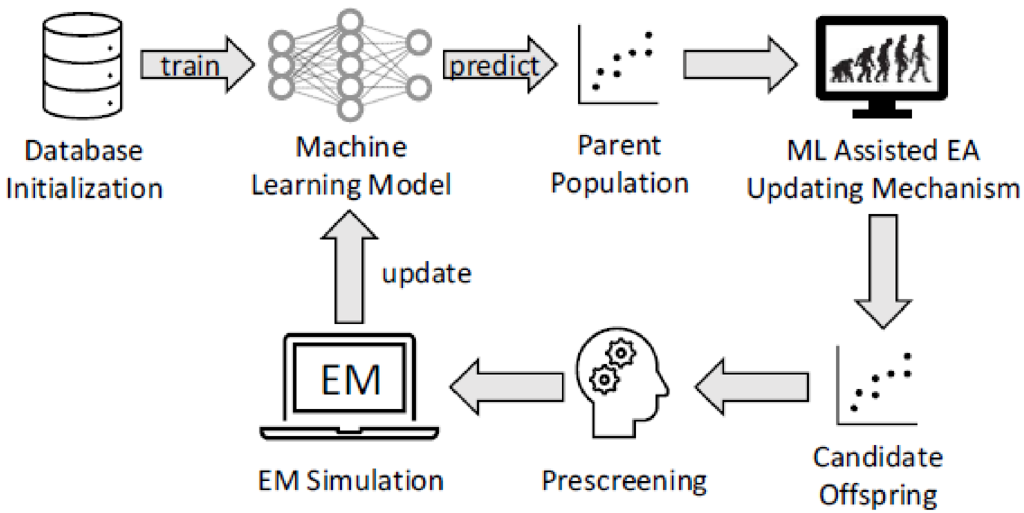


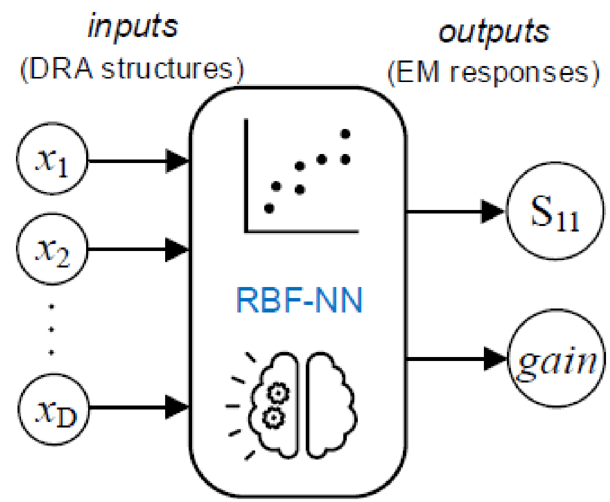
IoT technologies are a means for remote monitoring of a daily activities and they can be enhanced by ***Artificial Intelligence algorithms***.



From Sensors to Artificial Intelligence, creating dementia friendly “Healthy Homes”

AI/Machine Learning/Deep learning





IoT technologies are a means for remote monitoring of a daily activities and they can be enhanced by Artificial Intelligence algorithms.

Introduction to Health IoT security

Potential unintended consequences of health IoT that may affect patient safety:

- ✓ system-to-system data transfer that is inaccurate
- ✓ data entry in the wrong patient record
- ✓ incorrect data entry in the correct patient record
- ✓ system failure to function as intended
- ✓ system configuration that leads to errors.

IoT in Education

Benefits:

The implementation of technology gives education professionals new tools to optimize classwork, improve the efficiency of the learning process, connect with students better, and ensure on-site safety. Here are the benefits of putting the Internet of Things and education into a unified framework:

- **Improved school management efficiency.**
- **Real-time data collection.**
- **Addressed safety concerns.**
- **Improved resource management.**
- **Global interconnectedness.**

Example 1:
School of Computer Science & Eng. CLG.45

The project is about development of the Enhanced Educational Platform using Internet of Things and establishment of the smart computer laboratory classrooms (CLG. 45).

Aim:

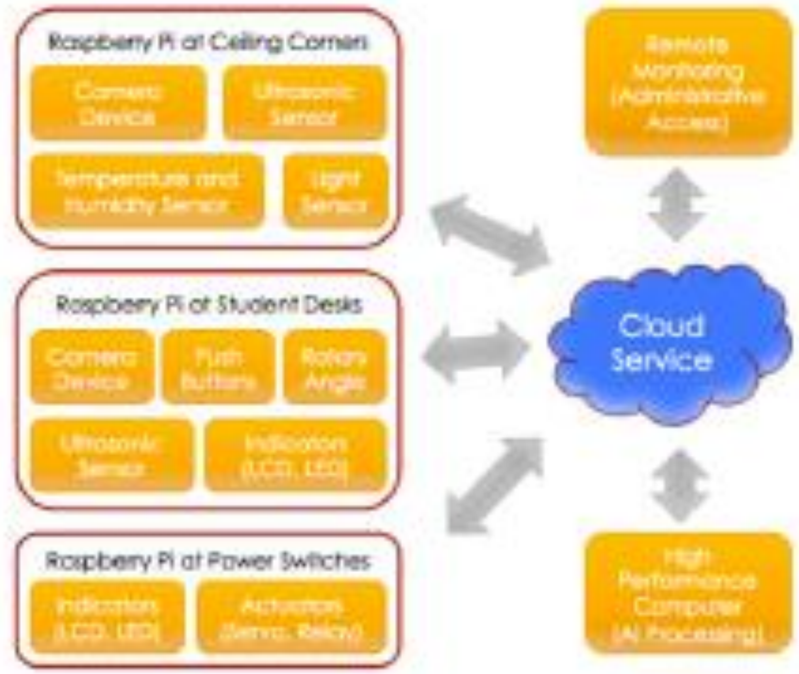
To set up a new smart classroom where each PC will be replaced by a small computer (e.g., Raspberry Pi /LTE-M/NB and a touchscreen display and additional sensors, and cameras. The new facility allows several general-purpose input and output connect student's desk.

At the same time, these connections facilitate IoT features for collecting data from student desks and monitoring status of students in the classroom.

Example 1: IoT Classroom
School of Computer Science &Eng. CLG.45

Conventional classroom
with multimedia facilities.

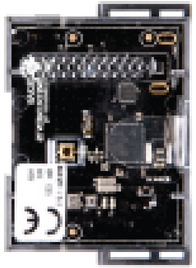
Proposed classroom with IoT
blended multimedia facilities.



Proposed framework for device
connection in a classroom

Example 1:
School of Computer Science &Eng. CLG.45

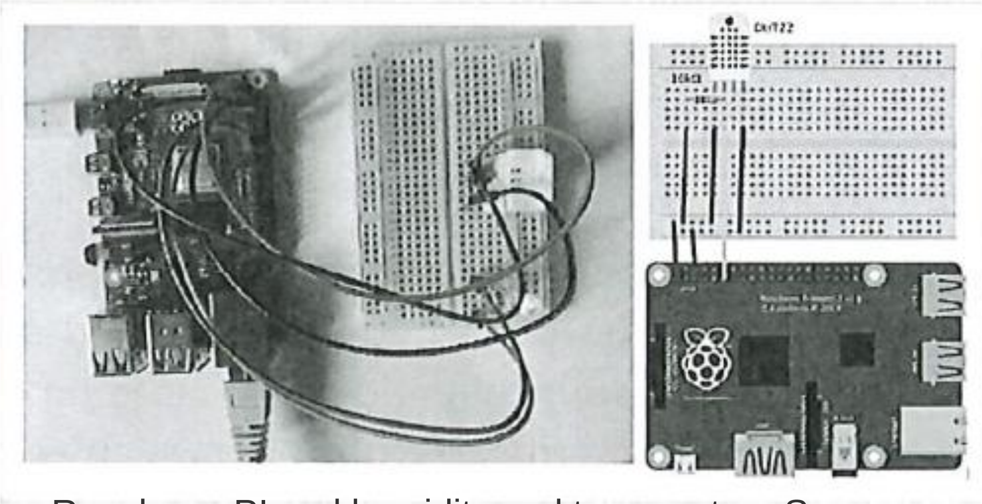
Sensors:
Motion Sensors:
Ultrasonic sensors/Light sensors:
Analog and Digital Temperature,
Humidity and Pressure Sensors:
Raspberry PI Camera Module:
Raspberry PI LCD Touch Screen:
Kit Raspberry Pi Zero:
Raspberry Pi v4:
Pycom 6Py-WiFi, BLE and LTE-M/NB:
Adafruit HUZZAH32–ESP32:
SD Cards 32 GB:
2-port HDMI USB KVM Switch:
Apple Digital AV lighting
to HDMI Adapter:
HDMI Cables:



IoT sensor device

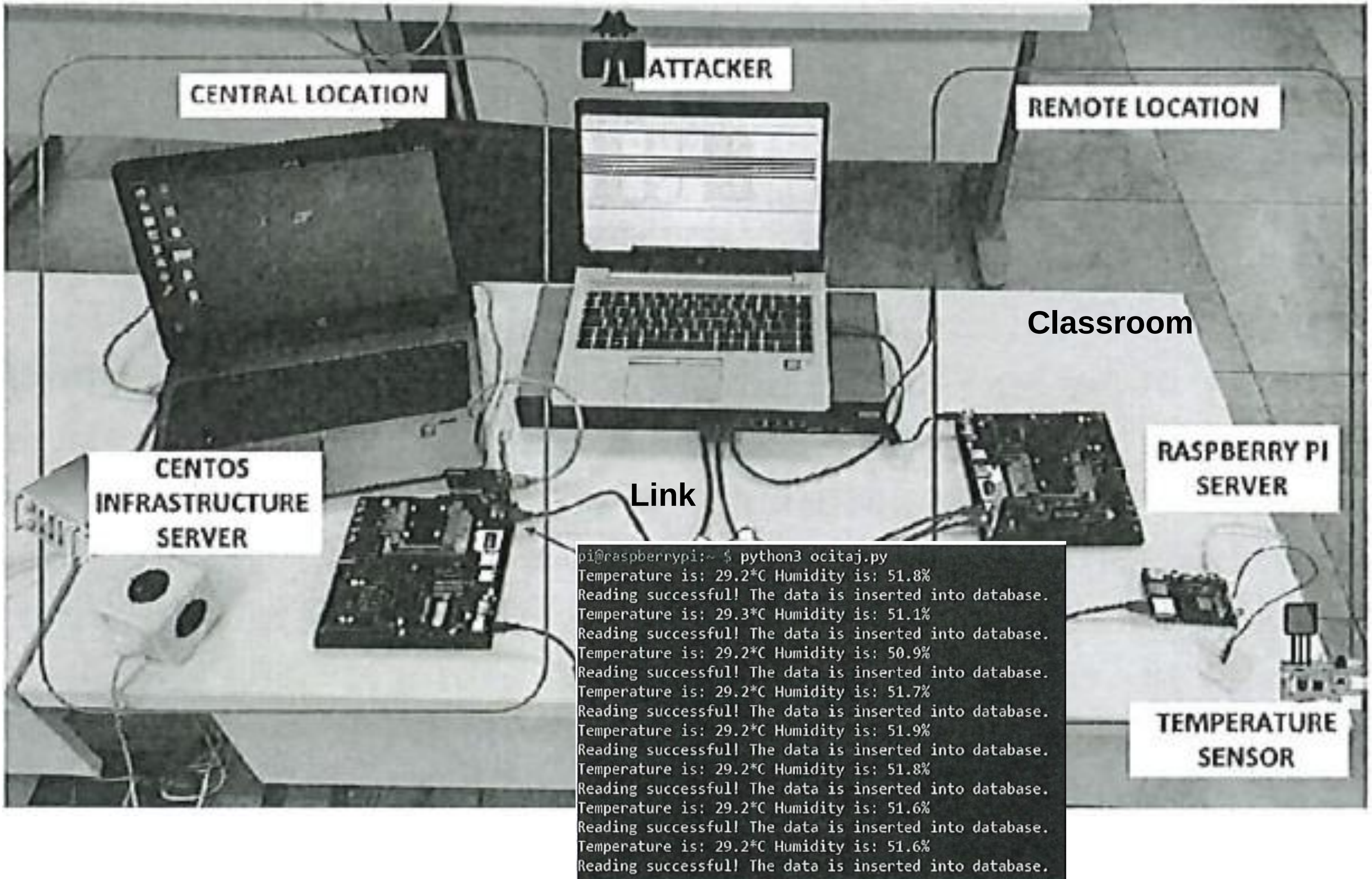
ZigBee IoT kit

Raspberry Pi v3 IoT



Raspberry PI and humidity and temperature Sensors

IoT Education Platform-Example 2



Output of the Python script on Raspberry Pi server for sensor vale reading.

IoT for Education: Example 3

- Based on the real data *develop AI-based methods to predict classroom attendance.*
- *Develop* an *optimization algorithm* for dynamic allocation of classes to classrooms based on predicted attendance rather than enrollments.
- Show gains of X% in room costs with a very low risk of room overflows.

System architecture of classroom occupancy monitoring

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IoT for Education: Example 3

This example describes experiences in adapting IoT to measure and *AI to predict* the attendance of lectures in courses at university campus to use these to *optimize* the usage of lecture rooms.

1. Testing several *sensing methods* in a lab environment and characterizing their tradeoffs in aspects such as cost, easy of installation, privacy and accuracy.

System architecture of classroom occupancy monitoring

Example 3 (cont.)

2.To make appropriate *sensor selections*, build a full system and deploy it across several lectures of varying size across the university campus.

3. To collect and clean the data to obtain visibility occupancy across these rooms in real time over a period of x weeks.

4. To *develop machine-learning models* to predict classroom attendance using several algorithms.

Example 3 (cont.)

There are three common regression learning algorithms including

Multiple linear regression (MLR)
Random Forest (RF) and
Support Vector Regression (SVR)

These models can predict attendance in advance with a *root mean square error (RMSE)/mean absolute error (MAE)/average weighted absolute error (WMAE)*. The dataset could be openly available to the research community.

Example 3 (cont.)

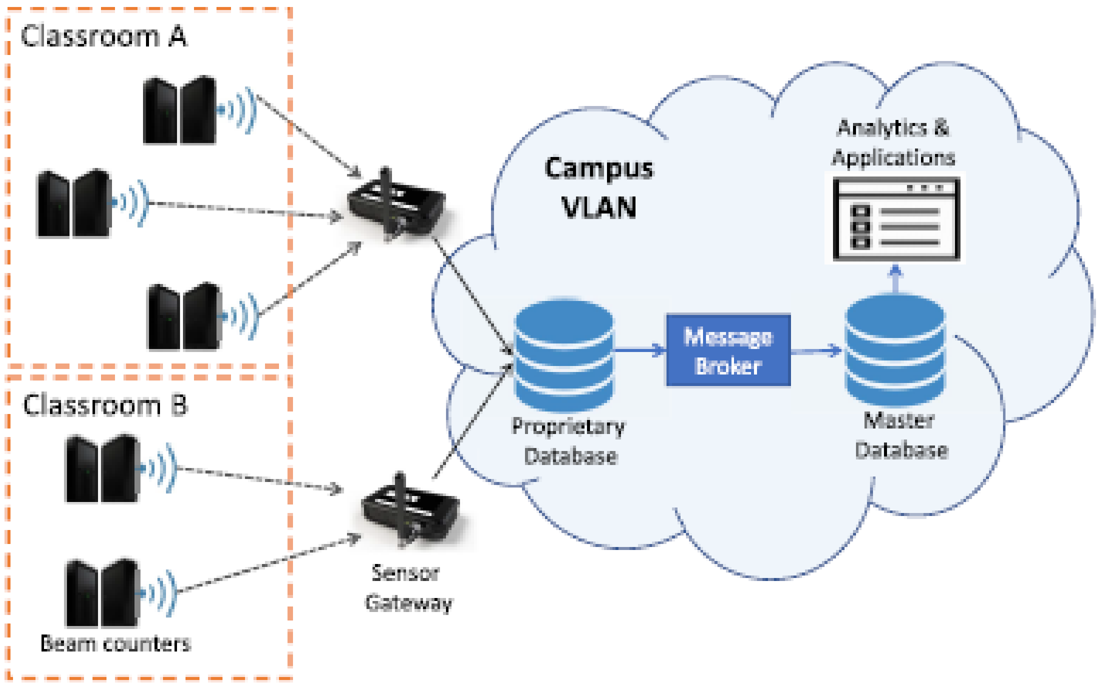
5. Finally, *to develop an optimization algorithm* for allocating classes to rooms based on predicted attendance rather than static enrollments and show potential saving of over x% in room costs.

Example 3 (cont.)

Sensing Classroom Occupancy

Sensor evaluation and selection

System architecture and data collection



System architecture of classroom occupancy monitoring

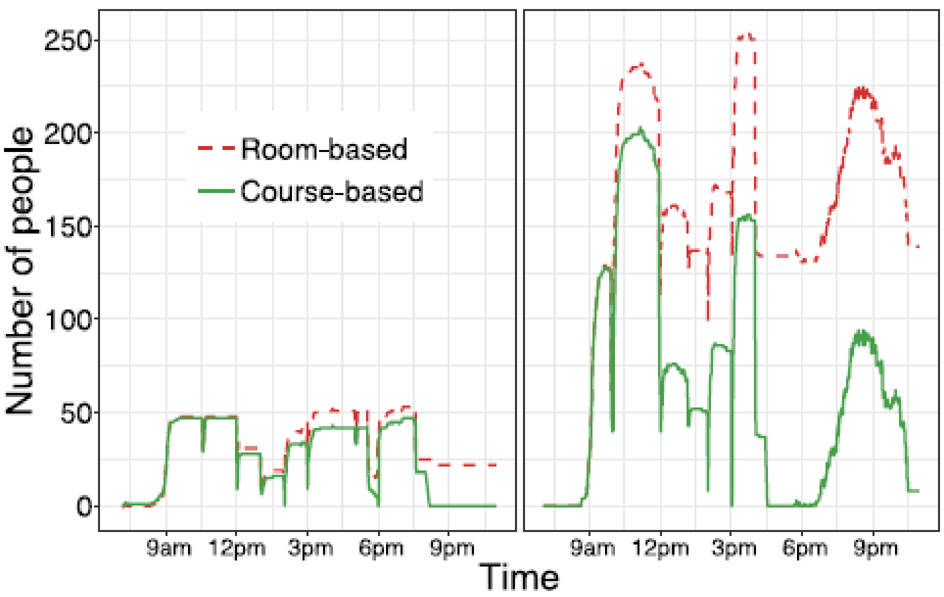
Example 3 (cont.)

Data Processing and Visualization

Occupancy and Attendance calculation

Room-based and Course-based methods

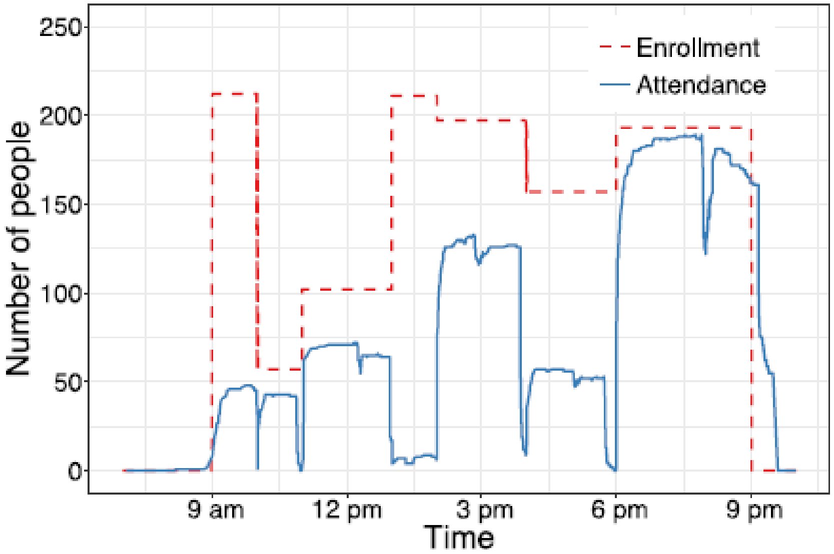
Small classroom | Large theatre



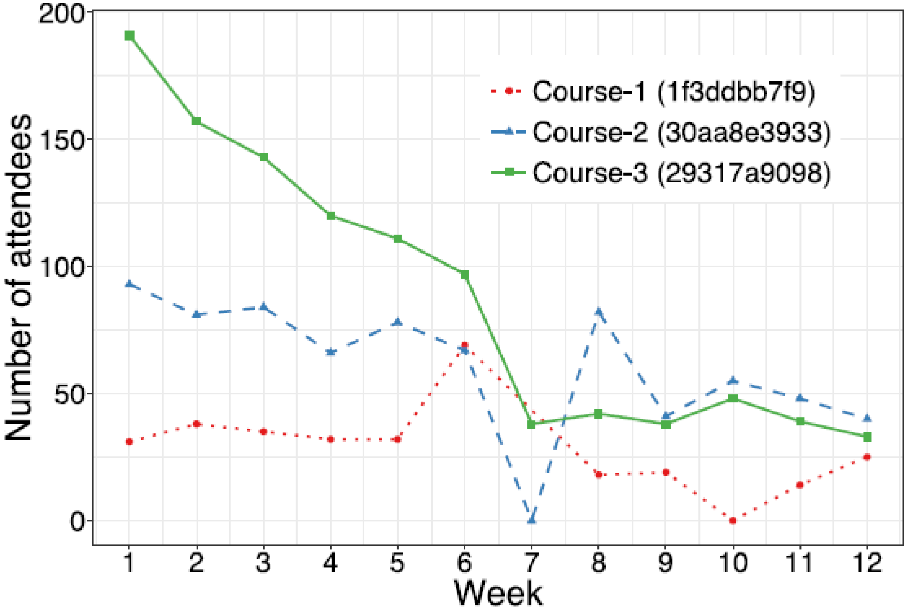
Occupancy computed by room-based and course-based methods

Example 3 (cont.)

Data visualisation



Occupancy pattern of a classroom



Occupancy pattern of three courses across weeks

Example 3 (cont.)

Prediction of Classroom Attendance

The following attributes can be used in prediction models:

- *Class type: lecture, tutorial, and laboratory*
- *College/faculty: science, engineering, and medicine*
- *Enrollment:*
- *Degree:*
- *Course duration:*
- *Week/Day and Time of Day*

Example 3 (cont.)

Prediction modeling

Algorithms for building prediction models:

Multiple linear regression (MLR)

Random Forest (RF) and

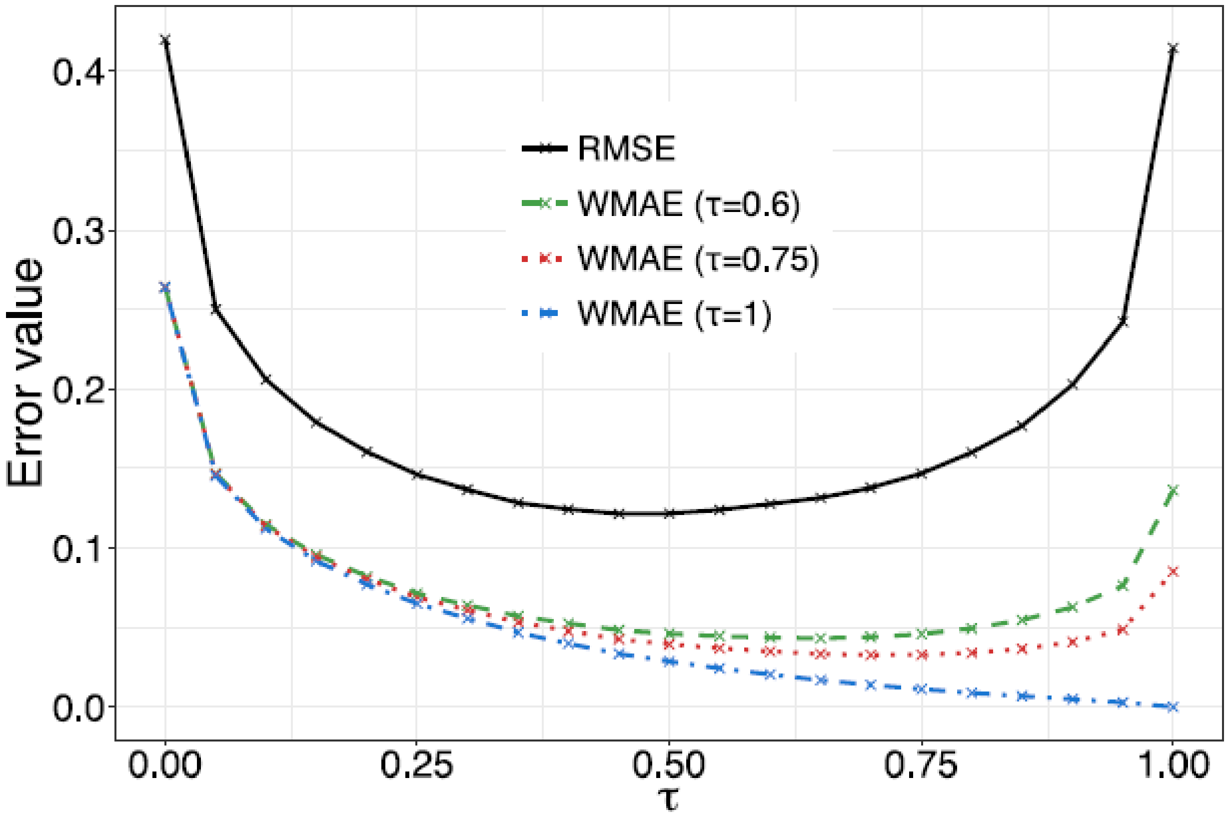
Support Vector Regression (SVR)

Error functions:

These models can predict attendance in advance with a *root mean square error (RMSE)/mean absolute error (MAE)/average weighted absolute error (WMAE)*. The dataset could be openly available to the research community.

Example 3 (cont.)

Performance Evaluation of Predicted Models



Impact of quantile parameter on prediction error.

Example 3 (cont.)

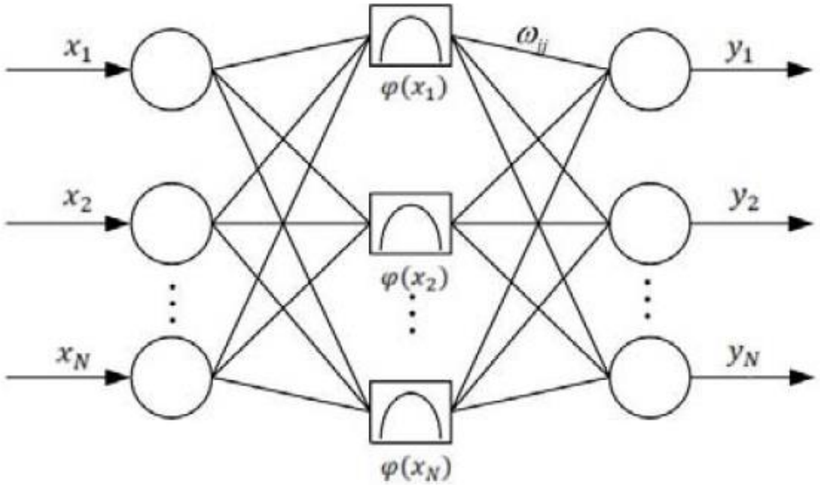
Performance of Predicted Models

Models	2017 train set DS1 (cross-validation)			2017 test set DS2 (testing)		
	RMSE	MAE	WMAE	RMSE	MAE	WMAE
Multiple Linear Regression (MLR)	0.163	0.123	0.060	0.149	0.118	0.060
Random Forest (RF)	0.120	0.086	0.043	0.121	0.089	0.044
Support Vector Regression (SVR)	0.135	0.094	0.041	0.125	0.086	0.042
Quantile Linear Regression	0.188	0.142	0.048	0.179	0.135	0.045
Quantile Regression Forests	0.147	0.102	0.033	0.154	0.108	0.034
Quantile Regression using SVM	0.141	0.095	0.035	0.147	0.100	0.036

Predicted Methods

Models
Multiple Linear Regression (MLR)
Random Forest (RF)
Support Vector Regression (SVR)
Quantile Linear Regression
Quantile Regression Forests
Quantile Regression using SVM

Genetic Algorithm (GA)



SVR network structure

Example 3 (cont.)

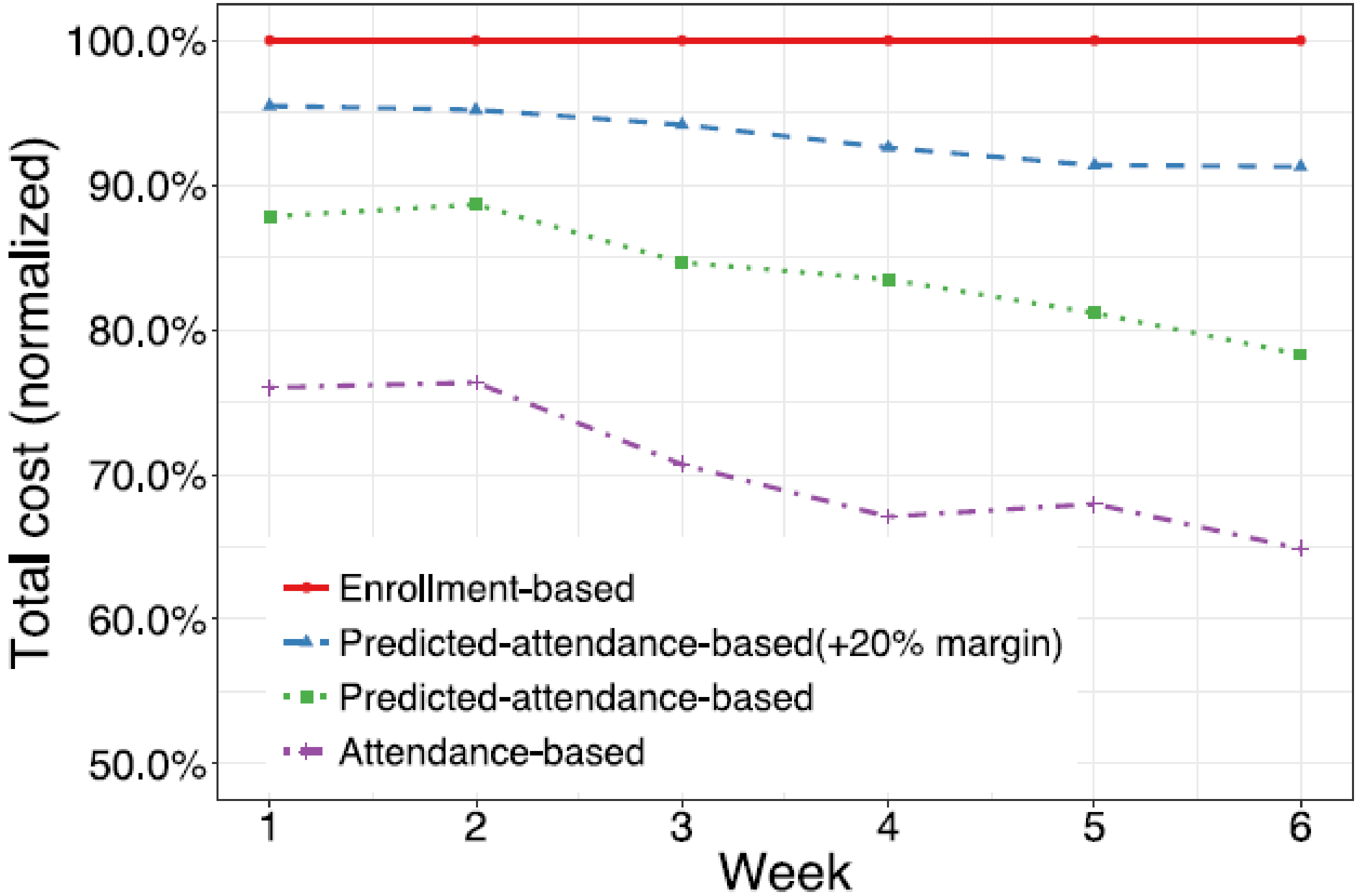
Optimal Allocation of Classrooms

- *Problem formulation*
- *Optomisation algorithms*

  To solve the optimization problem, we can use constraint programming (CP) algorithm using Google Optimisation Tools for Payton as a solver.
- *Optimization Results*

Example 3 (cont.)

Optimisation results



Allocation cost across weeks

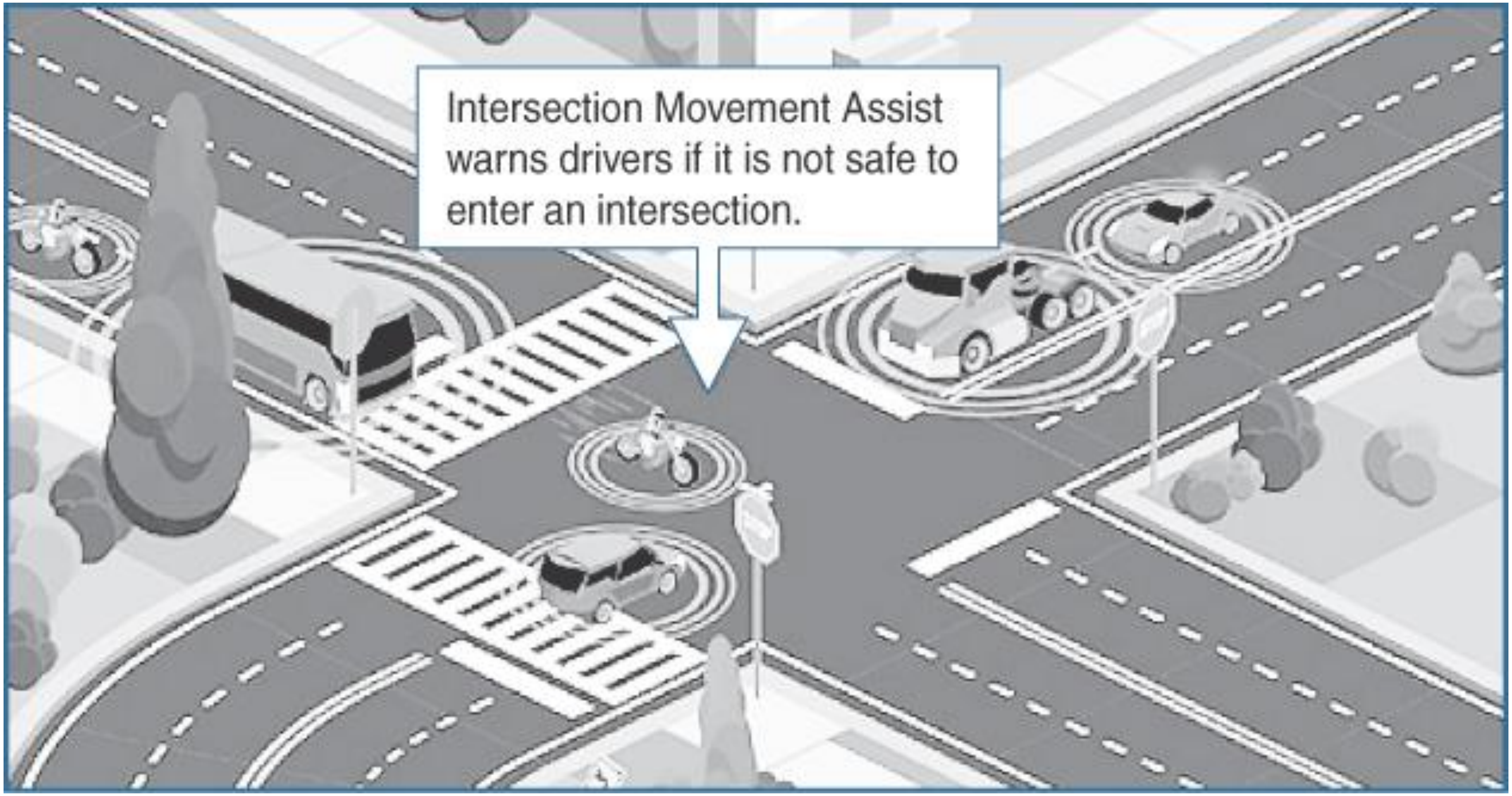
Transportation IoT

Technologies for deployment of massive IoT services in autonomous driving, transportation infrastructure and traffic monitoring.

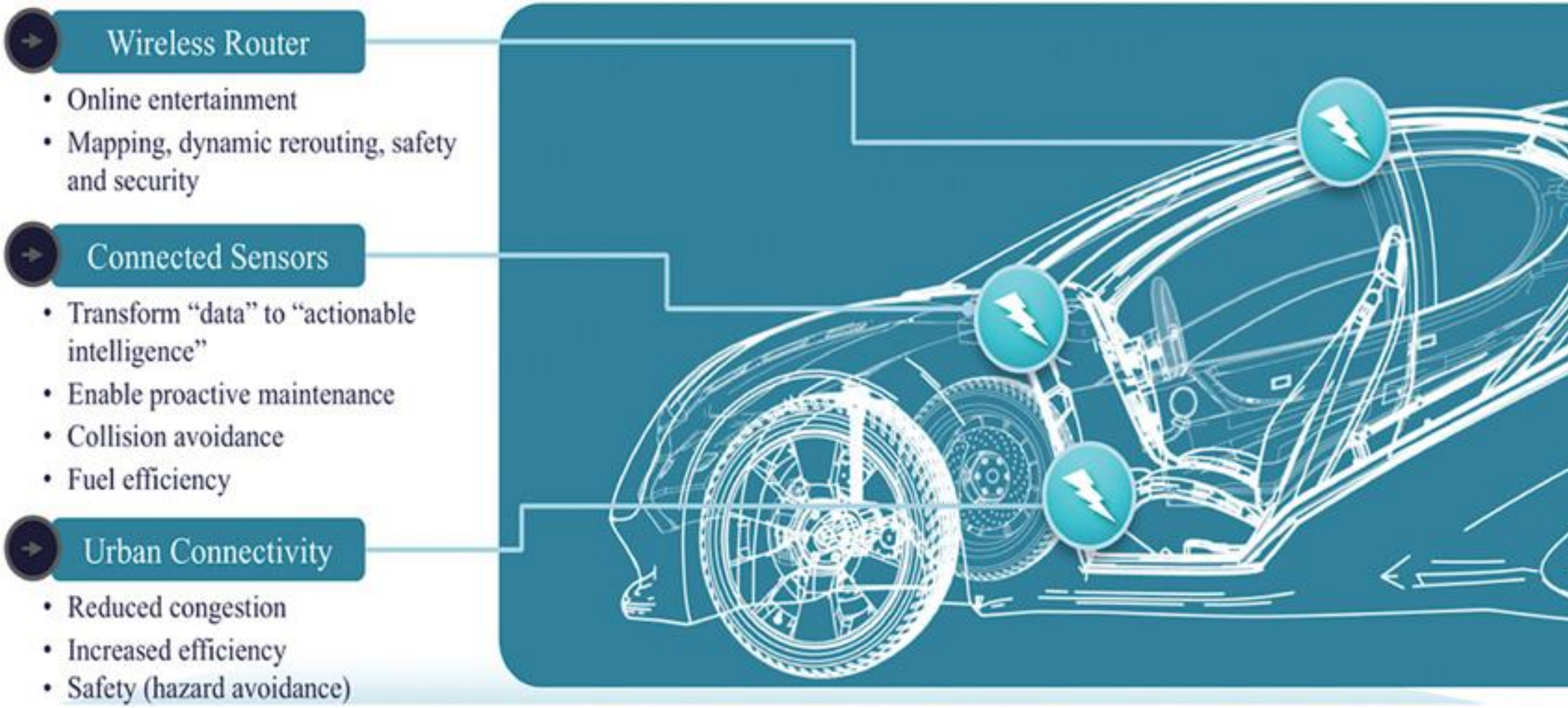
IoT is going to allow self-driving vehicles to better interact with the transportation system around them through bidirectional data exchanges while also providing important data to the riders. Self-driving vehicles need always-on, reliable communications and data from other transportation-related sensors to reach their full potential.

Smart Transportation Architecture.

Example: Connected Roadways

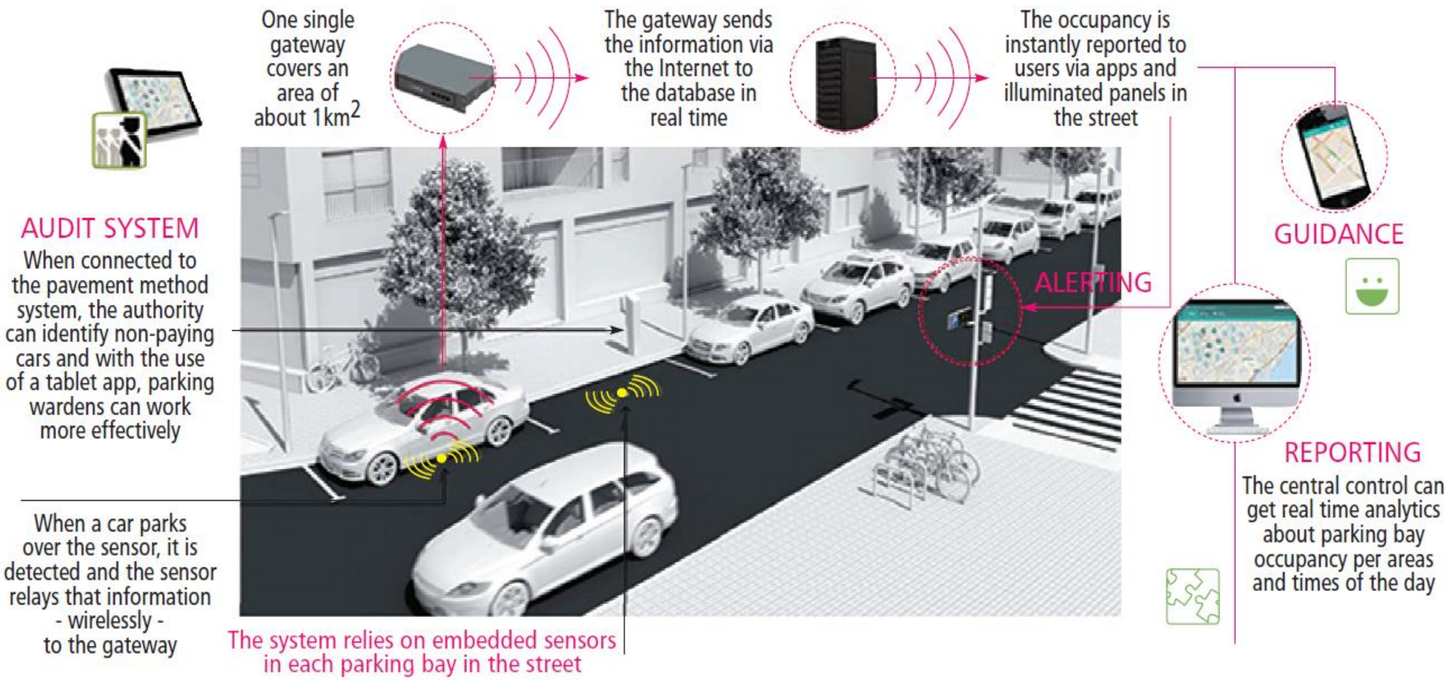


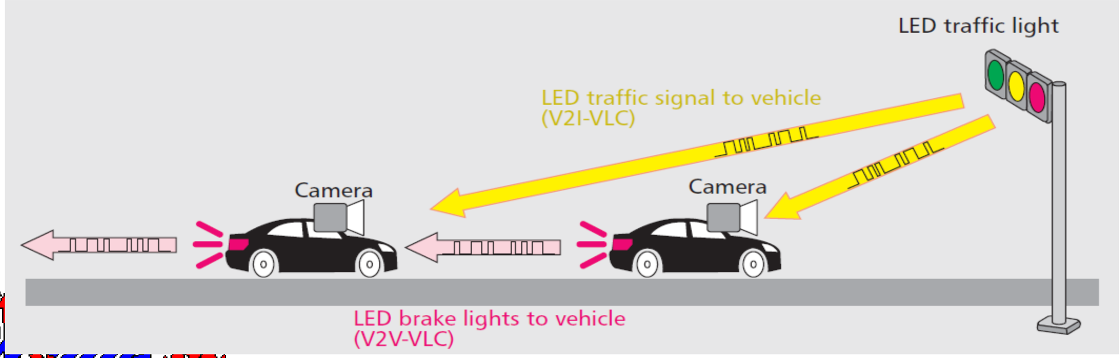
Example: Connected cars



In the future, car sensors will be able to interact with third-party applications, such as GPS/maps, to enable dynamic rerouting to avoid traffic, accidents, and other hazards. Similarly, Internet-based entertainment, including music, movies, and other streamings or downloads, can be personalized and customized to optimize a road trip.

Example: IoT deployment of smart parking technologies





Example: Vehicle-to-infrastructure visible light communication (V2IVLC)

Agriculture: IoT-Use case Example

A prototype NB-IoT-based quasi-smart water management platform in a vineyard is deployed.

Fig. Aerial photograph of the experimental vineyard (source: Google Maps).

The vineyard is about 44,515.421 square Meters and 3300 stumps of grape cultivar.

Fig. Installation of a new NB-IoT node in the Vineyard

Agriculture: IoT-Use case Example

IoT hardware includes low-cost microcontrollers with integrated sensor interfaces and telecommunication modems, open-source applications, open and standardized data transfer protocols, with low capital and operating costs.

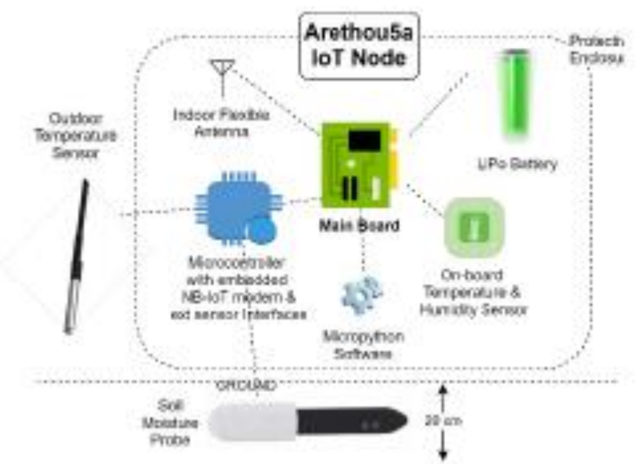


Fig. IoT Node architecture

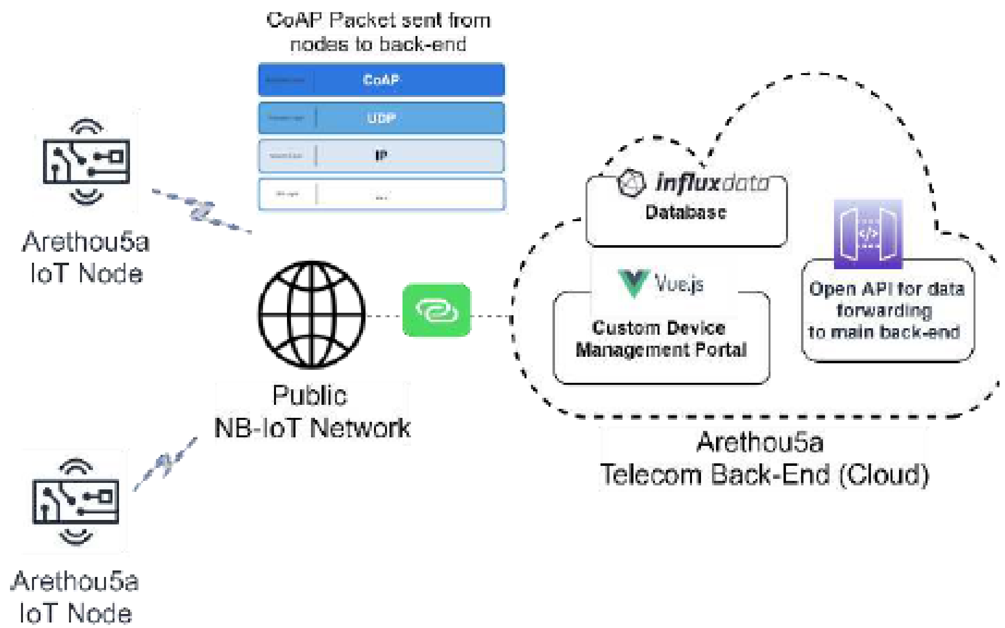


Fig. Constrained Application Protocol Packet sent from IoT Nodes to Telecom back end (Cloud)

Each IoT node:

a) collects soil moisture and temperature samples at a depth of 20 cm,
b) is battery powered and has a battery life of several months on a single charge,
c) and connects to the system back-end via NB-IoT

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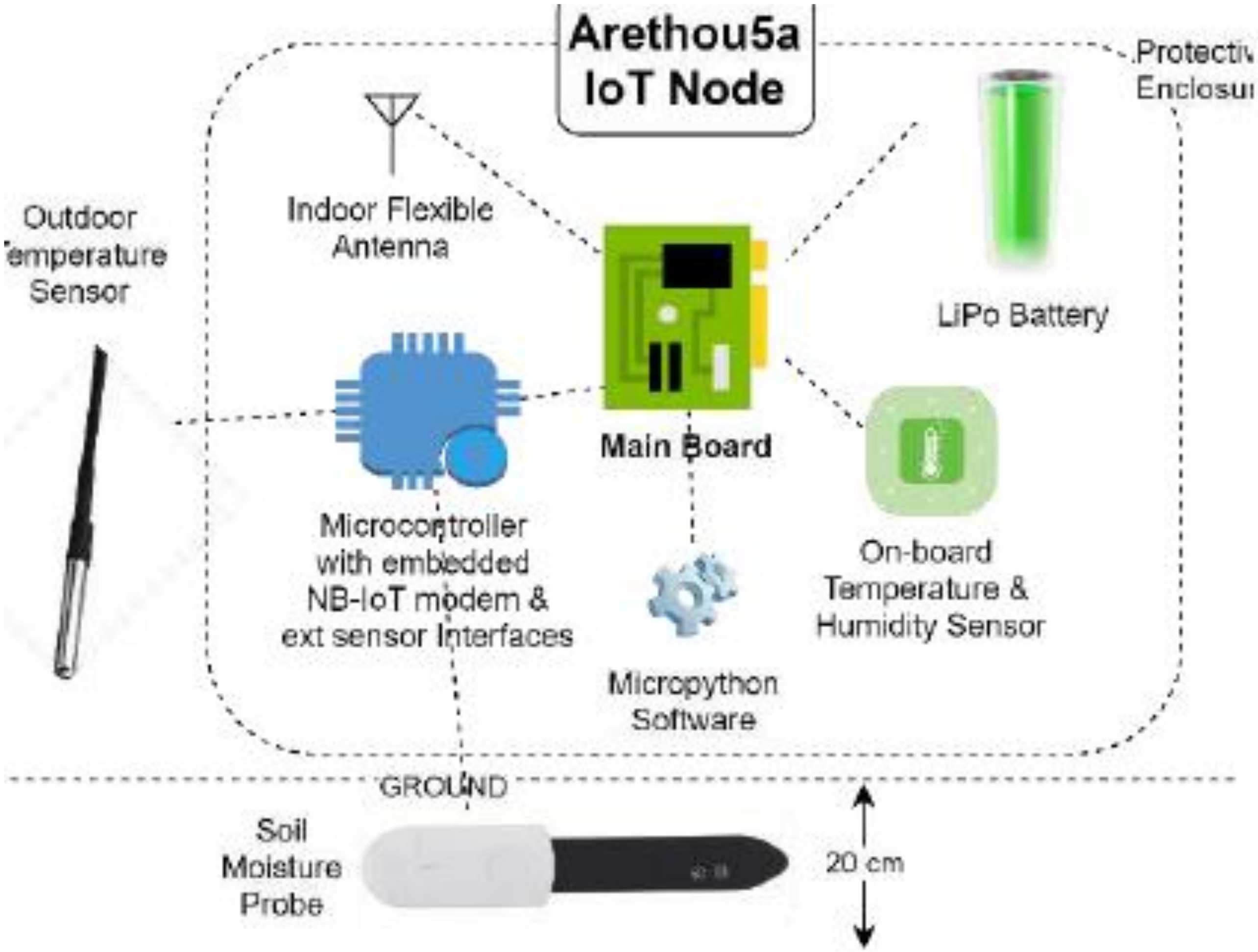
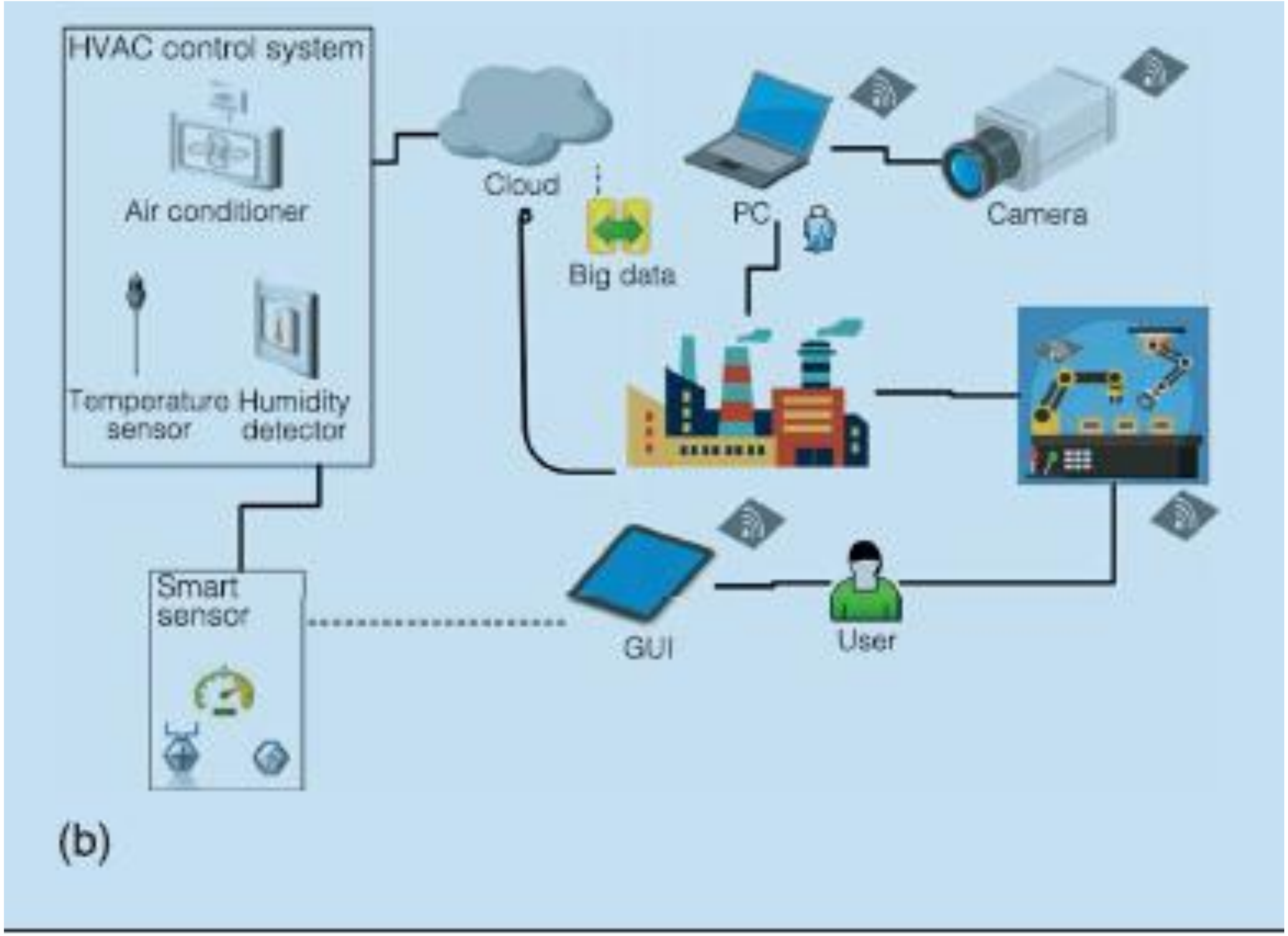
IoT Devices/Sensors



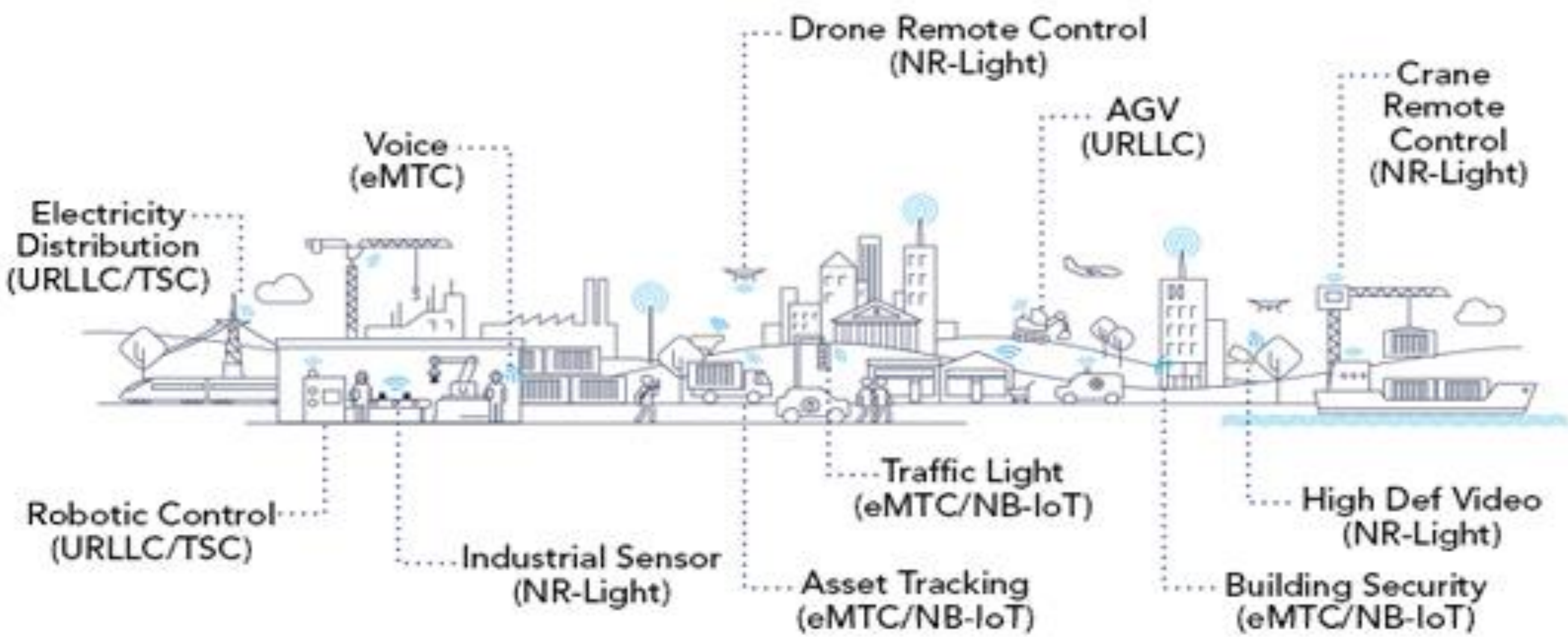
IoT Sensor node architecture

Industrial IoT



The human-machine interaction for an IIoT.

IIoT Use Cases



Industry 4.0 use cases and corresponding 5G NR features.

Industry digitalization with cellular IoT in the 5G era

Today, 4G networks are supporting Massive IoT based on *Cat-M/NB-IoT* and Broadband IoT based on LTE. Massive IoT continues to evolve with *Cat-M/NB-IoT* access in 5G-enabled networks, and Broadband IoT is being further enhanced with the introduction of 5G radio and core networks. With powerful, ultra-reliable and/or ultra-low latency capabilities, 5G networks are going to enable Critical IoT for time-critical communications. To seamlessly integrate 5G networks with Ethernet-based industrial wired communications networks, 3GPP has standardized additional capabilities that would be offered by Industrial Automation IoT connectivity.

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Manufacturing: 5G IoT-Use case Example

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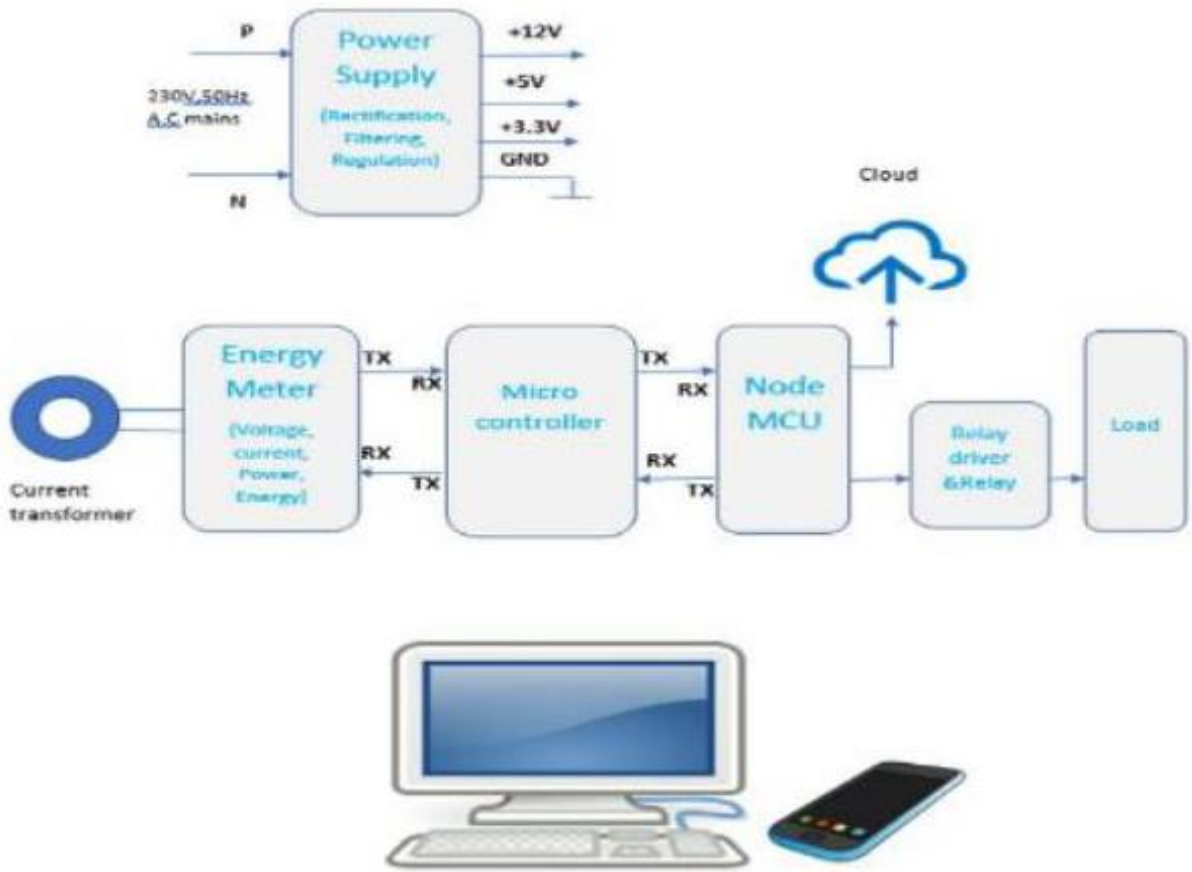
In the industrial sector 5G is being adopted for connecting *industrial robots* with various degrees of mobility. These robots range from static robots that are positioned to form tasks on production lines to fully mobile robots such as *autonomous guided vehicles* (AGVs). Industrial robots have many sensors to enable them to accurately perform tasks and move safely through production environments to deliver goods or carry out repairs.

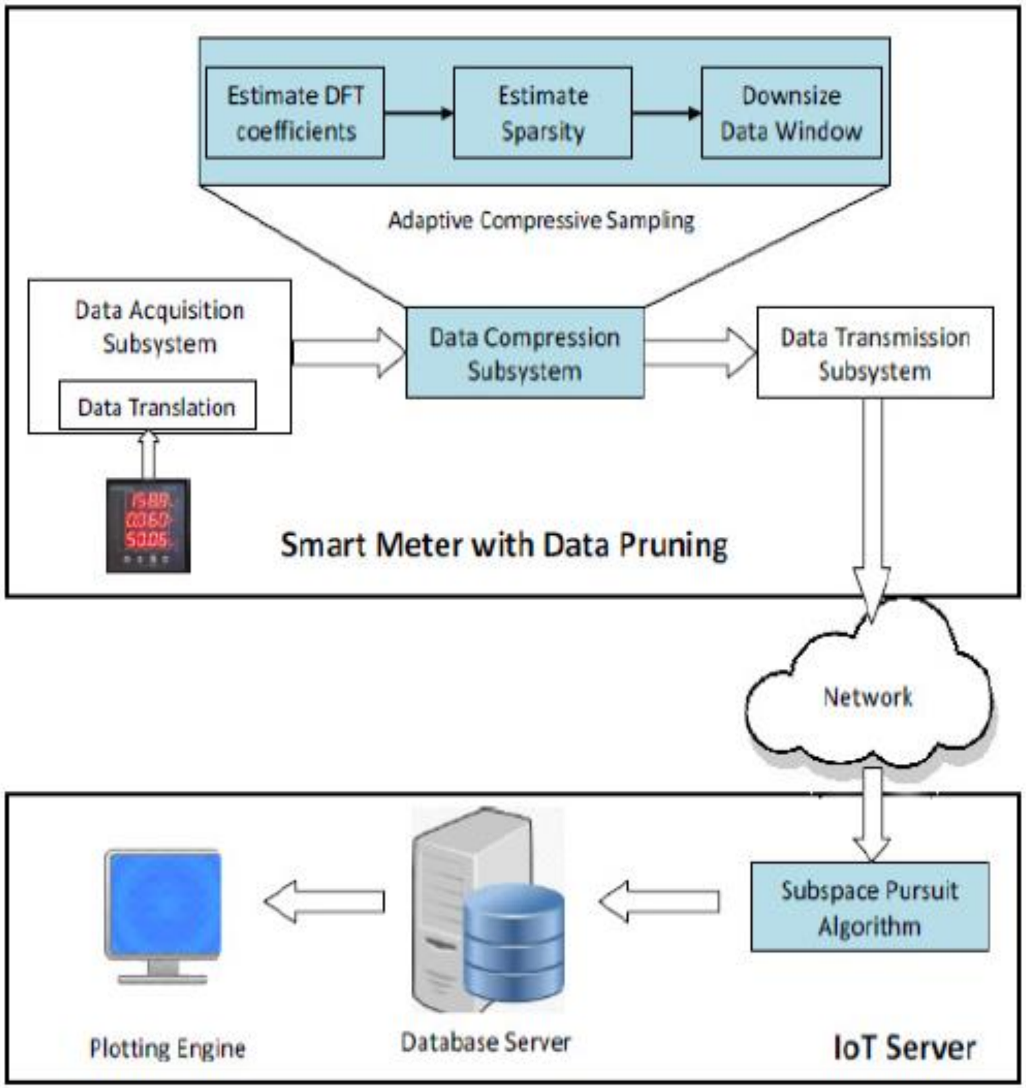
Manufacturing:
5G IoT-Use case Example

Source: Kearney analysis

Example: Smart Energy Meter and Monitoring System Using IoT using IoT

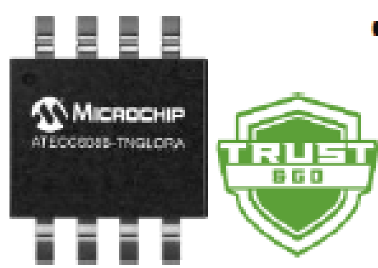


Real Life Example: Smart Metering:
Proposed Software Architecture.



Real Life Example:
Smart Water Meter with Wireless Connectivity

LoRaWAN



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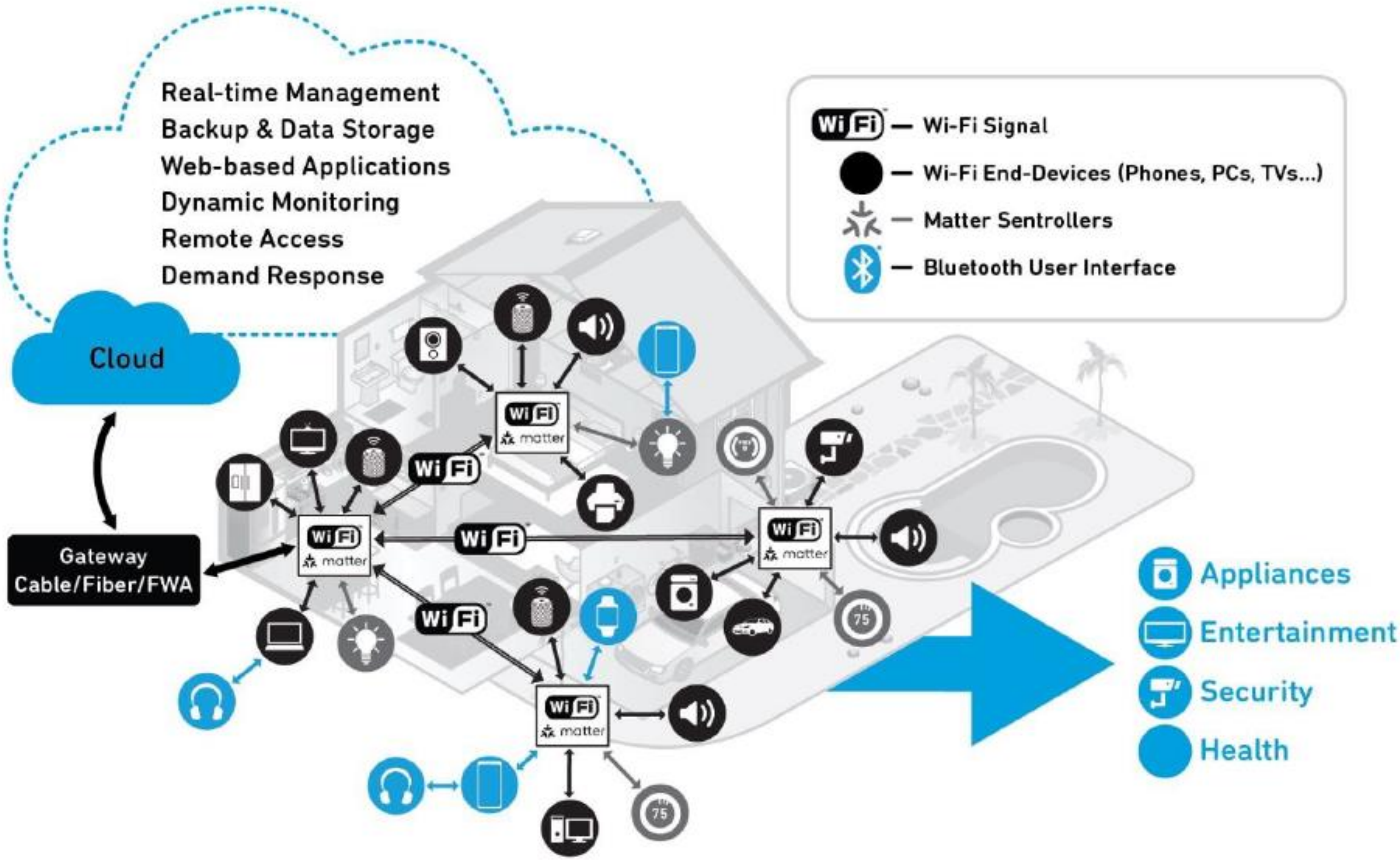
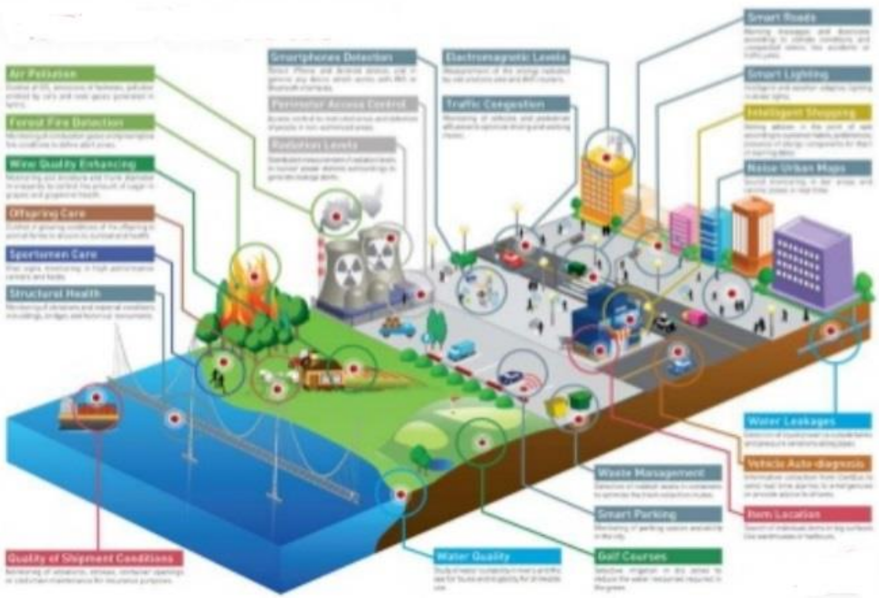
Source: Microchip

Sensors for a Smart Home Zigbee, Thread and WiFi smart home networking



Sensors for a Smart City

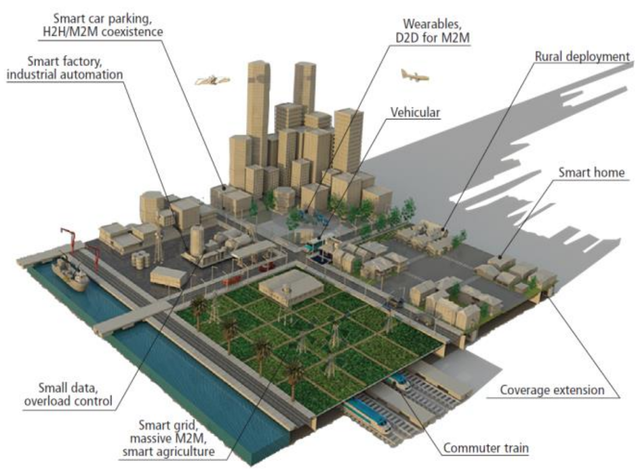
Perspectives of a Smart City



... sensor city

Sensors for

- Air pollution
- Fire detection
- Water quality
- Smart parking
- Traffic congestion
- Waste management
- Golf course conditions



What Really Maters:
Your Use Case

Key Points to consider when looking for connectivity

- Ecosystem
- Mechanical constrains (size and casing could be driving factors)
- Environment (water, metal, safety, temperature, EMC..)
- Battery life + coverage area + data throughput
- Network characteristics (# of nodes, latency, routers)
- Time to market
- System cost (with/without service charges)
- Robustness, security and compliance to standards and regulations.

Summary of case studies related to IoT applications

Case studies related to IoT applications such as:

home automation, smart city/transport, wearables, agricultural, medical and industrial applications, industrial control IoT, IoT for Energy Grids, Active Energy Distribution Grids, Transportation IoT, Connected Car Platooning, Transportation Infrastructure Monitoring, Wearables (smartwatch, sensors,...), Smart homes, Smart cities, Healthcare, Automotive, Asset tracking, Retail, and Drones.

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Introduction to IoT security

We may be in awe of the web's rise over the past 30 years, but Internet is dangerously unhealthy, from last year's Mirai botnet attacks, to market concentration, government surveillance and censorship, data breaches, and policies that smother innovation.

- These questions are even more critical now that we move into an age where the Internet starts to wrap around us, quite literally, pointing to the Internet of Things, autonomous systems, and artificial intelligence. In this world, we don't use a computer, we live inside it!

- The Internet of Things is as secure as an open barn door.

IoT risks

- An exploitation of the Universal Plug and Play protocol (UPnP) to gain access to many IoT devices (without authentication). UPnP is designed to self-configure when attached to an IP address, making it vulnerable to exploitation by running commands on the devices

IoT risks

- An exploitation of default passwords to send malicious and spam e-mails, or steal personally identifiable or credit card information
- Compromising the IoT device to cause physical harm
- Overloading the devices to render the device inoperable
- Interfering with business transactions.

Health IoT

- Potential unintended consequences of health IoT that may affect patient safety:
  - ✓ system-to-system data transfer that is inaccurate
  - ✓ data entry in the wrong patient record
  - ✓ incorrect data entry in the correct patient record
  - ✓ system failure to function as intended
  - ✓ system configuration that leads to errors.

Examples of IoT incidents

- Security cameras with default passwords with wireless networks with weak passwords without firewalls.
- Unsecured wireless connections for automated devices, such as security systems, garage doors, thermostats and lighting provides opportunity to obtain administrative privileges and control aforementioned devices.
- Time-dispense medicine health care devices endangering patient lives.
- Gas pumps registering incorrect levels, creating a false gas shortage or allowing overfilling the tanks and creating a fire hazard.

Examples of IoT incidents

- During 2015 attack against a German iron plant, the hackers were able to gain access to the production floor and cause physical explosions inside the production floor, causing massive damage to the equipment inside the environment.
- Smart locks allowing adding secret opening codes.
- 98 seconds after plugging a WiFi connected security camera into home network, it was compromised by a Mirai-like worm that knew the default login and password.

Recommended Reading list: Module 4COSC003W: Trends in Computer Science/Topic: Internet of Things

Dr. D. Budimir ext 65139; Email: d.dudimir@wmin.ac.uk

Essential reading:

- D. Hanes, G. Salgueiro, P. Grossetete, R. Barton, and J. Henry, IoT Fundamentals: Networking Technologies, Protocols, and Use Cases for the Internet of Things, Cisco Press, 2017.
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THE INTERNET OF THINGS

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Additional/Further references:

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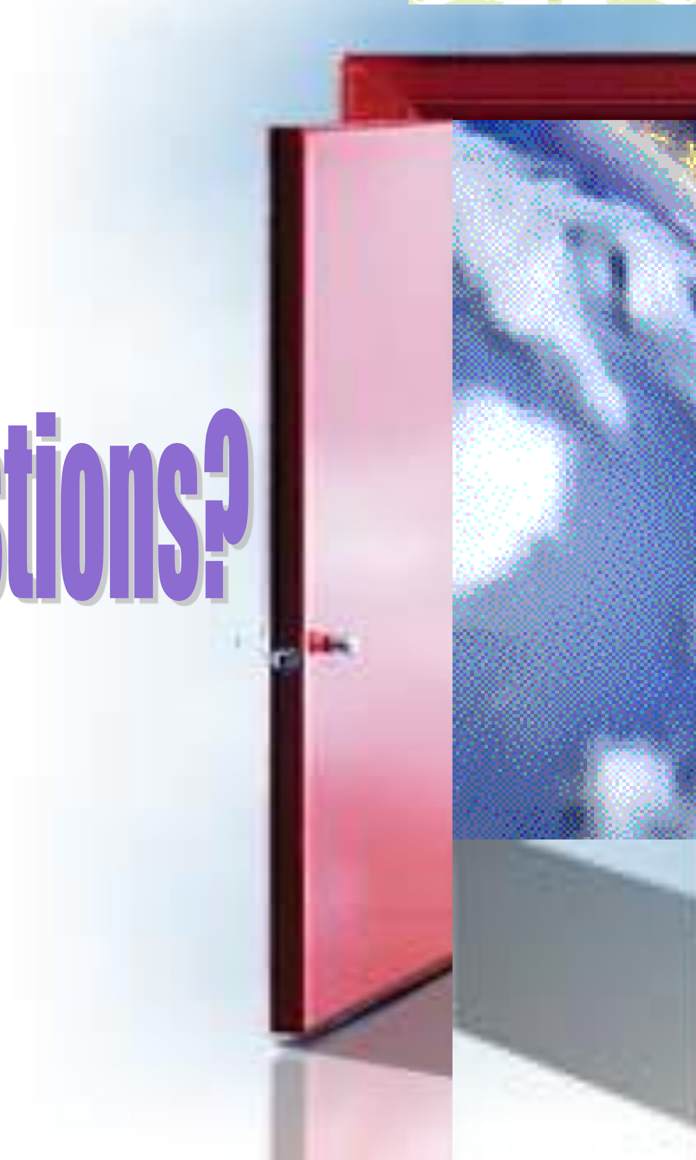
THANK YOU

Questions?



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