NiPS Summer School 2017
Energy Harvesting: models and applications

- Lecture 9: *IoT and the powering of autonomous devices (Sensor networks, autonomous sensors and actuators, energy budget for complex devices)*

Valerio Freschi, DiSPeA - University of Urbino

Outline

- Introduction
  - The IoT landscape
  - General architectures
- Power consumption sources in IoT
  - Communication
  - Computation
  - Sensing and actuation

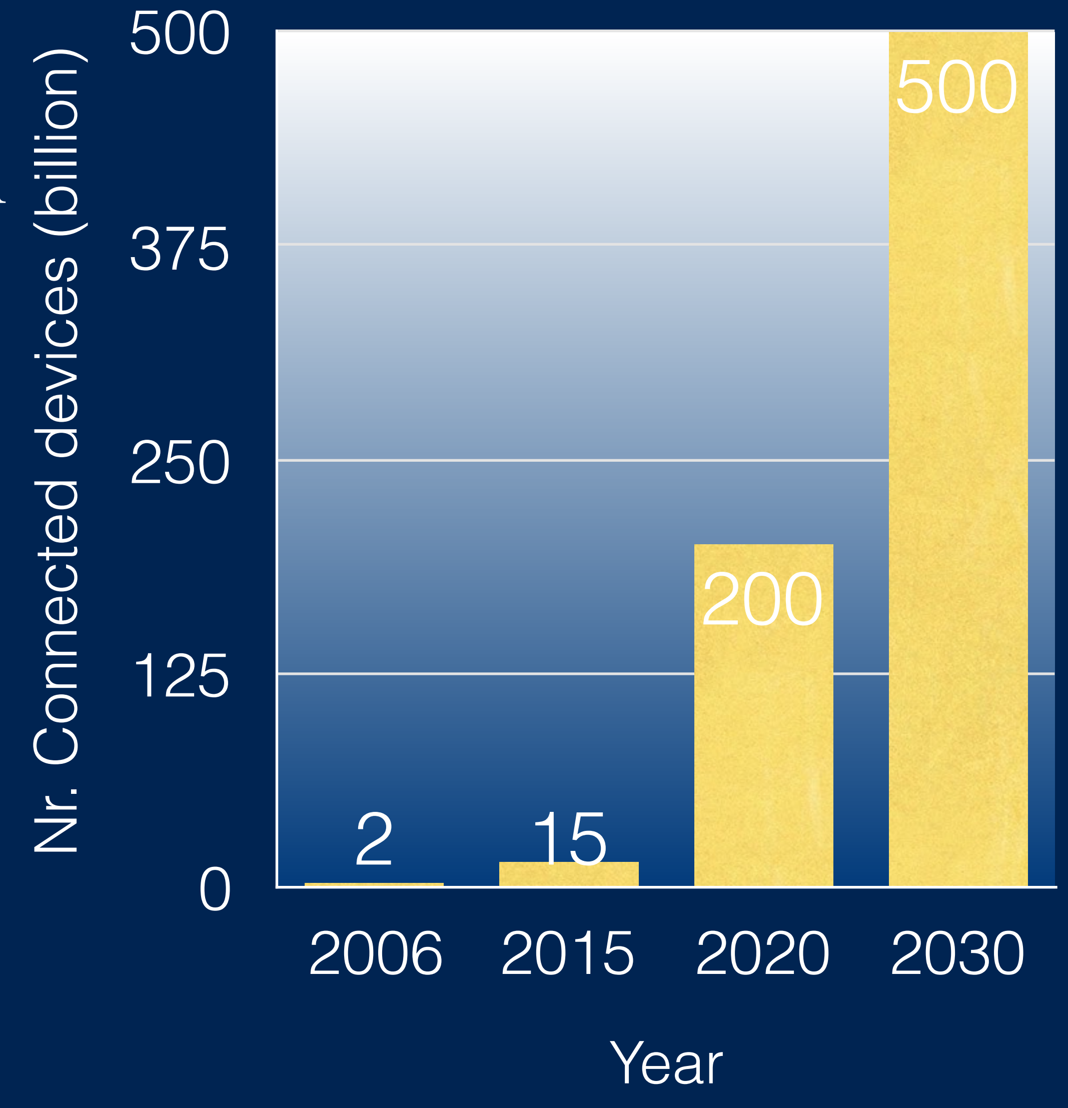
What is the IoT?

- What is the IoT?
- A global infrastructure for the information society, enabling advanced services by interconnecting things based on existing and evolving interoperable information and communication technologies [1].
- The Internet of Things (IoT) is a robust network of devices, all embedded with electronics, software, and sensors that enable them to exchange and analyze data [2].
- The Internet of Things (IoT) is a new paradigm that combines aspects and technologies coming from different approaches. Ubiquitous computing, pervasive computing, Internet Protocol, sensing technologies, communication technologies, and embedded devices are merged together in order to form a system where the real and digital worlds meet and are continuously in symbiotic interaction [3].

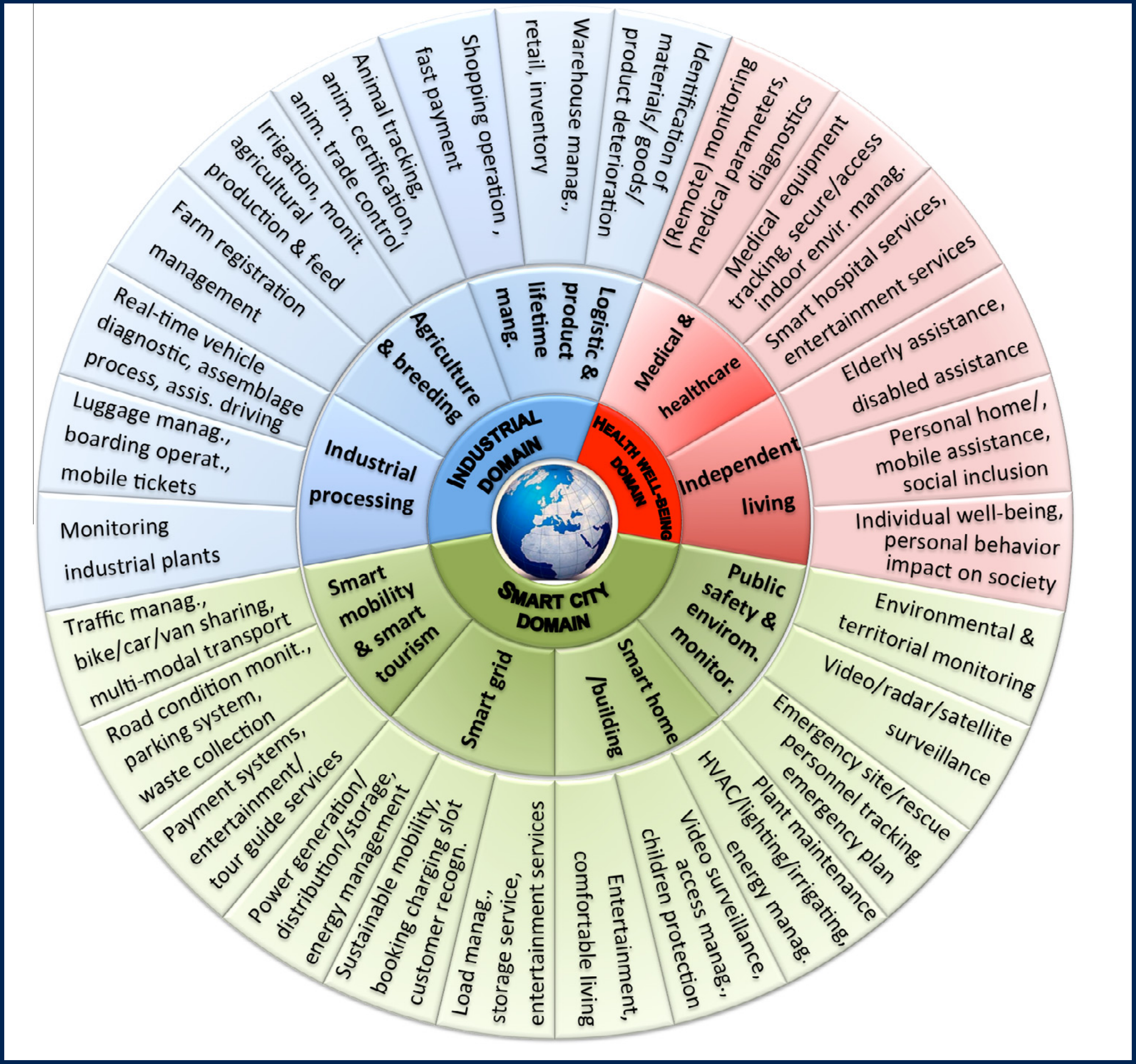
[1] ITU-T Recommendation Y.2060. Overview of the Internet of Things. 2012
[2] Intel: https://www.intel.com/content/www/us/en/internet-of-things/overview.html
[3] Borgia, E.: The Internet of Things vision: Key features, applications and open issues , Computer Communications, 2014

What is the IoT

- 2 billion objects in 2006
- Intel estimates will be 200 billions in 2020
- 500 billions in 2030 according to Cisco
- Forecasts agree on enormous growth
- Market expected to have global economic impact 2.5-11 T$

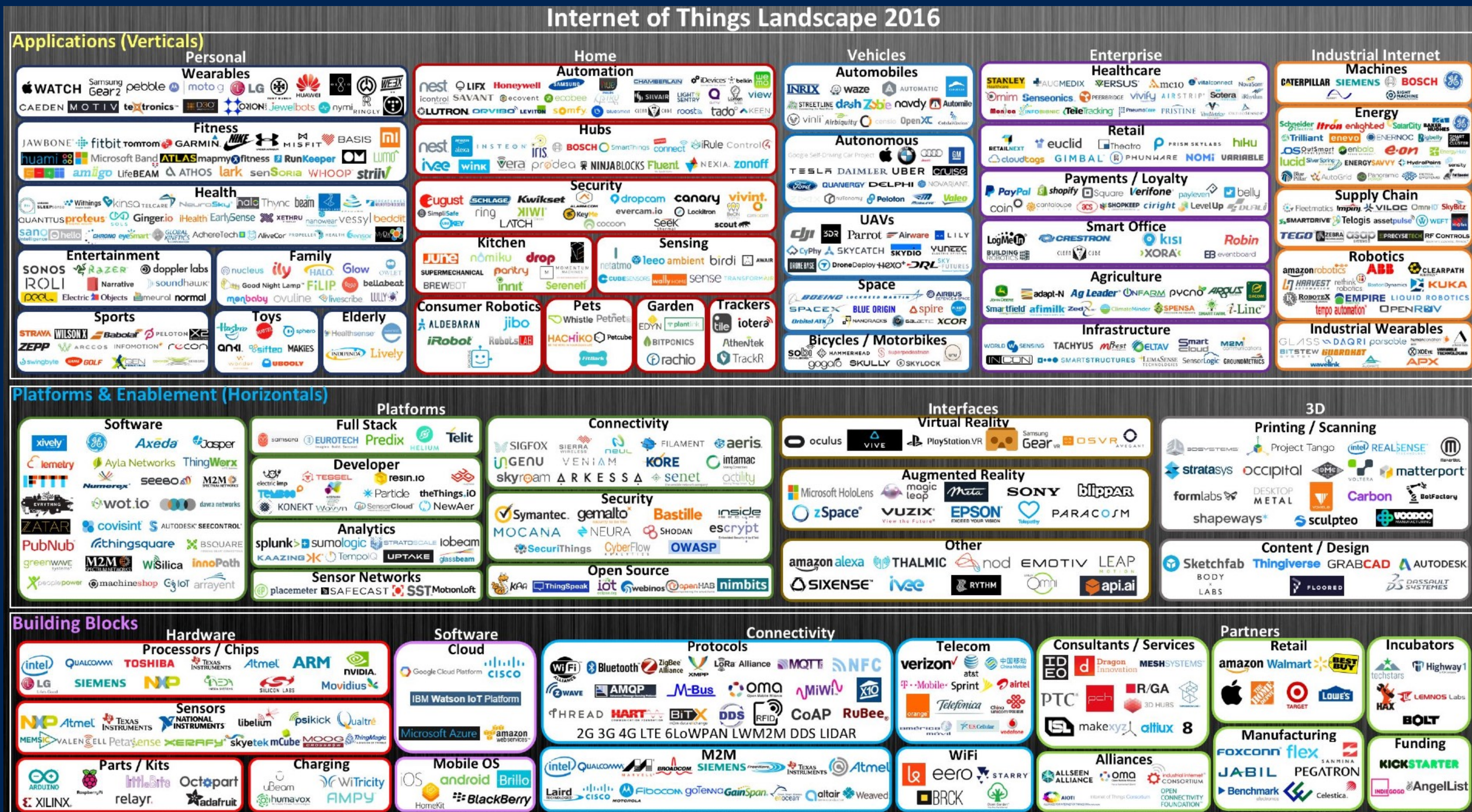


What is the IoT



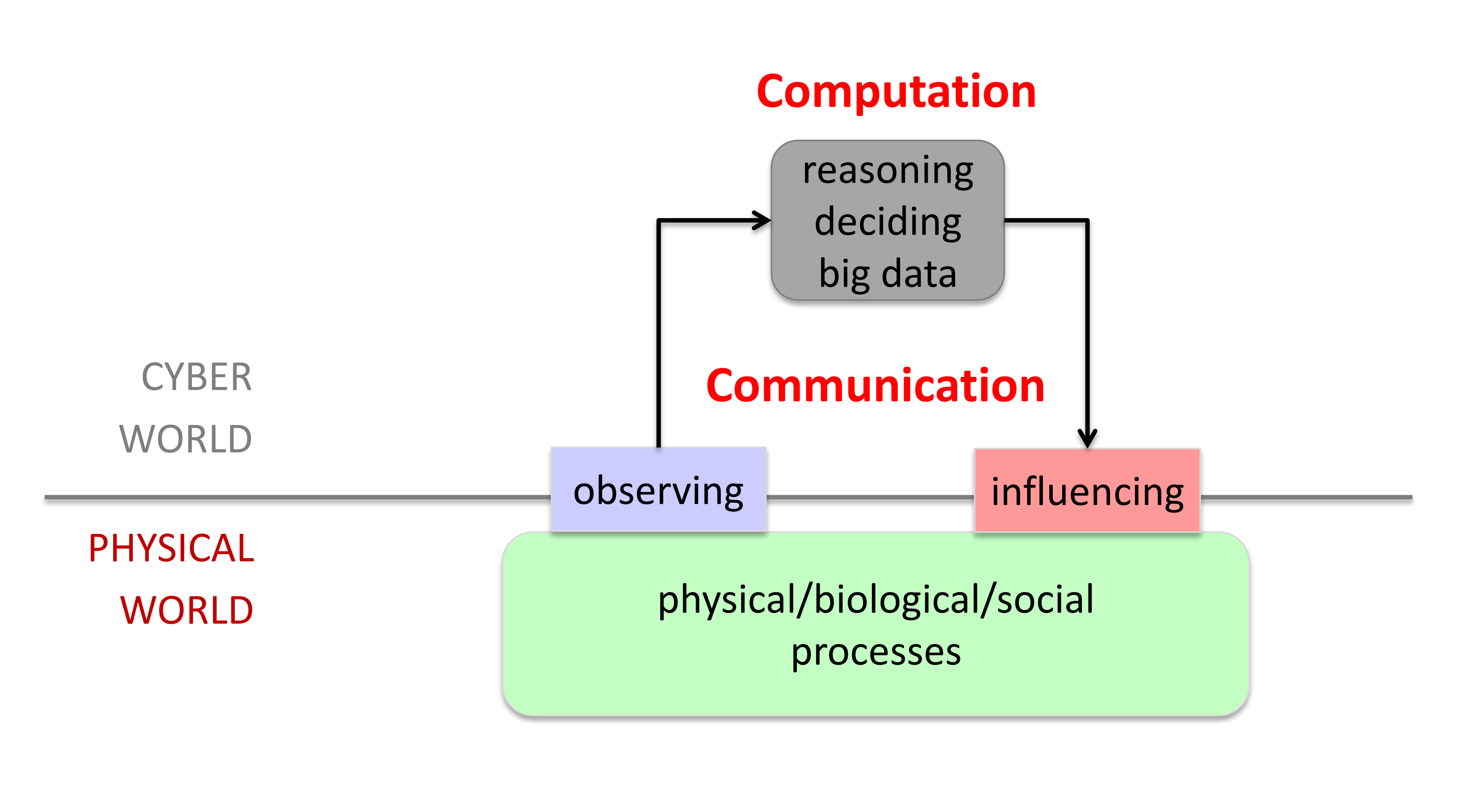
source: E. Borgia, The Internet of Things vision: Key features, applications and open issues, *Computer Communications, 2014*

The IoT world: a complex landscape



source: L. Thiele (ETH) *Design for IoT trustable things (DATE 17) keynote speech*

The smart world



source: L. Thiele (ETH) *Design for IoT trustable things (DATE 17) keynote speech*

Smart things

- Physical objects digitally augmented with one or more of the following:
  - Sensors (temperature, light, motion, etc.)
  - Actuators (displays, sound, motors, etc.)
  - Computation capabilities
  - Communication interfaces
- Physical/biological and cyber(digital) worlds are blended

Enabling technologies

source: A. Gaglione (University of Cambridge) *Mobile and Sensor Systems* course lectures

Enabling technologies

- Identification (e.g., RFID, NFC)
  - tag and track goods
  - smart logistics and supply chain

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Enabling technologies

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Enabling technologies

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- Sensing
  - microelectromechanical systems (MEMS)
- Computation & communication
  - hardware platforms able to run embedded software – wireless communication technologies
  - operating systems, wireless sensor networks (WSN)

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Enabling technologies

- Identification (e.g., RFID, NFC)
  - tag and track goods
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- Sensing
  - microelectromechanical systems (MEMS)
- Computation & communication
  - hardware platforms able to run embedded software – wireless communication technologies
  - operating systems, wireless sensor networks (WSN)
- Cloud computing & data analytics
  - smart object data combined to provide insight and recommendations

source: A. Gaglione (University of Cambridge) *Mobile and Sensor Systems* course lectures

IoT landscape

Tags (RFID, NFC, QR codes)

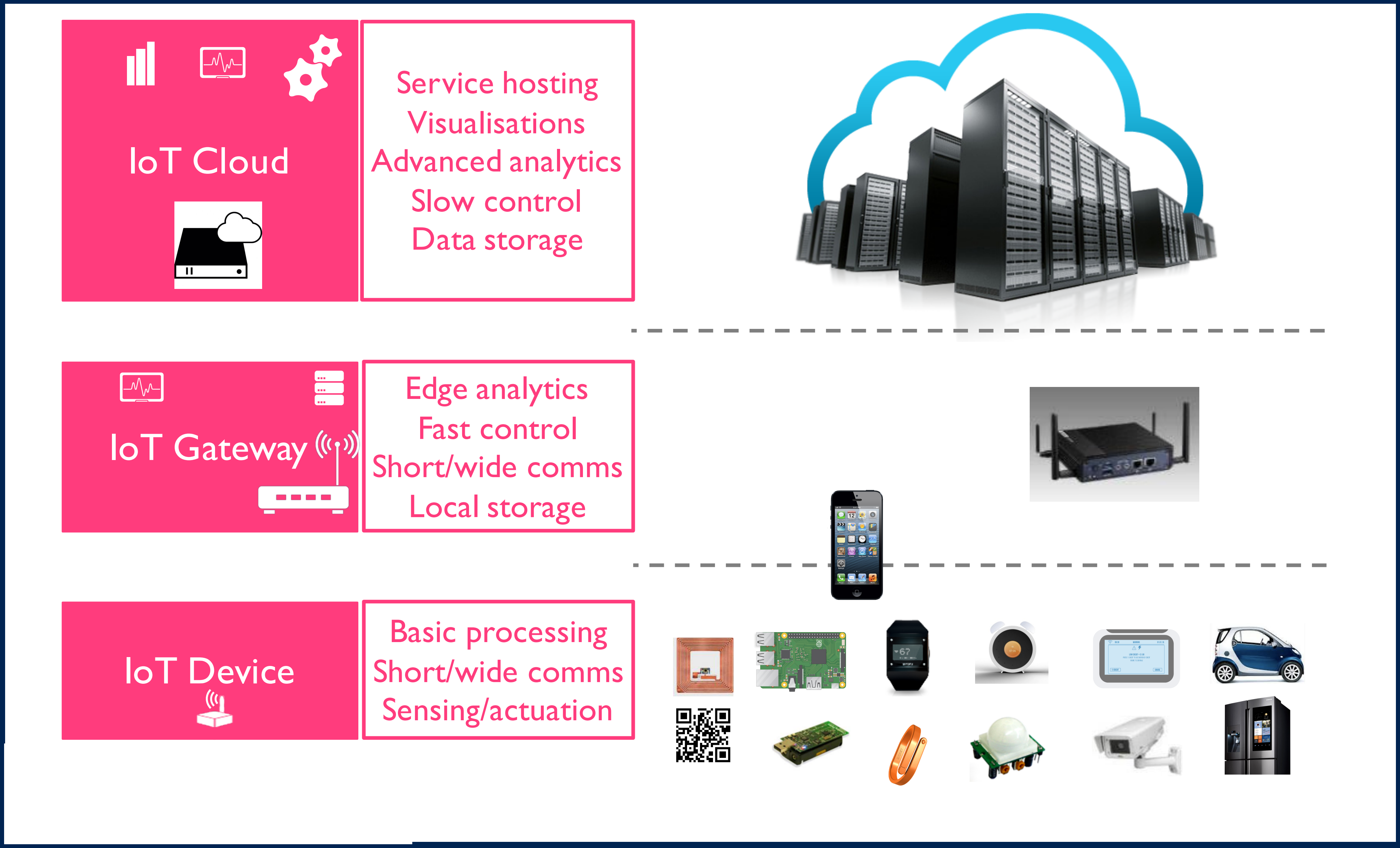
Devices (sensor nodes, mobile and wearable devices)

Machines (home appliances, security systems, vehicles, etc.)

Environments (smart homes, buildings, cities)

source: A. Gaglione (University of Cambridge) *Mobile and Sensor Systems* course lectures

The IoT reference architecture



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The IoT architecture

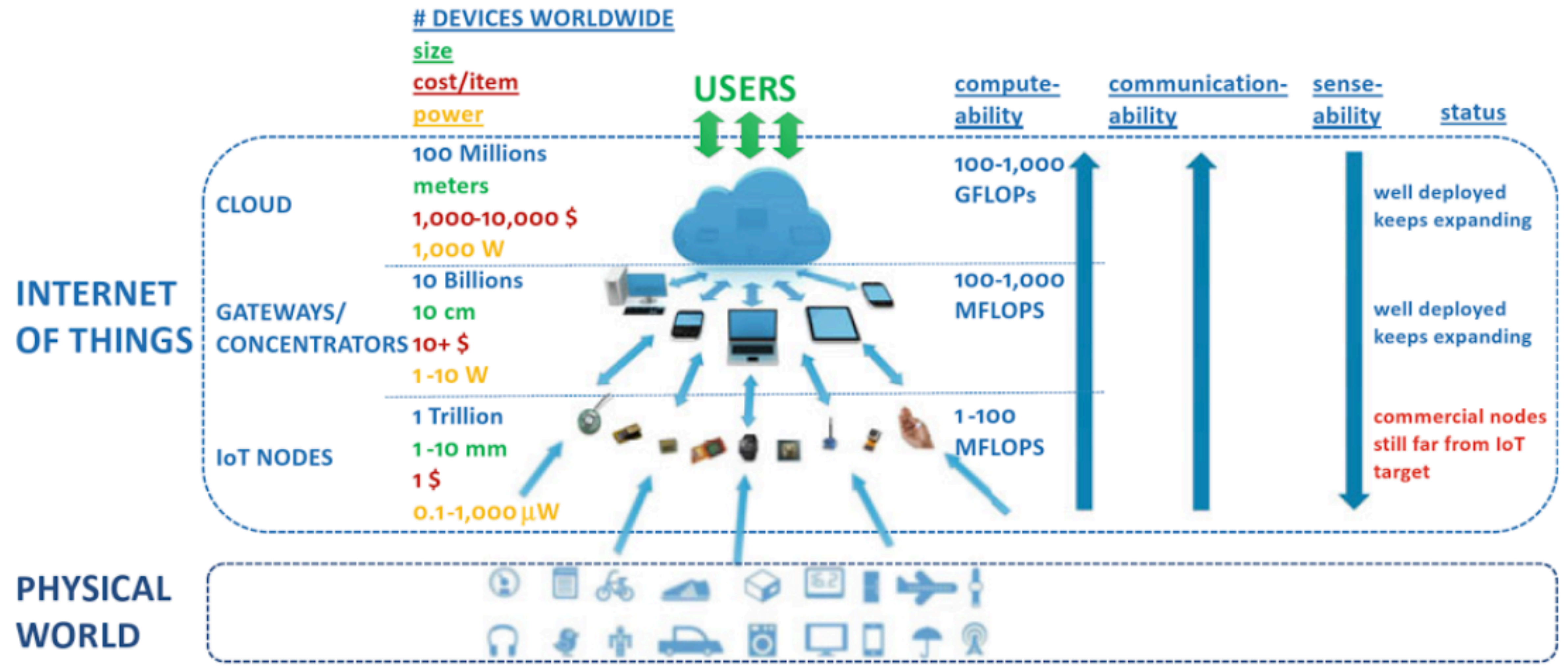


Fig. 1.1 A simplified architecture of the IoT

source: M. Alioto (University of Singapore) *Enabling the Internet of Things*, Springer 2017

The IoT architecture

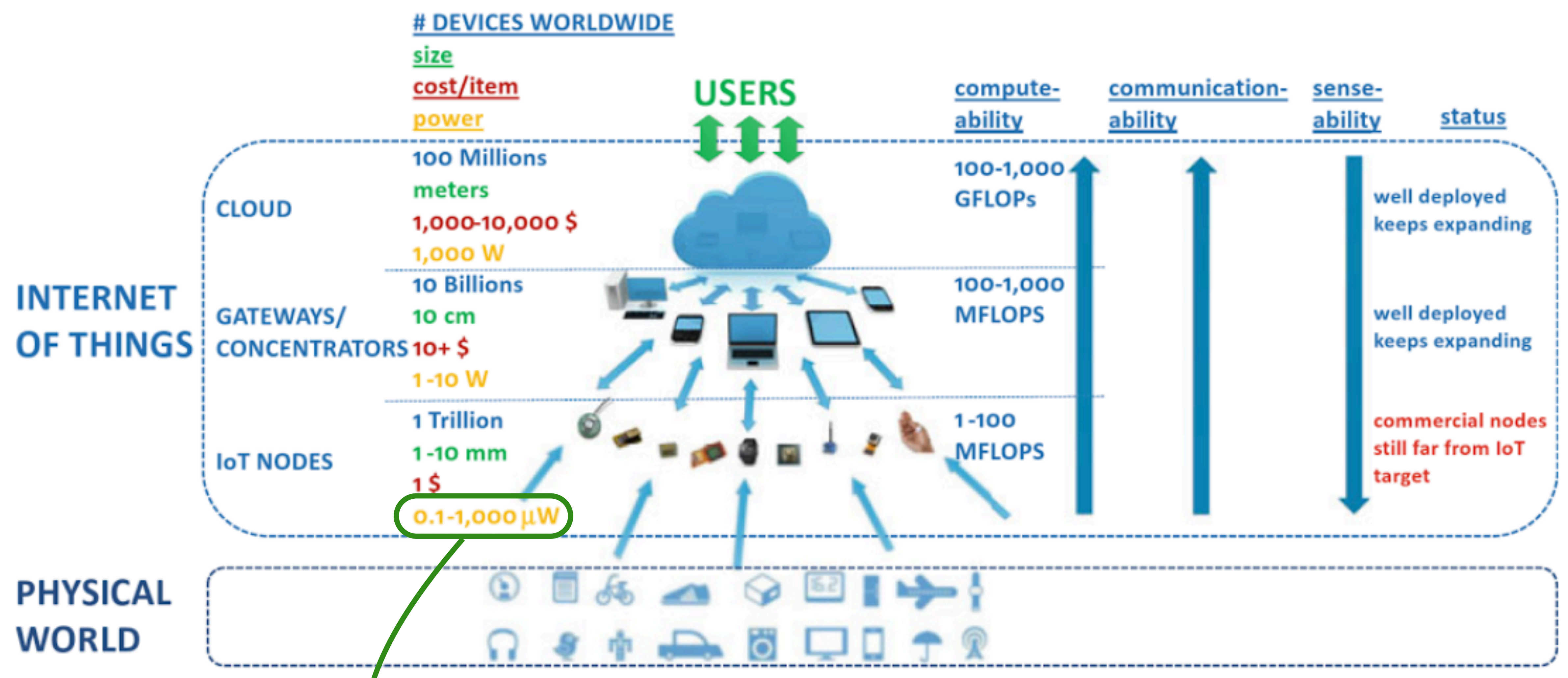
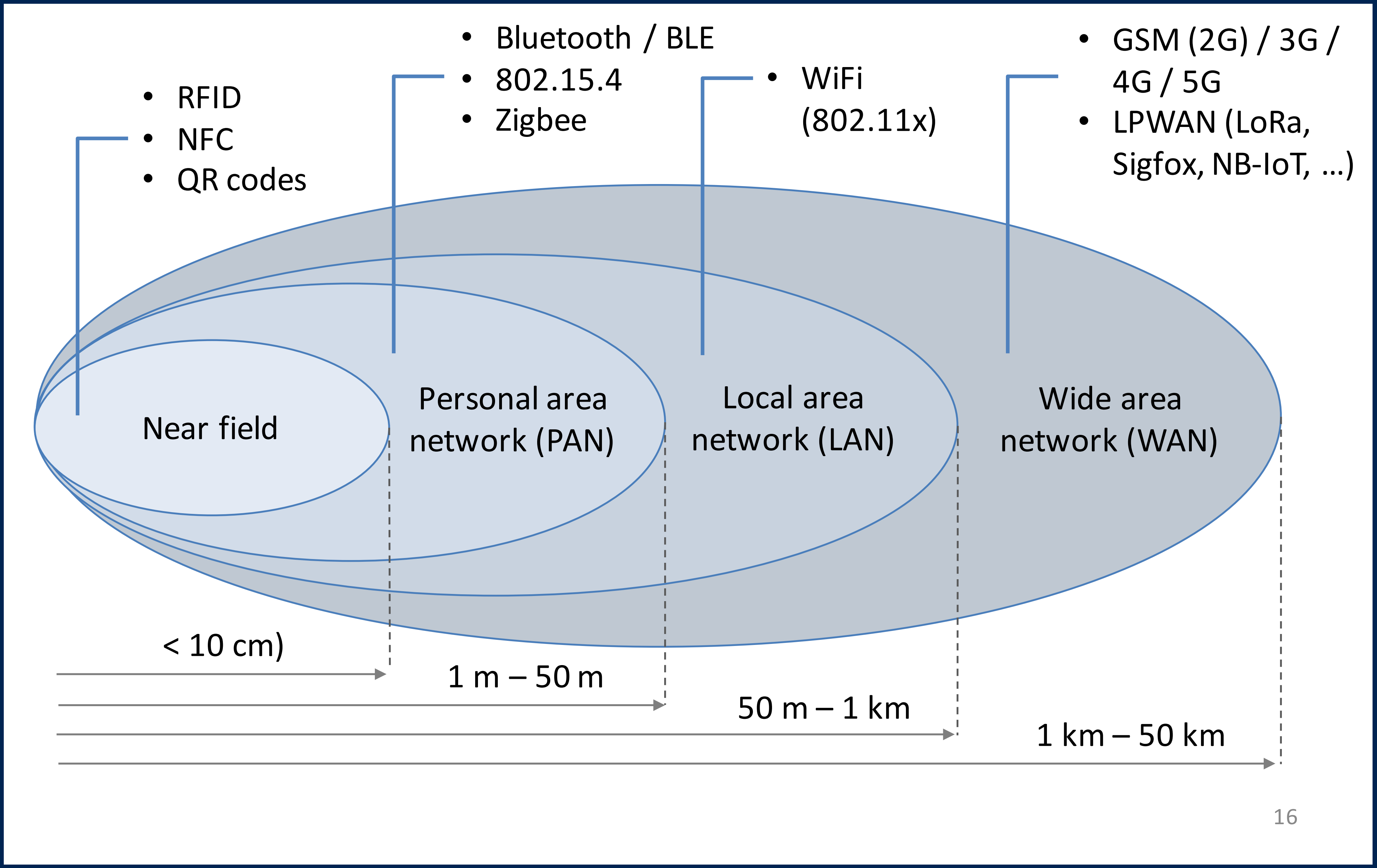


Fig. 1.1 A simplified architecture of the IoT

Untethered, ubiquitous, miniaturized —> very low power budget

source: M. Alioto (University of Singapore) *Enabling the Internet of Things*, Springer 2017

Communication technologies



source: A. Gaglione (University of Cambridge) *Mobile and Sensor Systems* course lectures

IoT communication issues

- Huge amount of (wirelessly transmitted) data (expected to be 10% of world's data in 2020)
- Number of devices prompts the transition from IPv4 (32 bit, $4x10^9$ different addresses) to IPv6 (128 bit, 10^{38} different addresses)
- Increasing need of real-time applications

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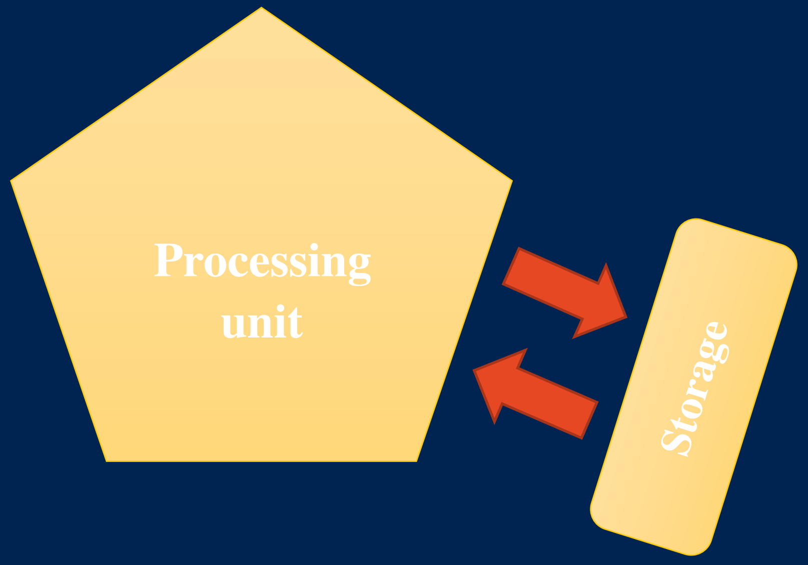
Move intelligence towards the edge
Design smarter IoT nodes
Avoid raw data transmission

Architecture of autonomous embedded systems

source: E. Farella (Bruno Kessler Foundation) "Node-centric IoT: opportunities and challenges", lecture slides

Architecture of autonomous embedded systems



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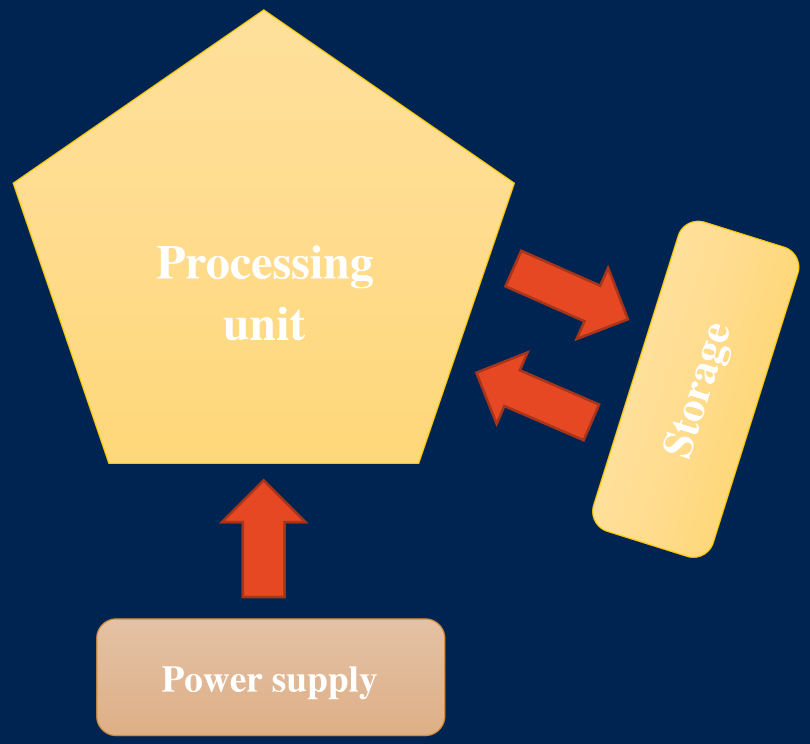
Architecture of autonomous embedded systems



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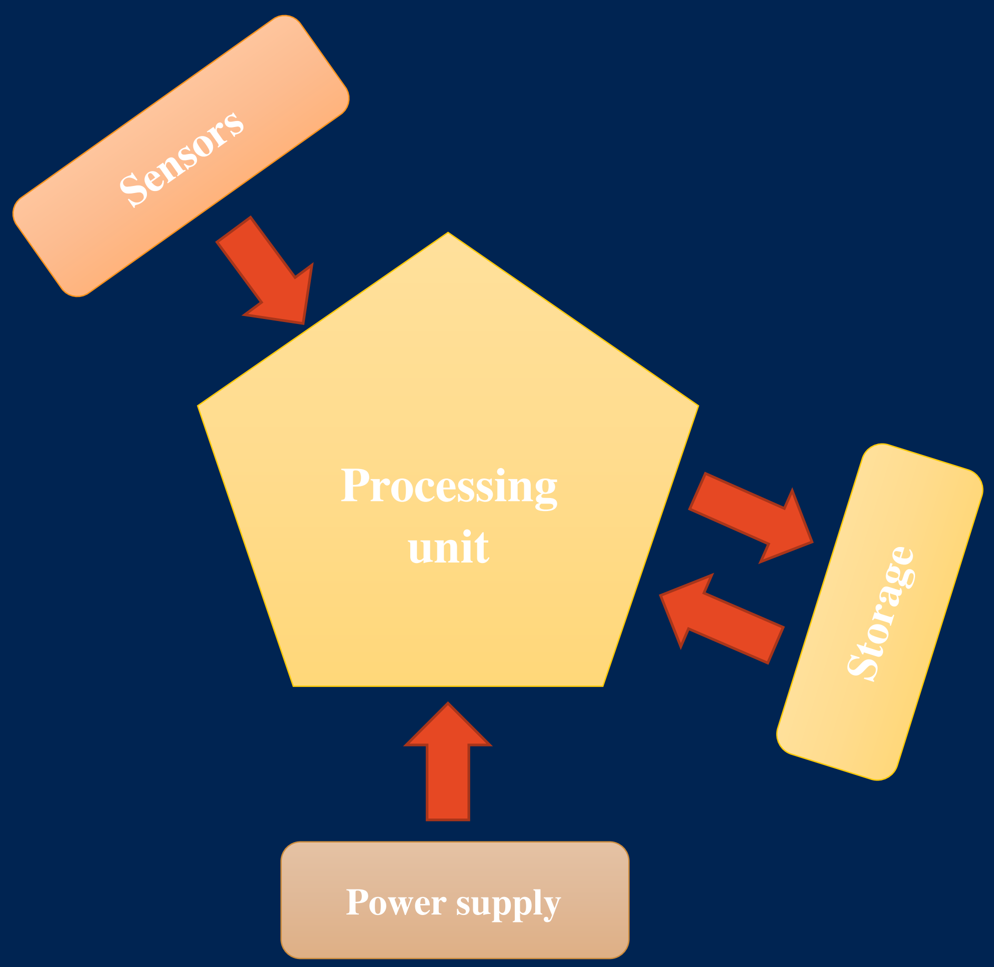

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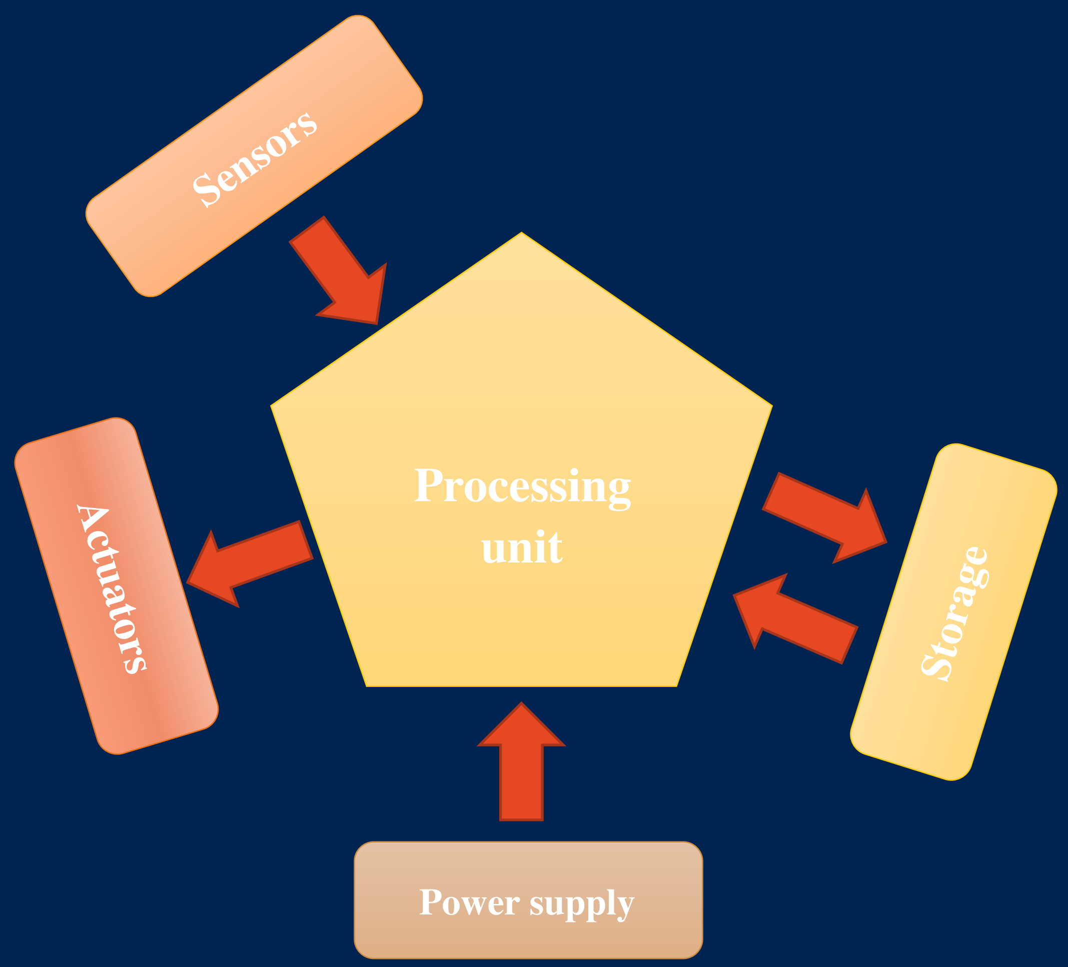

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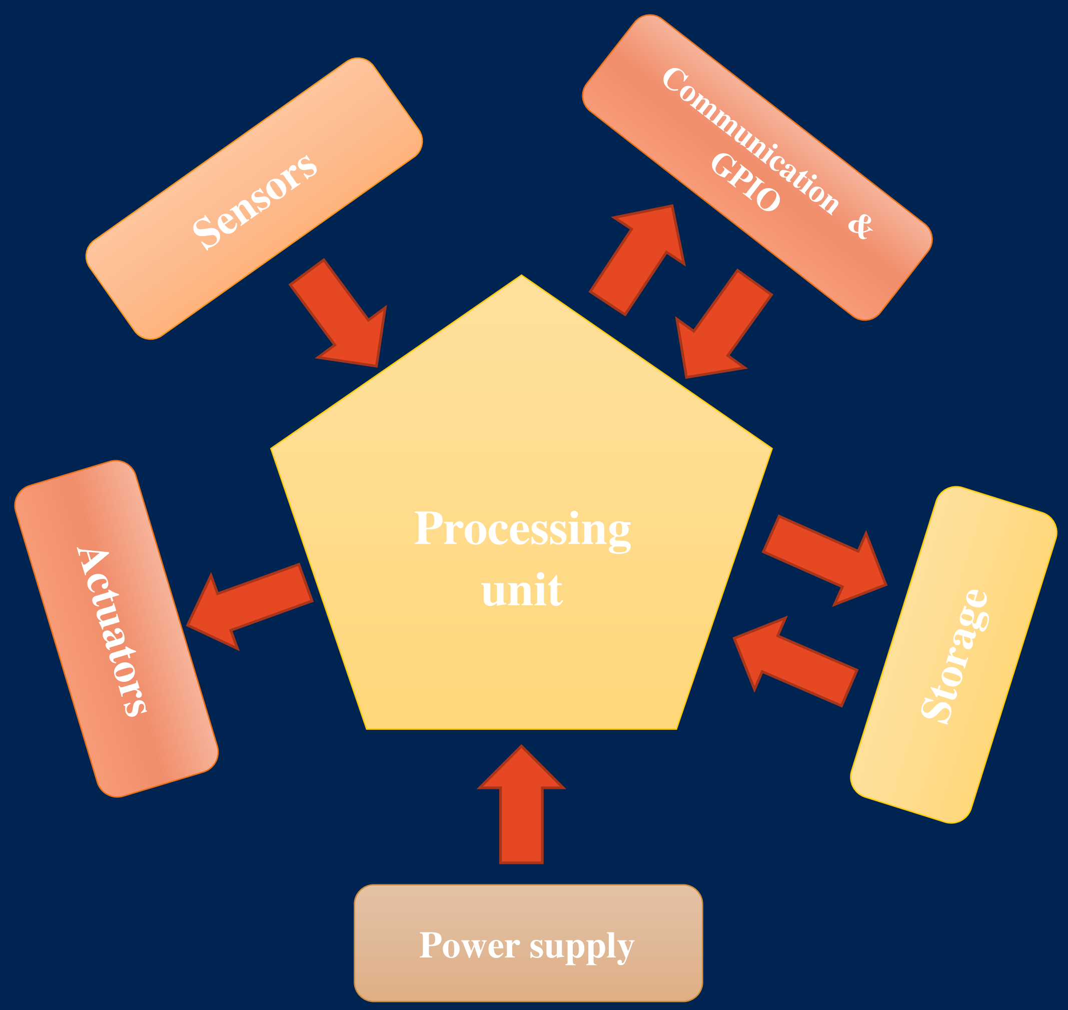

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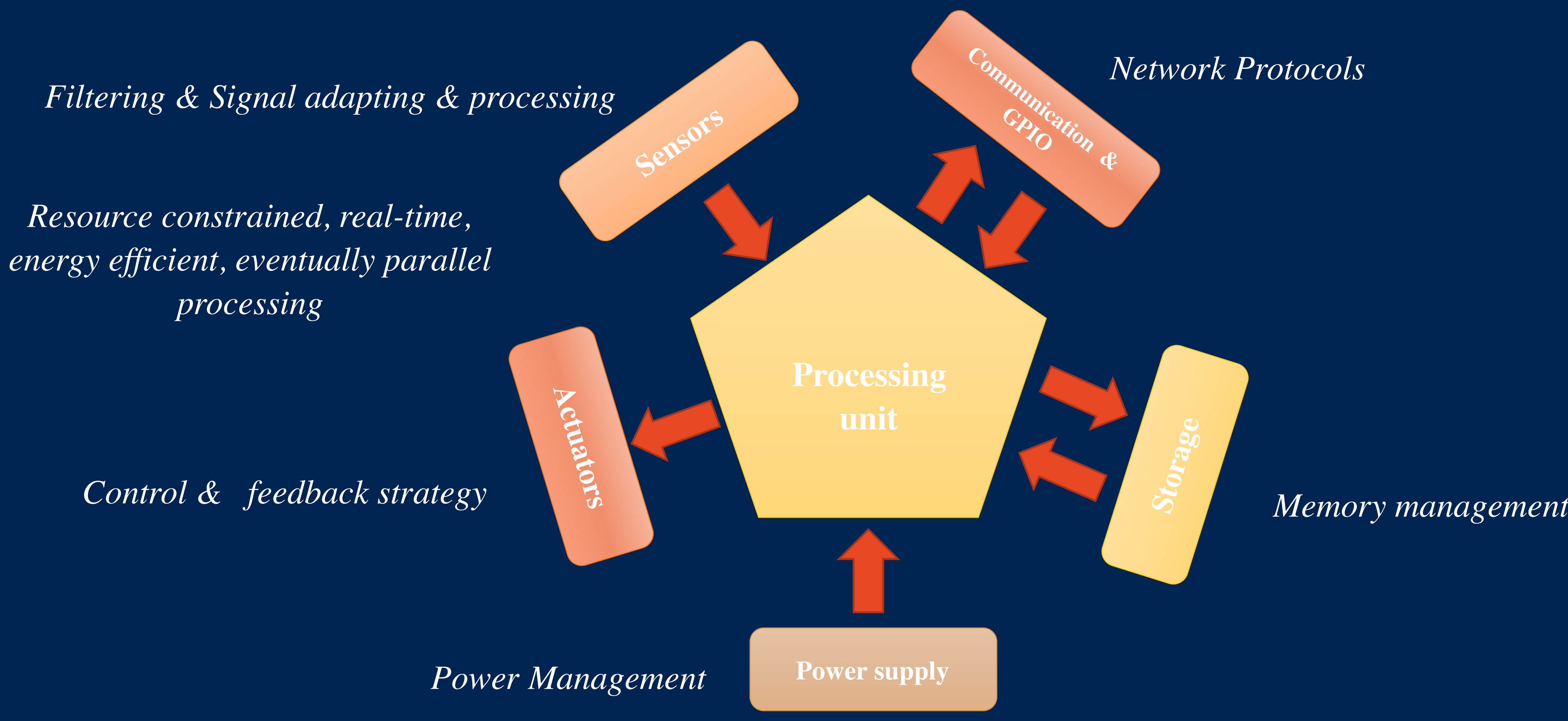

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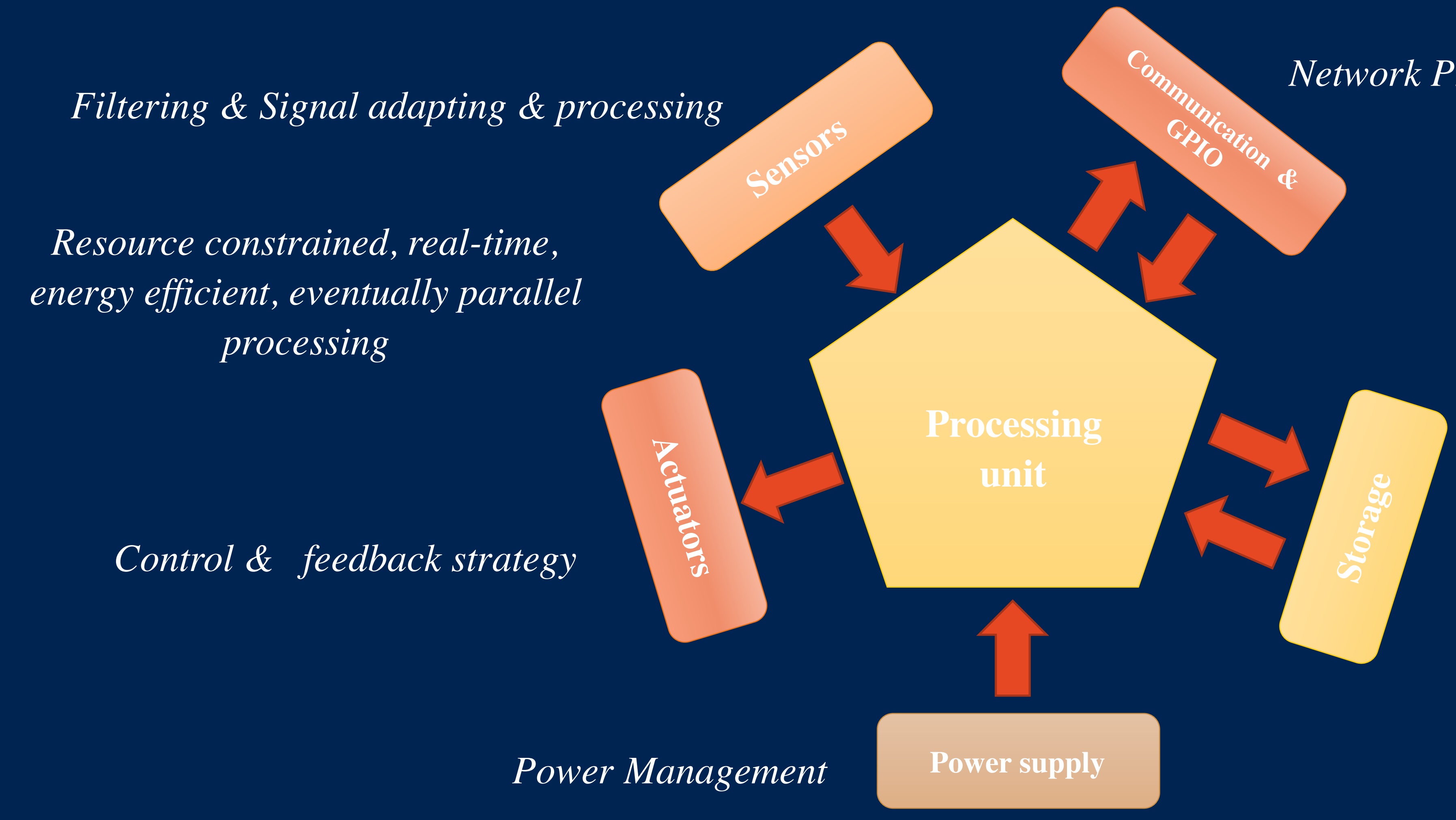

ENERGY CONSUMERS: SENSORS + and GPIO/ COMMUNICATION + data processing

source: E. Farella (Bruno Kessler Foundation) "Node-centric IoT: opportunities and challenges", lecture slides

Outline

- Introduction
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Power consumption

- Nodes power consumption distribution across:
  - Communication
  - Computation
  - Sensing/actuation

Power consumption: communication

$$P_{radio} = N_{tx}[P_{tx}(T_{on-tx} + T_{st}) + P_{out}T_{on-tx}] + N_{rx}[P_{rx}(T_{on-rx} + T_{st})]$$

source: Shih E.et al.,"Physical Layer Driven Protocols and Algorithm Design for Energy-Efficient Wireless Sensor Networks", *Proc. of the 7th ACM conference on Mobile computing and networking, 2001*

Power consumption: communication

$$P_{radio} = N_{tx}[P_{tx}(T_{on-tx} + T_{st}) + P_{out}T_{on-tx}] + N_{rx}[P_{rx}(T_{on-rx} + T_{st})]$$

- $N_{tx/rx}$ is the average number of times per second that the transmitter/receiver is used
- $P_{tx/rx}$ is the power consumption of the transmitter/receiver
- P_{out} is the output transmit power
- $T_{on-tx/rx}$ is the transmit/receive on-time (actual data transmission/reception time)
- T_{st} is the startup (transient) time of the transceiver

source: Shih E.et al.,"Physical Layer Driven Protocols and Algorithm Design for Energy-Efficient Wireless Sensor Networks", *Proc. of the 7th ACM conference on Mobile computing and networking, 2001*

Power consumption: communication

$$P_{radio} = N_{tx}[P_{tx}(T_{on-tx} + T_{st}) + P_{out}T_{on-tx}] + N_{rx}[P_{rx}(T_{on-rx} + T_{st})]$$

- $N_{tx/rx}$ is the ter/receiver
- $P_{tx/rx}$ is the
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- $T_{on-tx/rx}$ is t time)
- T_{st} is the startup (transient) time of the transceiver

- $N_{tx/rx}$ will largely depend on the application scenario and the media-access control (MAC) protocol being used
- $T_{on-tx/rx} = L/R$, where L is the packet size in bits and R is the data rate in bits per second
- In this radio model the power amplifier is on only when communication occurs. During the startup time, no data can be sent or received by the transceiver

source: Shih E.et al.,"Physical Layer Driven Protocols and Algorithm Design for Energy-Efficient Wireless Sensor Networks", *Proc. of the 7th ACM conference on Mobile computing and networking, 2001*

Idle listening

- The power consumption of “short range” (i.e., low-power) wireless communications devices is roughly the same whether the radio is transmitting, receiving, or simply ON, “listening” for potential reception

- Radio must be ON (listening) in order receive anything.

  - Transmission is infrequent.

  - Listening (potentially) happens all the time

- Total energy consumption dominated by idle listening

source: M. Cesana (Politecnico Milano) *Internet of Things* course lectures

Idle listening

- A significant fraction of energy budget is consumed for listening the channel for incoming packets
- A problem, especially in low data rates applications
- Solutions: protocols that power off radios as often and as long as possible —> rendez-vous problem
  - Synchronous (time slot synchronization): difficult in multi-hop ad-hoc, possibly resulting into power overhead
  - Pseudo-asynchronous: nodes powered off and on periodically. Beaconing is used for expressing willingness to communicate
  - Purely asynchronous: nodes have the capability to wake-up one another on demand (requires extra-hardware, i.e. ultra-low-power wakeup-receivers)

Power consumption: computation

$$P = \boxed{0.5V_{DD}^2 f_{clock} C_L E_{sw}} + \boxed{t_{sc} V_{DD} I_{peak} f_{0\to 1}} + \boxed{V_{DD} I_l}$$

- Switching (or dynamic) PC
  - E_{sw}: probability to make a transition at each clock cycle
  - C_L: switching CMOS capacitance
- Short circuit PC
  - short circuit path between supply rails during switching
- Leakage (or stand-by) PC
  - leaking diodes and transistors
  - becomes one of the major factors due to shrinking feature sizes in semiconductor technology (35-50% of power budget at 90nm)

source: E. Farella (Bruno Kessler Foundation) "Node-centric IoT: opportunities and challenges", lecture slides

Multiple power consumption

- Multiple modes (possible “Deeper”sleep modes)
- Strongly dependent on hardware
  - TI MSP 430: four different sleep modes
  - Atmel ATMega: six different modes
- Not only microcontroller have different power profiles
  - TI CC2520: two different low power modes

Power consumption: sensing/ actuation

- Lack of a single cohesive framework (multifaceted and fragmented field)
- Broad array of low-power micro-devices:
  - Temperature, light, proximity, magnetic field, acceleration, etc.
- Many interfaces
  - Analog
  - Digital (SPI, I^2C, etc.)

IoT nodes requirements

- Physical constraints
  - nodes have to be untethered —> energy autonomous —> battery operated/ energy harvester
  - Small form factor (e.g. wearables)
  - Size dominated by energy sources (power consumption sets the volume of IoT nodes)

IoT nodes requirements

- On board capabilities
  - Sensing, computation, wireless communication
- Meeting power budgets of few microW is feasible only if aggressive duty cycle is performed

IoT nodes requirements

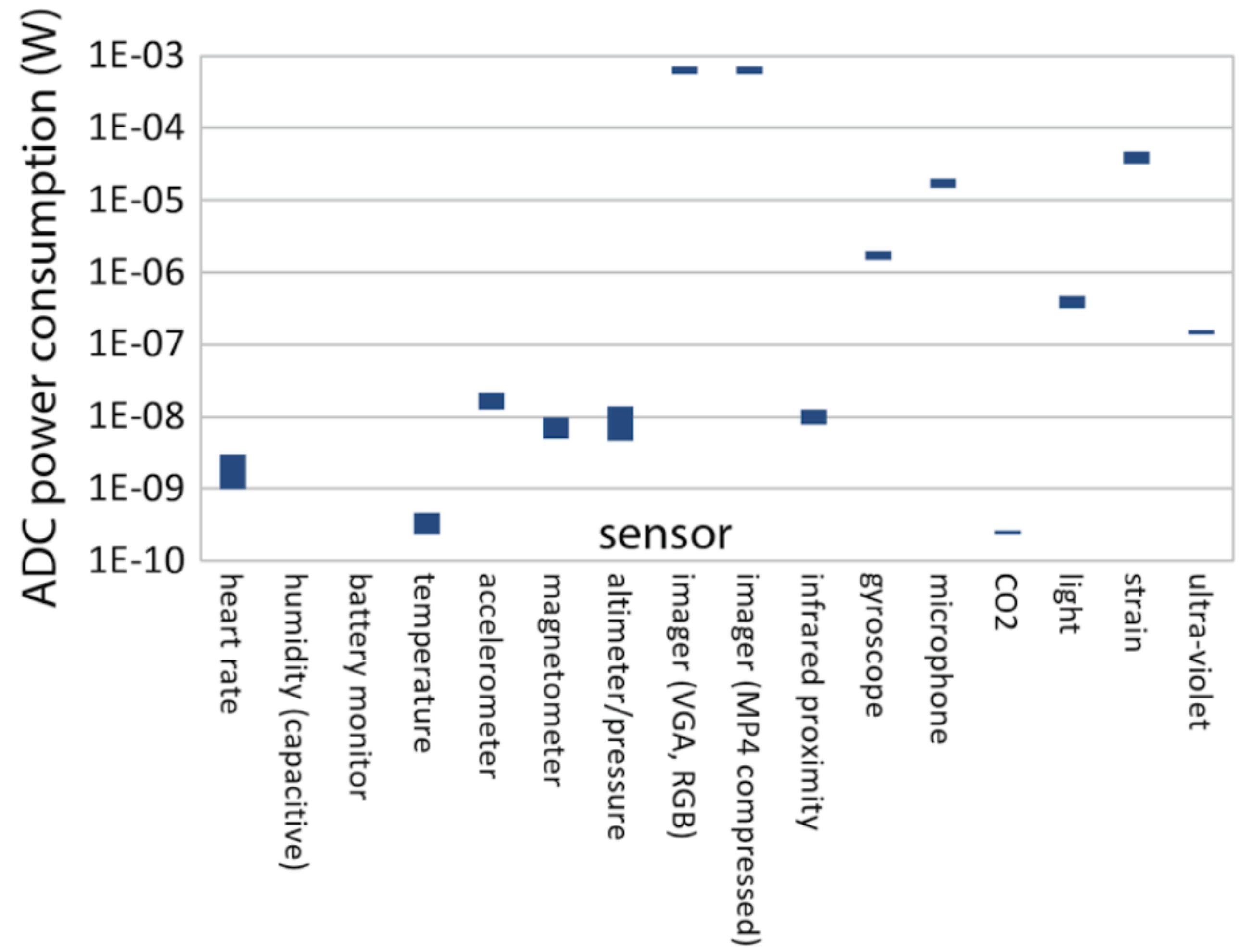


Fig. 1.8 ADC power consumption under sampling rate associated with the datarate in Fig. 1.7, assuming an energy/conversion step of 30 fJ

source: M. Alioto (University of Singapore) *Enabling the Internet of Things*, Springer 2017

IoT nodes requirements

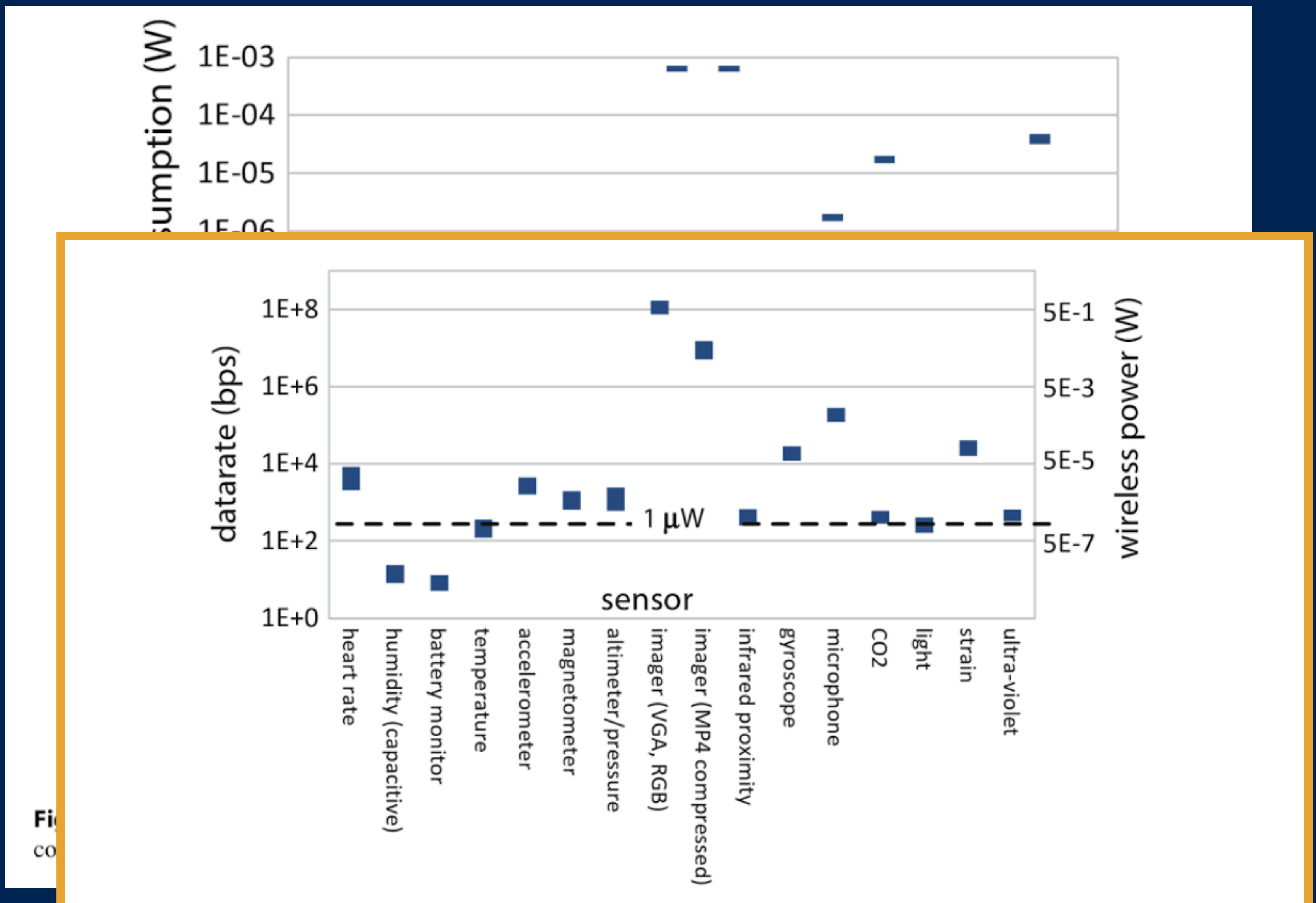


Fig. 1.7 Datarate range required by various sensors, and wireless power required to continuously transmit data (energy/bit assumed to be 5 nJ/bit)

source: M. Alioto (University of Singapore) *Enabling the Internet of Things,* Springer 2017

IoT nodes requirements

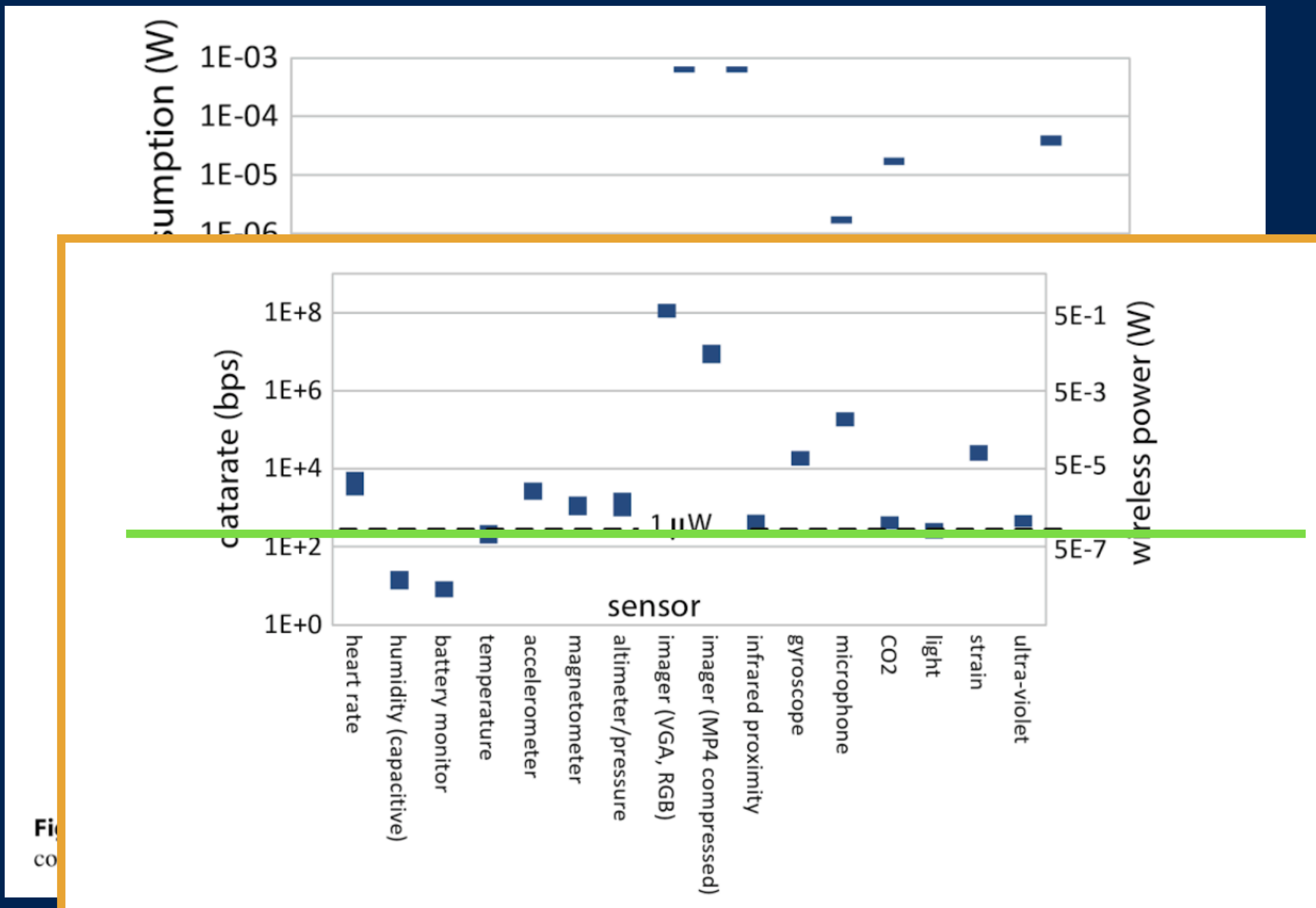


Fig. 1.7 Datarate range required by various sensors, and wireless power required to continuously transmit data (energy/bit assumed to be 5 nJ/bit)

- Computation offloading (sending raw data to cloud) is not an option

- Computation/ communication tradeoff

source: M. Alioto (University of Singapore) *Enabling the Internet of Things*, Springer 2017

Computation communication tradeoff

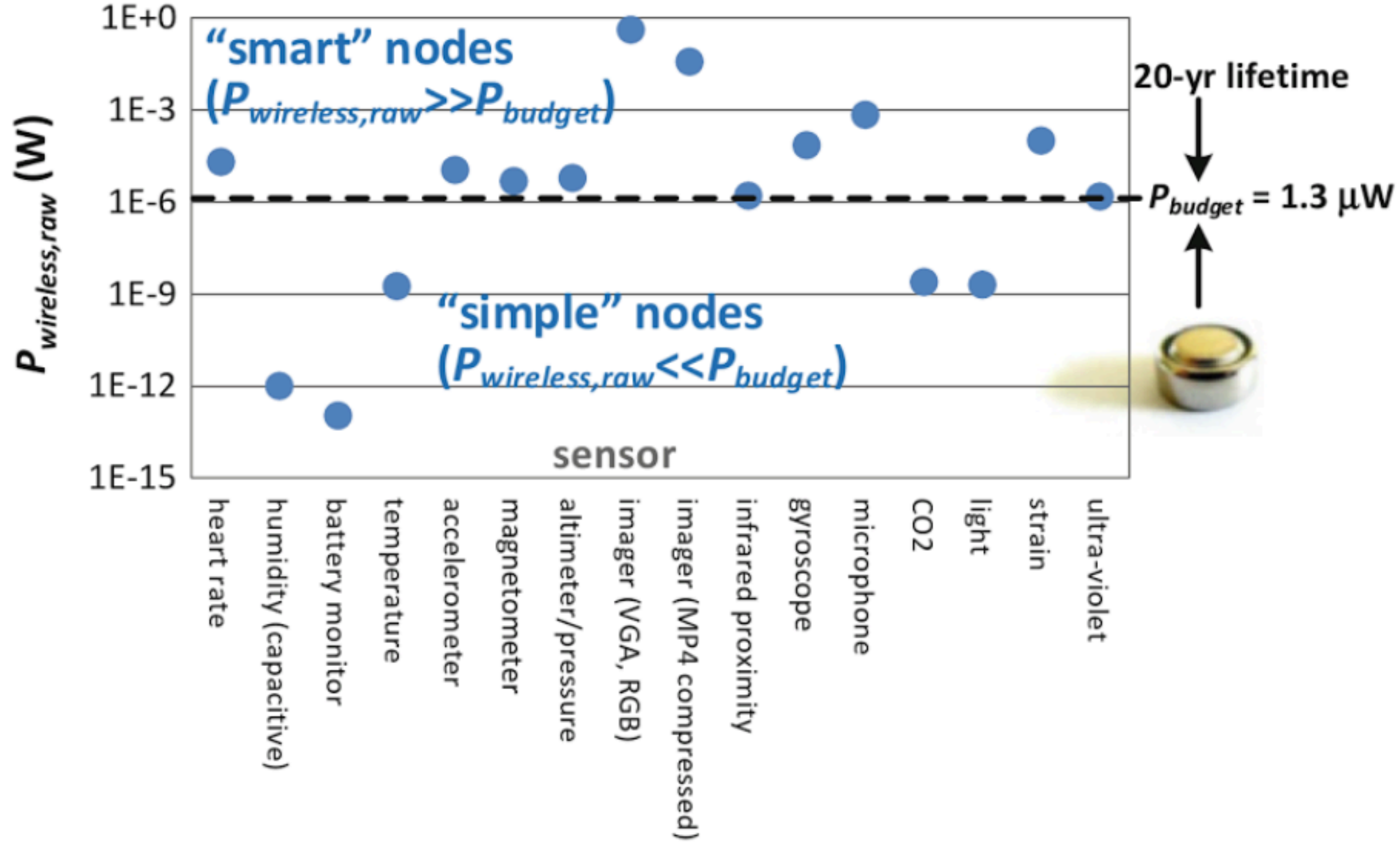


Fig. 1.17 Average wireless power $P_{wireless,raw}$ required by sensors in Fig. 1.7, assuming best-in-class 5-nJ/bit radio and comparison with power budget imposed by LR44 battery under 20-year lifetime target. IoT nodes above the black dashed line need on-board intelligence to reduce the amount of wireless data communication

IoT nodes energy budget

Processors and MCUs (Freq = 8 MHz)				Wireless Standards				Sensors			
Product	Architecture Family	Current Active (mA)	Current Sleep (µA)	Standard (Product)	Current Tx (mA)	Current Rx (mA)	Current Sleep (µA)	Sensor	Product	Current Active (µA)	Current Sleep (µA)
MSP430F5438A	MSP430	1.84	0.1	WiFi (TI CC3200)	229	59	4	Temperature	TMP102	85	0.5
STM32L051x6	ARM CM0+	1.55	0.29					Humidity	SHT21	300	0.15
STM32L100C6	ARM CM3	2.16	0.3	IEEE 802.15.4 (Atmel AT86RF231)	14	12.3	0.02	Accelerometer	ADXL362	13	0.01
SAM4S	ARM CM4	4.5	1.8					Light	ISL29033	65	0.01
PIC24FJ128GC010	PIC	1.5	0.075	Bluetooth Smart (Nordic nRF8001)	12.7	14.6	0.5	Proximity	AD7150	100	1

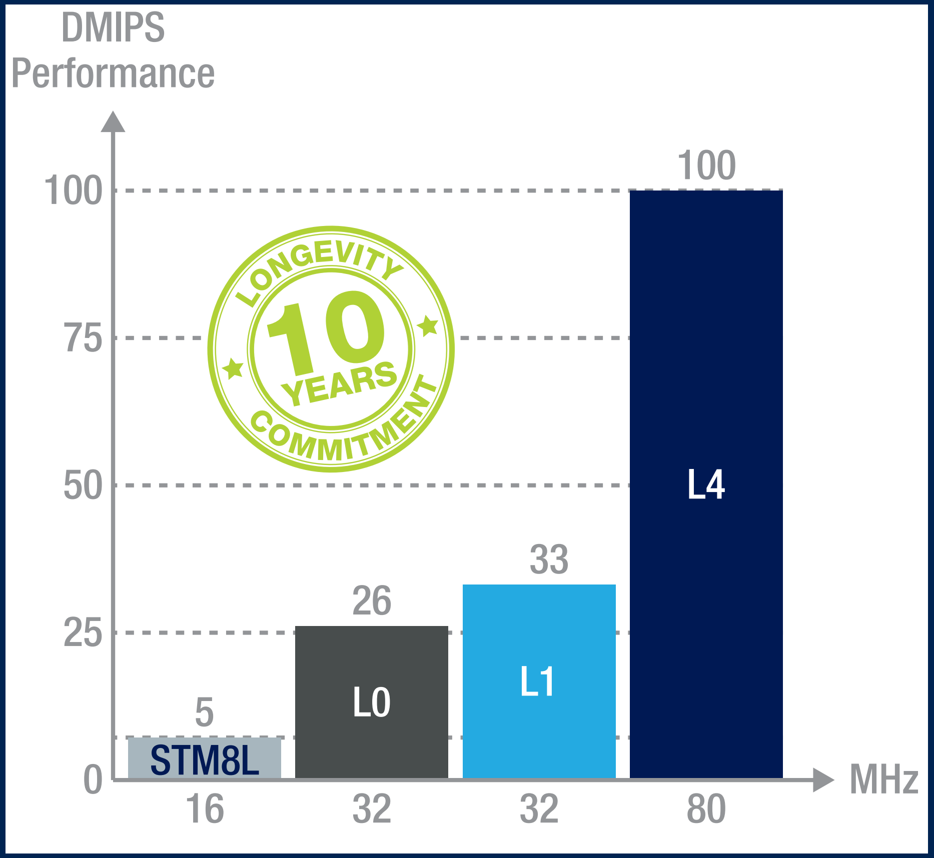
Table 1: Power consumption of a few representative hardware components used in IoT devices (sourced from datasheets).

Jayakumar, H., Lee, K., Lee, W.S., Raha, A., Kim, Y., and Raghunathan, V.

Powering the Internet of Things

Proceedings of the 2014 International Symposium on Low Power Electronics and Design ISLPED'14

Multiple power consumption

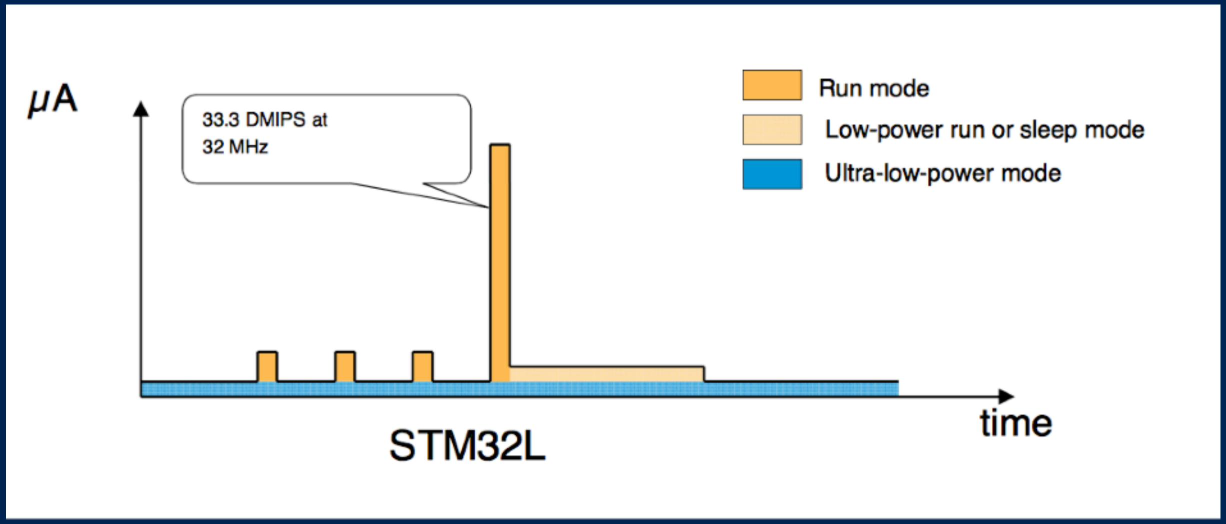


- 32-bit ARM Cortex-M4 + FPU at 80 MHz
- From 256 Kbytes to 1 Mbyte of Flash
- Lowest power mode + RAM + RTC: 0.6 µA

- 32-bit ARM Cortex-M3 at 32 MHz
- From 32 to 512 Kbytes of Flash
- Lowest power mode + RAM + RTC: 1.2 µA

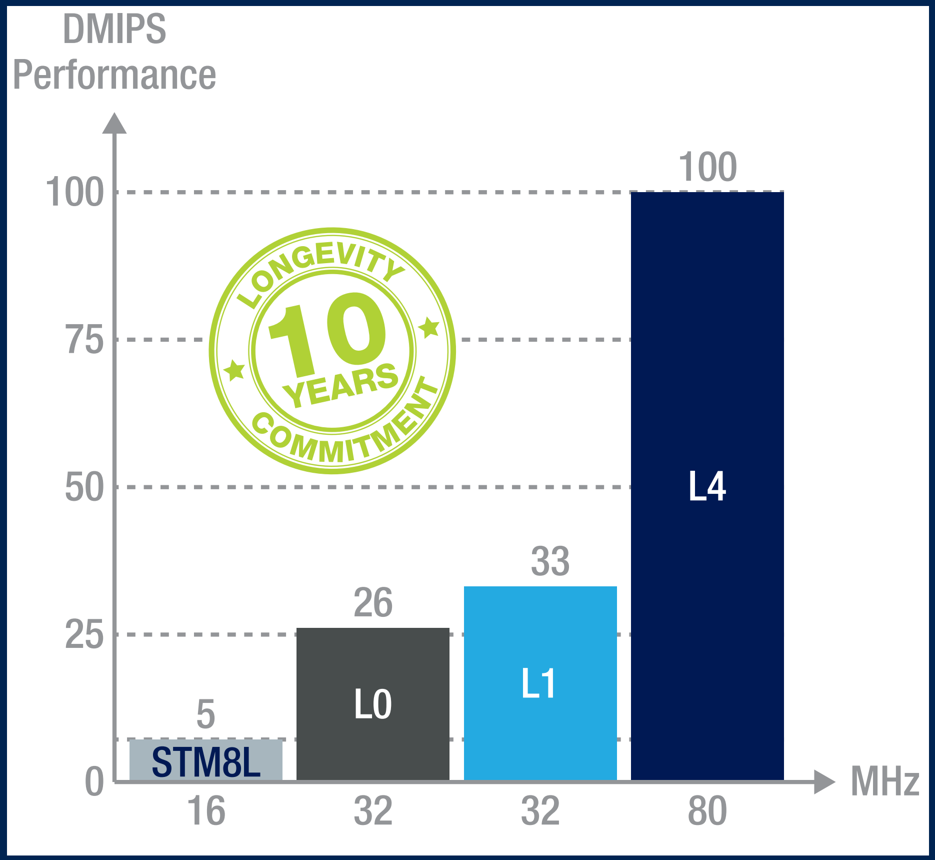
- 32-bit ARM Cortex-M0+ at 32 MHz
- From 8 to 192 Kbytes of Flash
- Lowest power mode + RAM + RTC: 0.8 µA

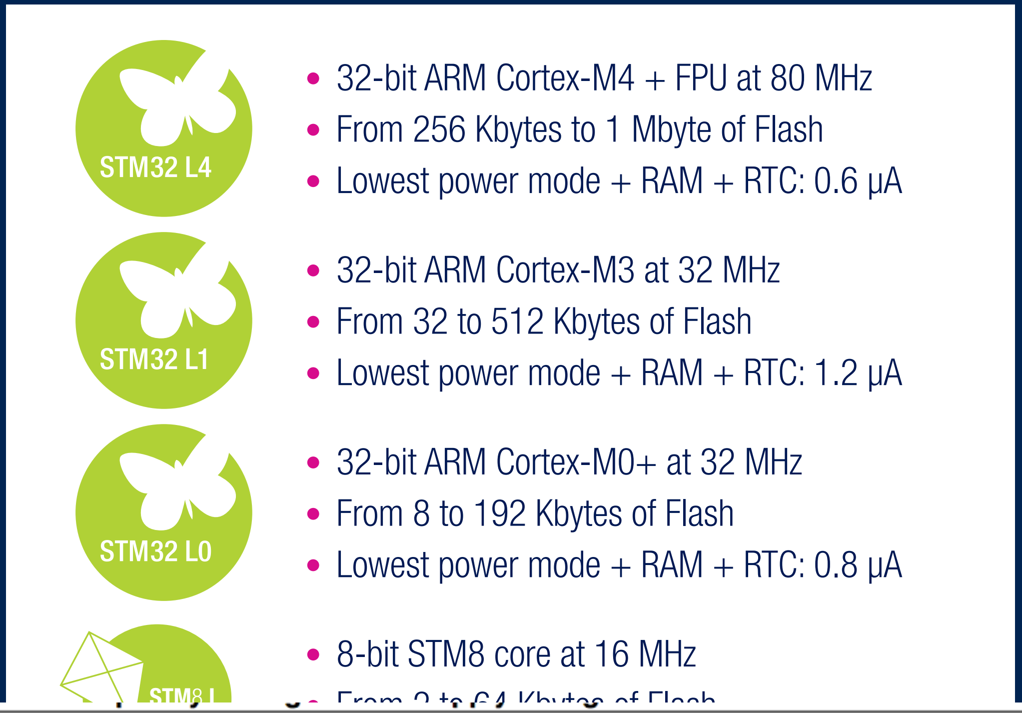
- 8-bit STM8 core at 16 MHz
- From 2 to 64 Kbytes of Flash
- Lowest power mode + RAM +RTC: 0.5 µA

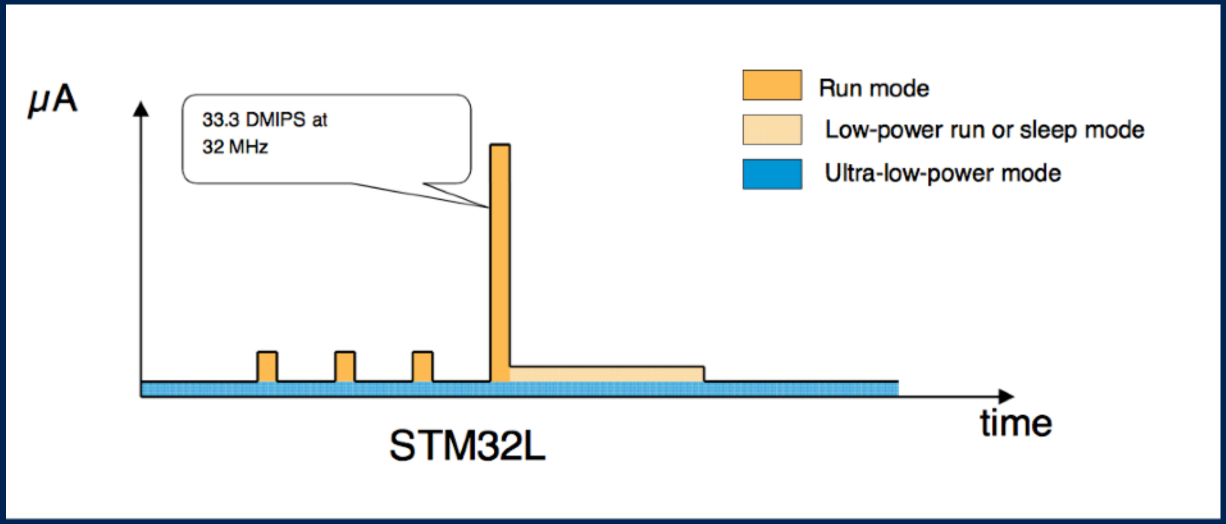


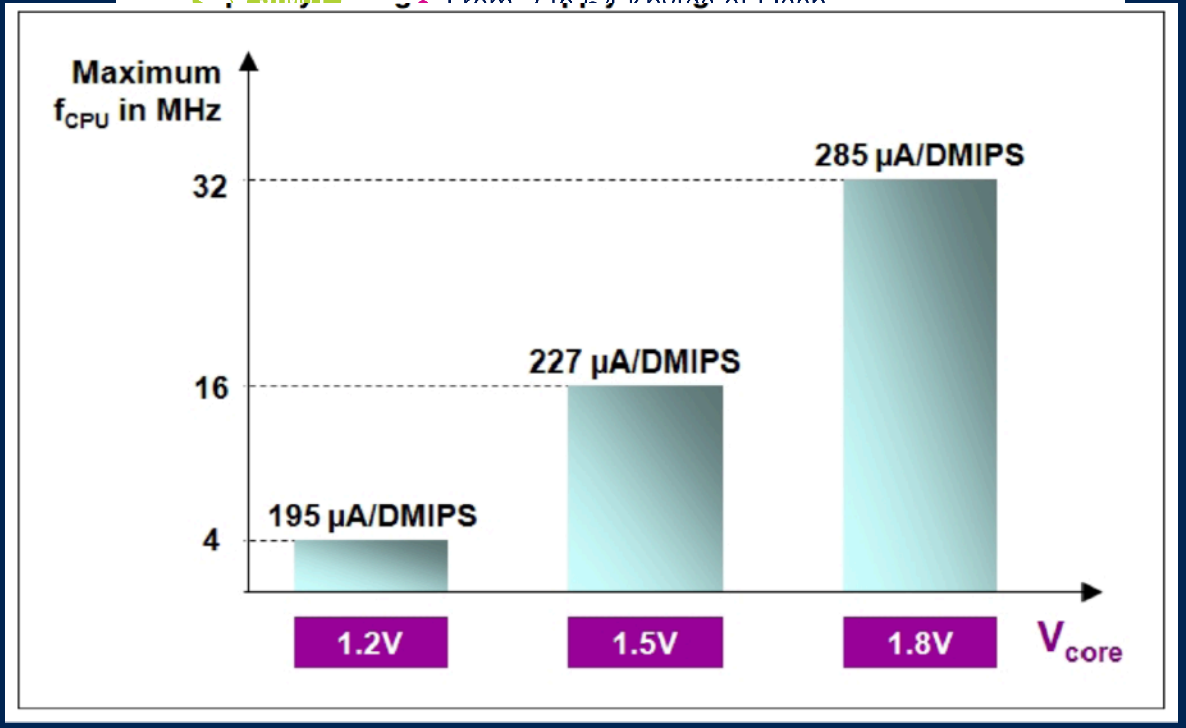
source: STMicroelectronics

Multiple power consumption





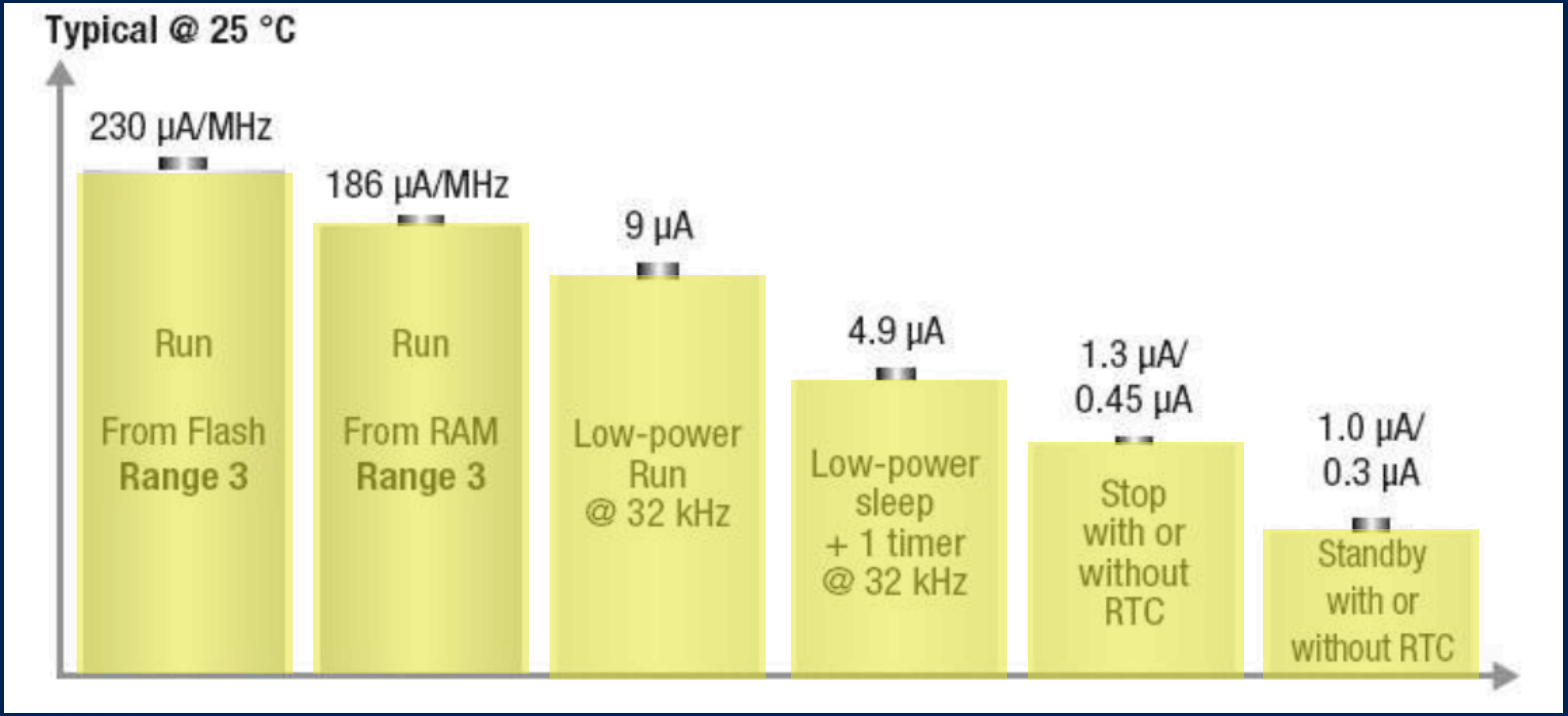




source: STMicroelectronics

Multiple power consumption

STM32L Cortex-M3 power profile



IoT sensors

Digital output barometer

Part number	Package (mm)	Pressure range (hPa)	Relative accuracy (hPa)	Absolute accuracy (hPa)	Noise	ODR (Hz)	Current consumption	Highshock survivability (g)	Advanced digital features	Reliability
LPS25HB	HLGA-10L, 2.5 x 2.5 x 0.76 Full-molded	260 to 1260	±0.1	±0.2	3 Pa RMS (without embedded filter) 1 Pa RMS (with embedded filter)	1, 10, 25	25 µA @ 1 Hz 4 µA @ 1 Hz (low res)	10.000	FIFO for Pressure Sensor data Programmable Interrupt/Data ready	• Improved moisture resistance • Improved shock/ vibration suppression • Proven experience: 250 Mpcs in the market
LPS22HB	HLGA-10L, 2 x 2 x 0.76 Full-molded	260 to 1260	±0.05	±0.1	1 Pa RMS (without embedded filter) 0.5 Pa RMS (with embedded filter)	1, 10, 25, 50, 75	15 µA @ 1 Hz (high resolution mode) 4 µA @ 1 Hz (low power mode)	22.000	FIFO for Pressure and Temperature Sensor data Programmable Interrupt/Data ready	

MEMS microphones

Part number	Sensitivity (dBV)	SNR (dB)	AOP (dB)	Supply voltage range (V)	Supply current (µA)	Dual mode	Package (mm)
MP23AB02B	-38±3	64	125	1.6-3.6	150	-	RHLGA metal cap 2.5 x 3.35 x 0.98

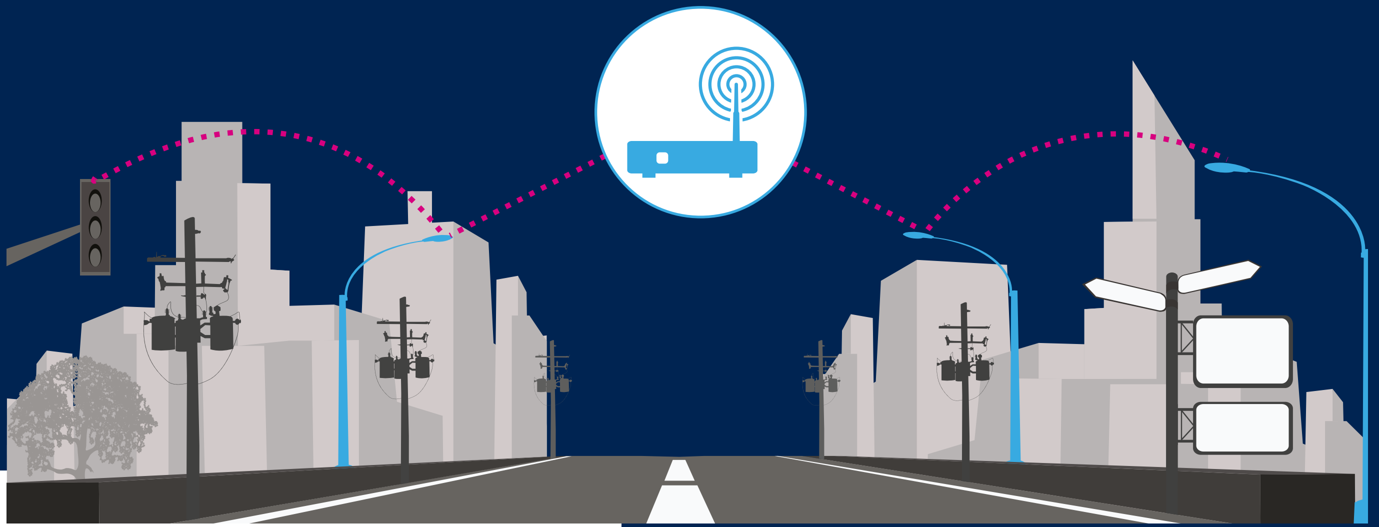
Temperature sensors

Part number	Package	General description	I/O Interface	Operating voltage min-max (V)	Standby current (µA typ)	Operating current (µA typ)
STTS751	UDFN-6L (2 x 2 mm)	2.25 V low-voltage local digital temperature sensor	SMBus/I²C compatible	2.25-3.6	3	15
STLM20	UDFN-4L (1 x 1.30 mm)	Ultra-low current 2.4 V precision analog temperature sensor	-	2.4-5.5	-	4.8

source: MEMS and Sensors/wearable (STMicroelectronics brochures)

Sub-GHz communication

Spirit1 low-power transceiver



Key Features

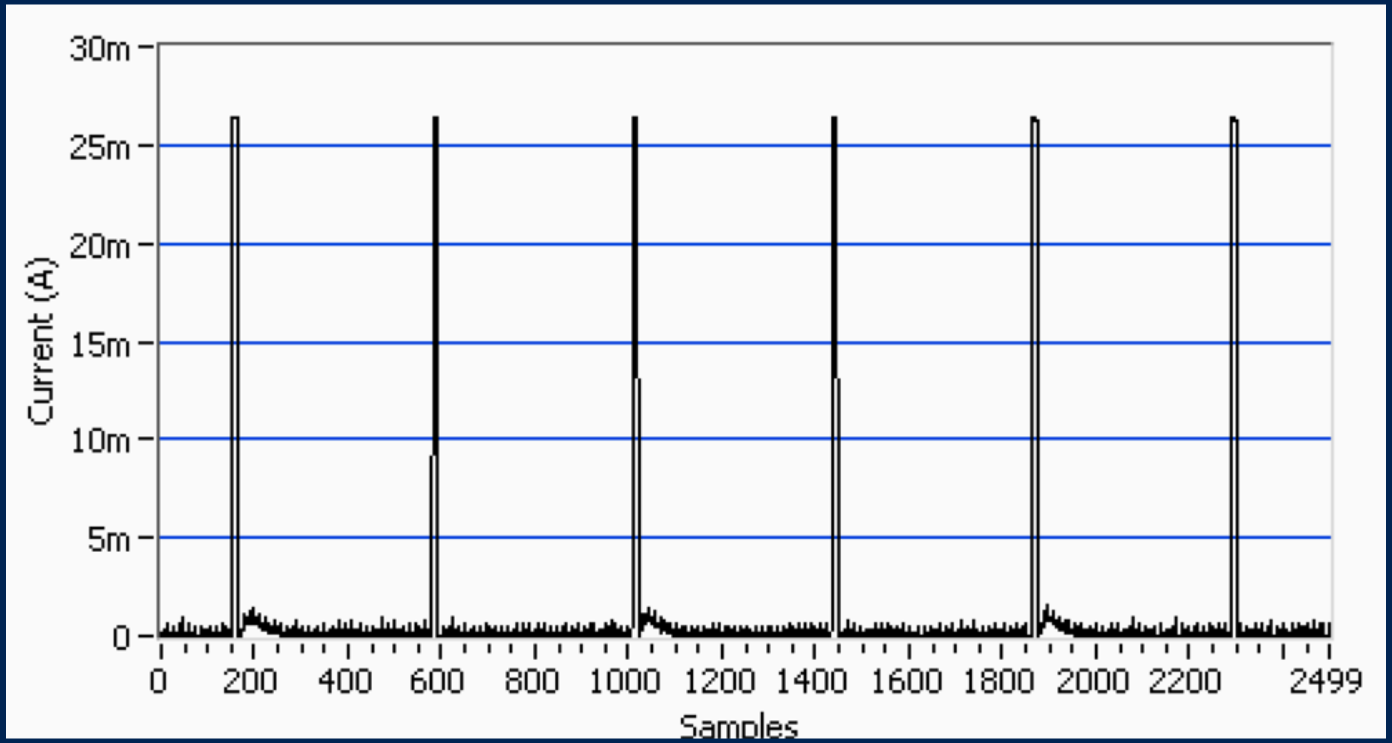
- Frequency bands: 150-174 MHz, 300-348 MHz, 387-470 MHz, and 779-956 MHz
- Modulation schemes: FSK, GFSK, MSK, OOK and ASK
- Air data rate from 1 to 500 kbit/s
- Programmable output power: from -30 dBm to +16 dBm (Boost mode)
- RX sensitivity: -122 dBm
- Low current consumption:
  - Shutdown: 2.5 nA
  - Standby: 650 nA
  - Sleep: 950 nA
  - RX: 9 mA
  - TX: 21 mA @ +11 dBm
- Programmable channel spacing (12.5 kHz minimum).
- Frequency hopping, antenna diversity algorithm
- 128-bit AES encryption co-processor
- Automatic acknowledgement, retransmission, and timeout protocol engine

source: Wireless connectivity for IoT applications (STMicroelectronics brochure)

IoT actuators

A Solar Energy Powered Autonomous Wireless Actuator Node for Irrigation Systems

Lajara, R., Alberola, J. and Pelegrí-Sebastiá, J. *Sensors* **2011**, *11*(1), 329-340



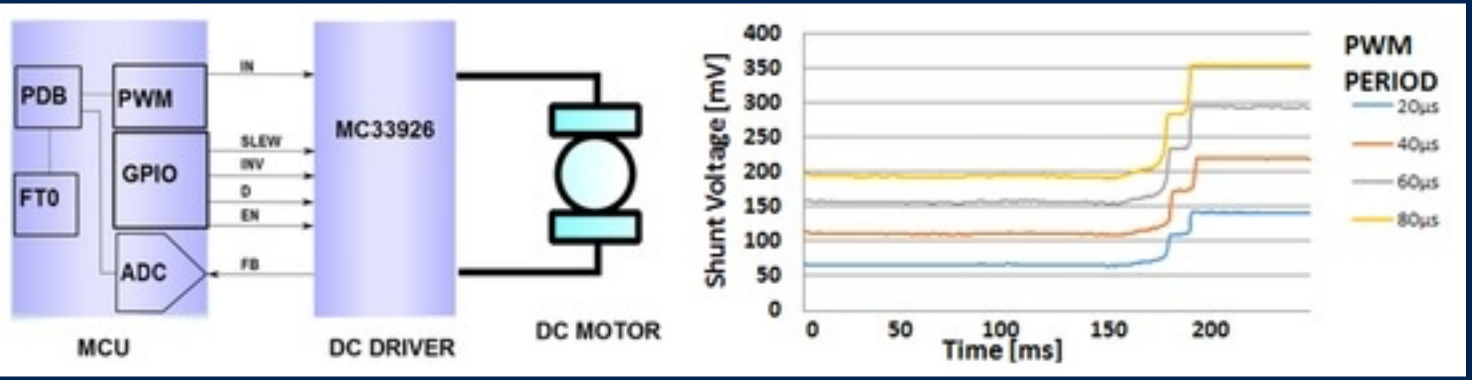
wEcoValve mote avg current consumption = 836.76 µA

IoT actuators

A Prosthetic Hand Body Area Controller Based on Efficient Pattern Recognition Control Strategies

Benatti, S. ,Milosevic, B., Farella E., Gruppioni, E. and Benini, L.

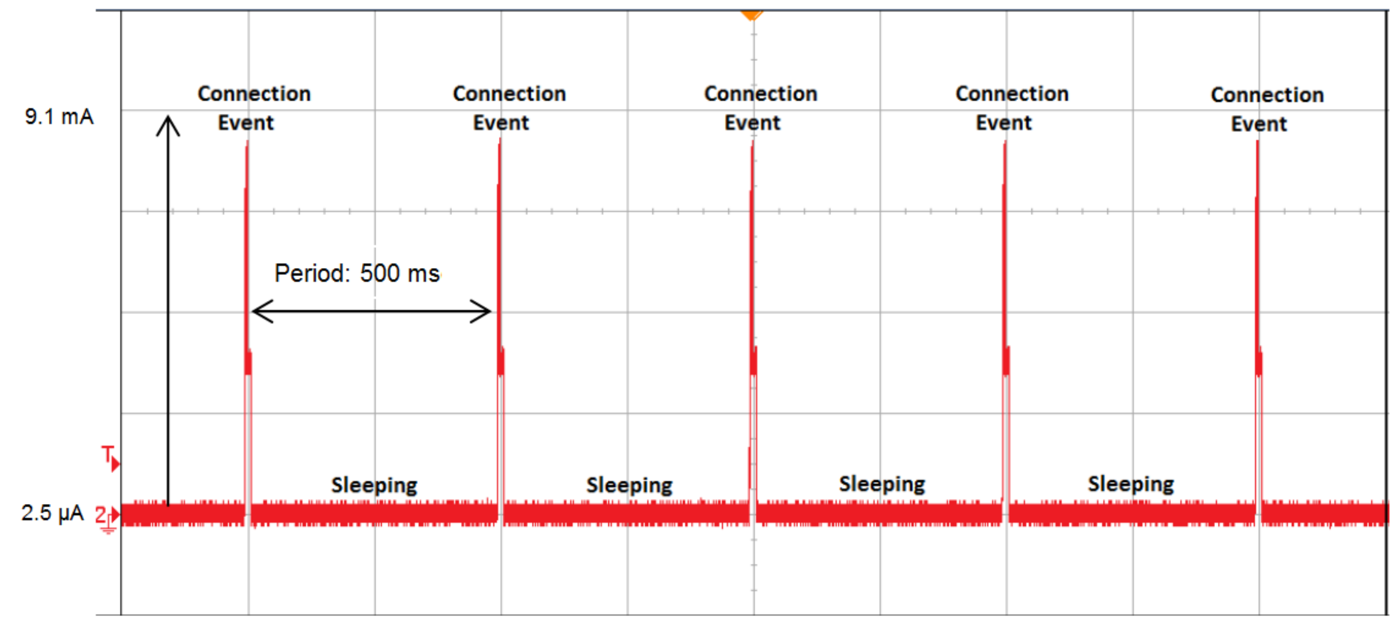
Sensors **2017**, *17*(4), 869



Block diagram of the interface between the MCU and the DC motor driver (**left**) and example motor current absorption curves (**right**)

IoT actuators

- A smart lock application

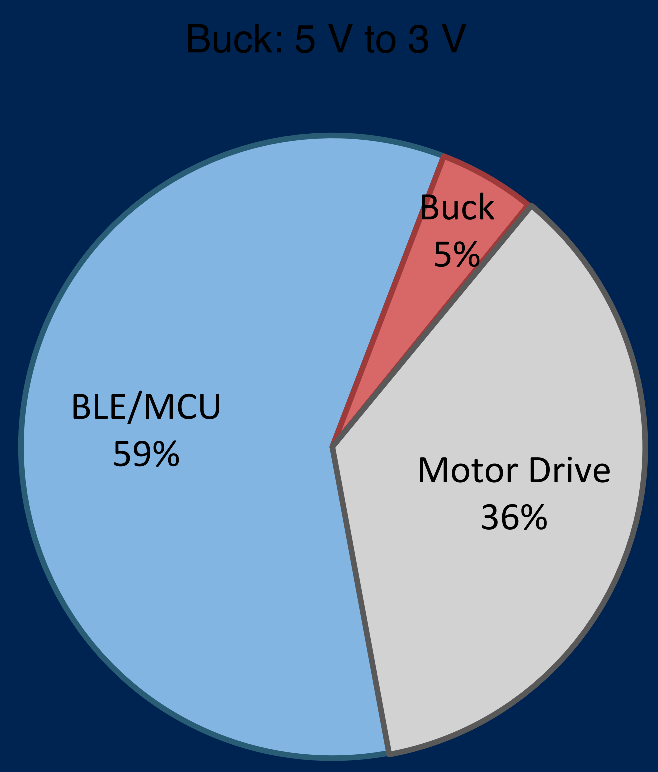


Current Consumption versus Time During *Bluetooth*® low energy Connections

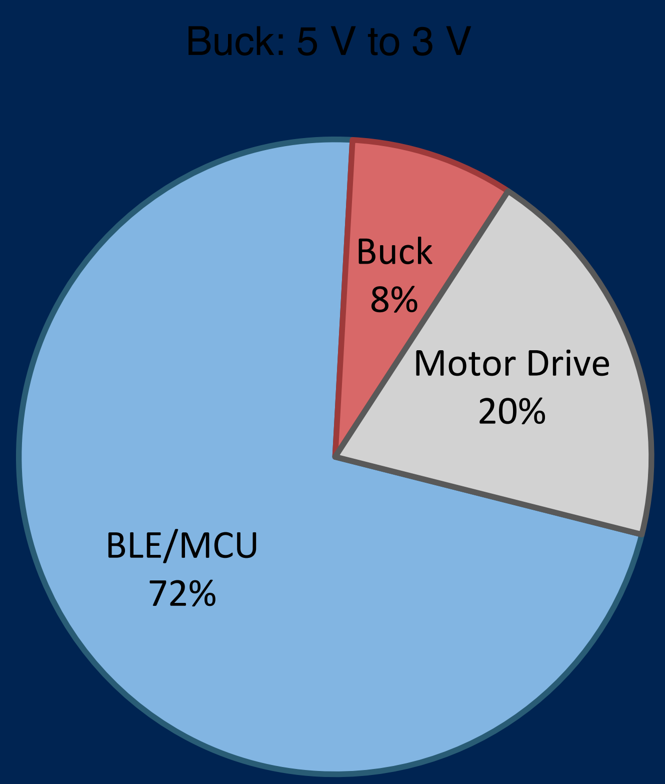
source: Smart Lock Reference Design Enabling More Than Five Years of Life on Four AA Batteries, Texas Instruments

Energy budget

- A smart lock application



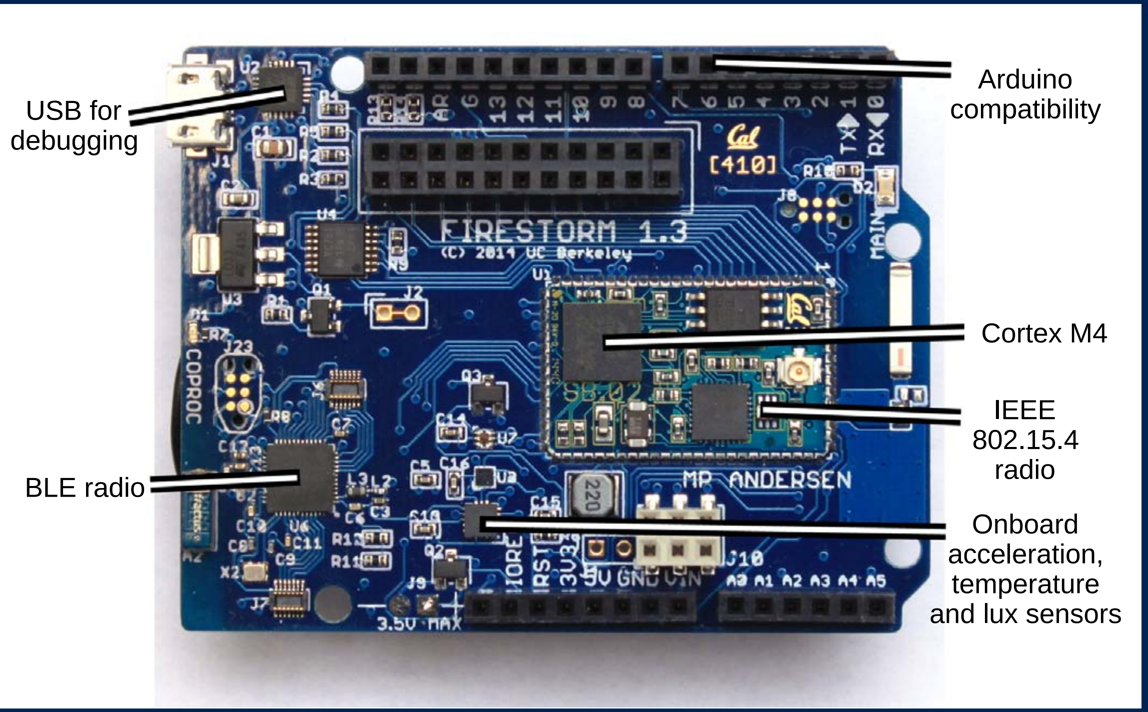
Power Consumption With 500 ms *Bluetooth*® low energy Connection Period, Using 24 Lock and Unlock Events



Power Consumption With 220 ms *Bluetooth*® low energy Connection Period, Using 24 Lock and Unlock Events

Low power IoT platforms

- Firestorm (UC Berkeley)
- Brings together: mobile, wearable, maker and WSN technologies



- Built around the Storm module:
  - 32 bit MCU
  - ARM Cortex-M4 that achieves 2.3µA idle current with a 1.5µS wake up time.

Andersen, M.P., and Culler, D.E.. “System Design Trade-Offs in a Next-Generation Embedded Wireless Platform ”. *UC Berkeley EECS Technical Report, UCB/EECS-2014-162*, 2013.

Low power IoT platforms

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Low power IoT platforms

Table 4: A small sample of available Cortex-M4 processors

Vendor	Device	f_{max}(Mhz)	SRAM(KB)	Flash(KB)	Sleep(μA)	Wake(μS)
NXP	LPC408x	120	96	512	550	240
STMicro	STM32F372xx	72	32	256	1.32	42.7
Silabs	EFM32WG990	48	32	256	0.95	2
Freescale	K20Dx	50	16	128	1.3	130
Atmel	**SAM4L**	**48**	**64**	**512**	**3**	**1.5**

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Table 5: Key metrics for select radio transceivers

Year	Vendor	Device	TX (dBm)	RX (dBm)	Wake (μs)	Sleep (μA)	TX (mA)	RX (mA)	CCA	AES	Auto ACK	Auto RE-TX
2013	Atmel	RF233	+4	-101	450	0.02	13.8	11.8	Y	Y	Y	Y
2007	Ti	CC2520	+5	-98	500	1	33.6	24.8	Y	Y	Y	N
2013	Freescale	MKW24D512V	+8	-102	-	-	18	19.5	Y	Y	-	-

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Table 7: Idle power comparison between a TelosB and a Storm

Voltage	TelosB μA	Storm μA
3.300	8.8	21.0
3.000	7.1	13.8
2.700	5.7	7.2
2.400	-	3.8
2.100	-	2.6
1.800	-	2.3

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Table 8: Benchmark power comparison results. The bold line indicates the anticipated common configuration

Device	Supply (V)	CFG	Freq (Mhz)	Run time (μS)	Current (mA)	Energy (μJ)	Percentage
TelosB	3.3	-	4	712.7	2.29	5.386	100%
Storm	3.3	LDO	4	393.0	1.049	1.360	25%
Storm	3.3	BUCK	4	393.5	0.501	0.651	12%
Storm	1.8	LDO	4	393.7	0.896	0.634	11%
Storm	3.3	LDO	48	32.8	13.625	1.479	27%
Storm	**3.3**	**BUCK**	**48**	**32.9**	**8.602**	**0.934**	**17%**
Storm	1.8	LDO	48	32.9	13.124	0.777	14%

Andersen, M.P., and Culler, D.E.. "System Design Trade-Offs in a N
EECS-2014-162, 2013.

Low power IoT platforms

- OpenMOTE
- TI CC2538 SoC
- Industrial IoT target
- Low power synchronous communication (IEEE 802.15.4-2015 TCSH (Time synchronised channel hopping) MAC)
- IPv6 connectivity support

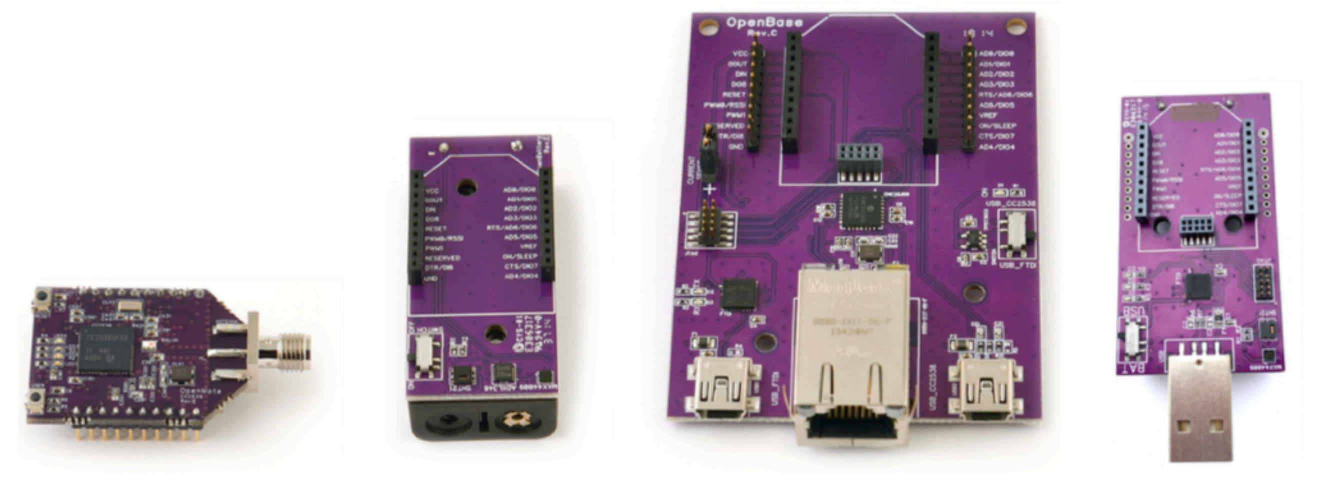


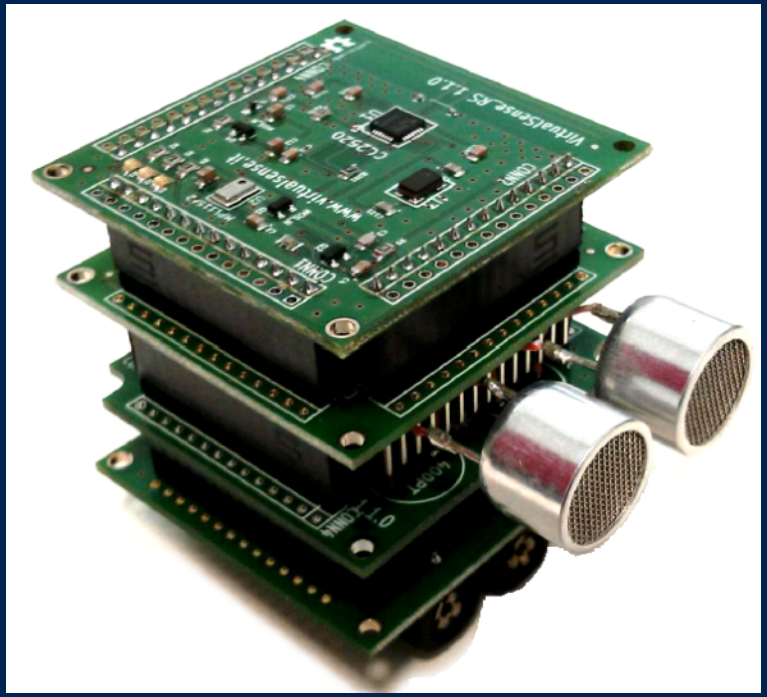
Fig. 2. The OpenMote hardware ecosystem: (from left to right) OpenMote-CC2538, OpenBattery, OpenBase, OpenUSB.

- 32-bit ARM Cortex-M3 micro-controller
- 32 kB of RAM memory and 512 kB of flash memory
- Radio transceiver compliant with the IEEE802.15.4 standard (-97 dBm sensitivity level, transmit power up to +7 dBm, current consumption 20 mA in receive mode, transmit current is 24 mA at 0 dBm)

Vilajosana, X., Tuset, P., Watteyne, T., and Pister,.K. “OpenMote: Open-Source Prototyping Platform for the Industrial IoT”, *International Conference on Ad Hoc Networks,* 2015.

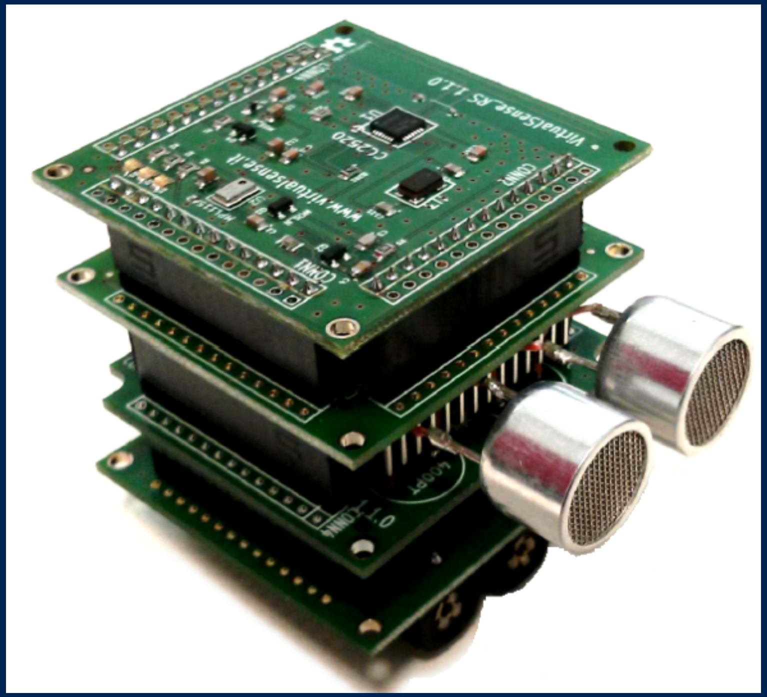
Low power WSN platforms

- VirtualSense (UniUrb)
  - Ultra low power platform
  - Ideal for energy harvesting WSNs
- Features
  - Dynamic power management
    - MCU: TI MSP430F5418a
    - RF transceiver: CC2520
  - Wake-up receiver
  - Java-compatible
- Currently migrating to 32bit



Raza, U., Bogliolo, A., Freschi. V, Lattanzi, E., Murphy, A.L., “A two-prong approach to energy-efficient WSNs: Wake-up receivers plus dedicated, model-based sensing “, *Ad Hoc Networks*, 2016

Low power WSN platforms



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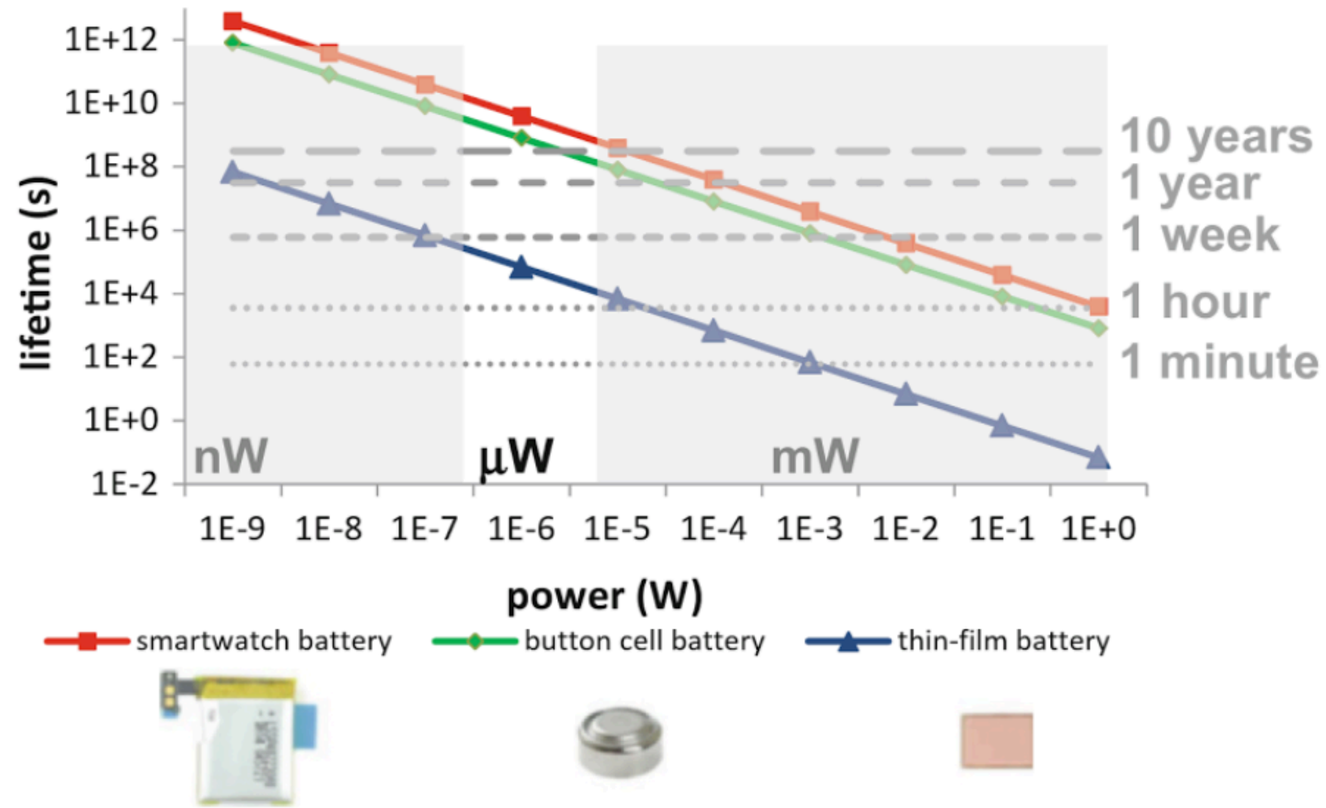
- Features
  - Dynamic power management
    - MCU: TI MSP430F5418a
    - RF transceiver: CC2520
  - Wake-up receiver
  - Java-compatible
- Currently migrating to 32bit
- Power consumption
  - Active: 13mW (processing), 66mW (transmission)
  - 14.67µW (standby), 25ms transition time to active
  - 1.32µW (sleep), 25ms transition time to active
  - 0.36µW (hibernation), 500ms transition time to active

Raza, U., Bogliolo, A., Freschi. V, Lattanzi, E., Murphy, A.L., "A two-prong approach to energy-efficient WSNs: Wake-up receivers plus dedicated, model-based sensing ", *Ad Hoc Networks*, 2016

IoT nodes energy budget



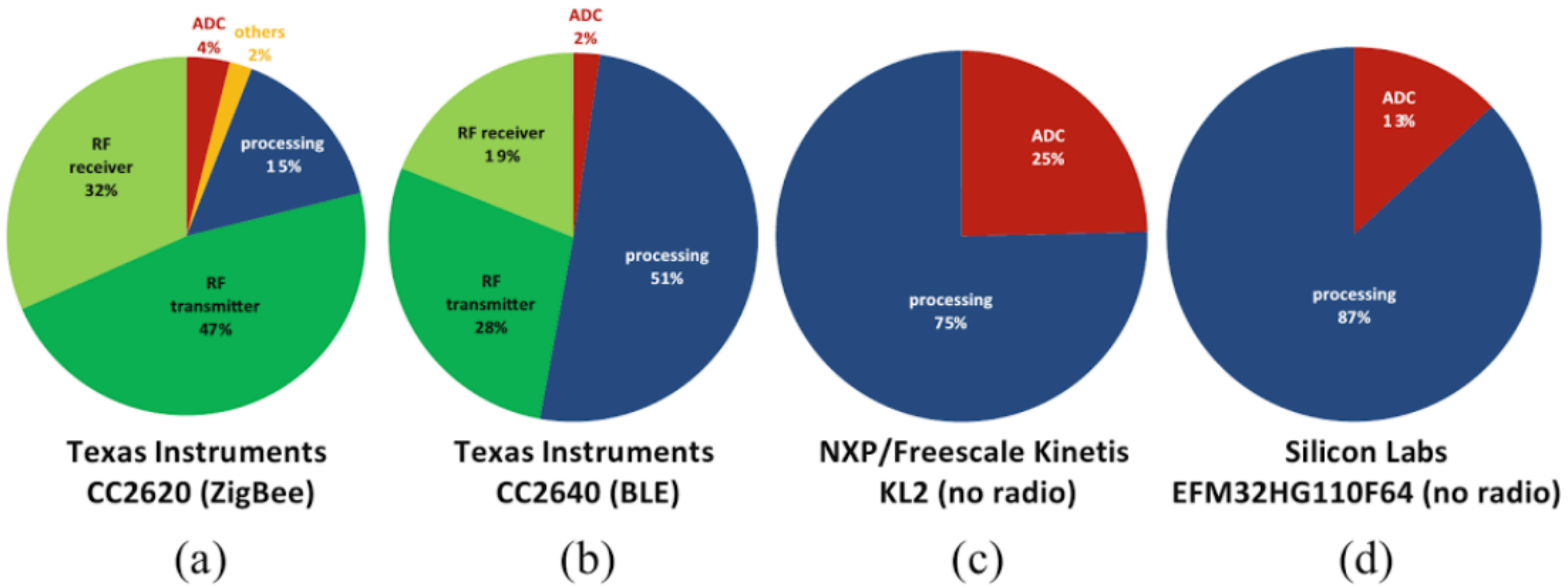
type	cost	capacity	volume	energy density
GH43-03992A	30$	300 mAh	2,400 mm^3	0.12 mAh/mm^3
LR44	<1$	150 mAh (non-rechargeable)	500 mm^3	0.28 mAh/mm^3
Cymbet CBC005	0.2$	5 µAh	0.7 mm^3	6.5 $\mu Ah/mm^3$

Lifetime vs. average power consumption for different batteries

- Self-leakage and ageing neglected

source: M. Alioto (University of Singapore) *Enabling the Internet of Things,* Springer 2017

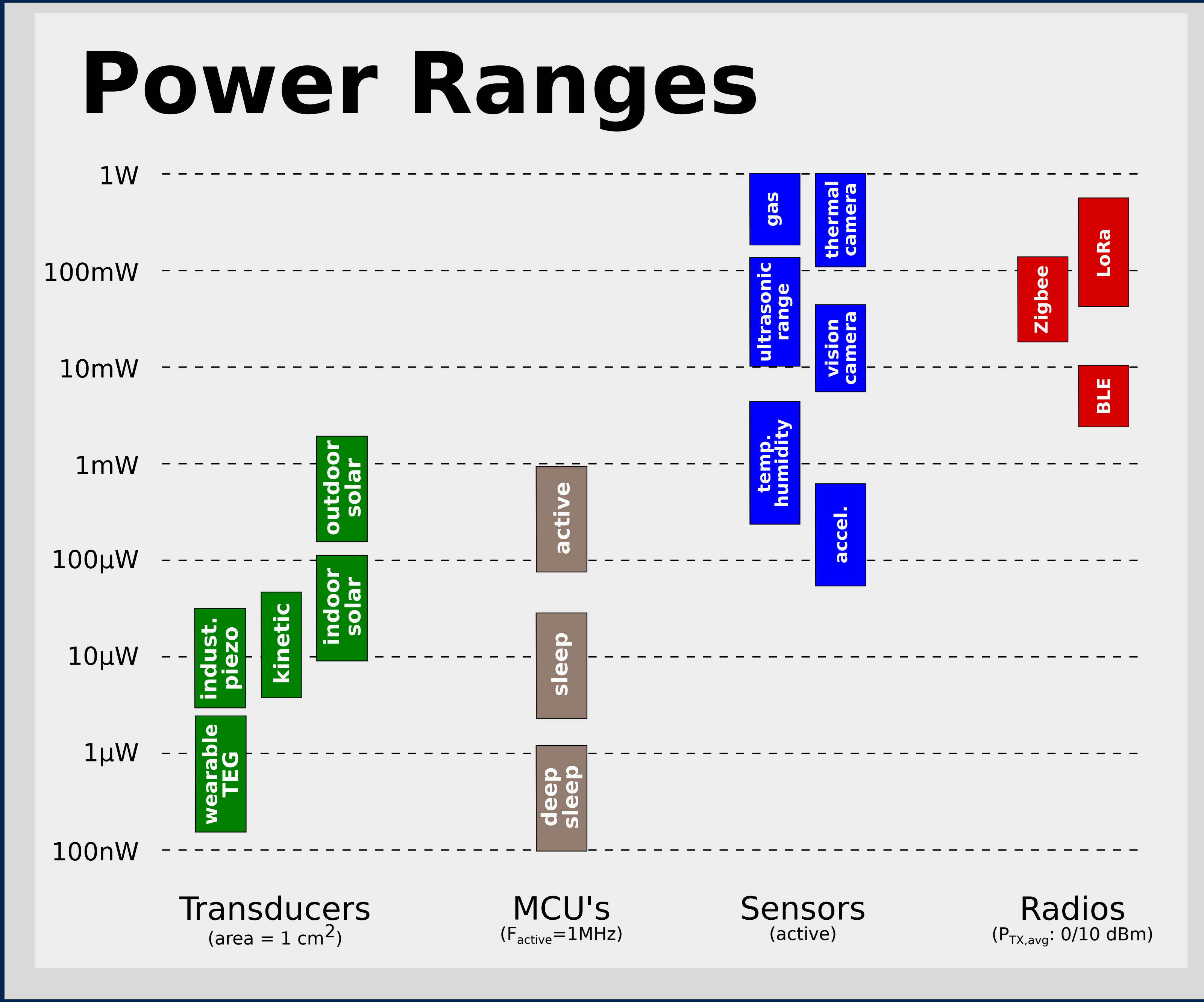
IoT nodes energy budget



Power breakdown of commercial motes (*on the left*) and MCUs (*on the right*)

source: M. Alioto (University of Singapore) *Enabling the Internet of Things,* Springer 2017

IoT nodes energy budget



source: Gomez, A., Benini, L., and Thiele, L., Designing the Batteryless IoT, *Proc. IEEE DATE conference*, 2017

Energy consumption reduction

- The target of reducing energy consumption of IoT devices can be achieved at different levels
  - Novel hardware low power solutions (leakage reduction, power gating, hierarchical methods, etc.)
  - Dynamic voltage and frequency scaling
  - Dynamic power management —> low power states (event based wake-up in distributed embedded systems)
  - Data compression/reduction (computation vs. communication)

Energy consumption reduction

- Communication is (often) the most power hungry component
- How can we deal with it?
  - Ultra low power devices
  - novel (network stack) solutions (MAC, routing, etc.)
  - design smarter algorithms that reduce communication requirements

Conclusions

- IoT is a emerging technology with increasing potential applications
- Many opportunities to be taken and challenges to be faced
- Energy efficiency is one of the most important
- Issues and challenges must be tackled at many levels

Conclusions

- Thank you for the attention
- Any question?