Rise of Battery-less IoT

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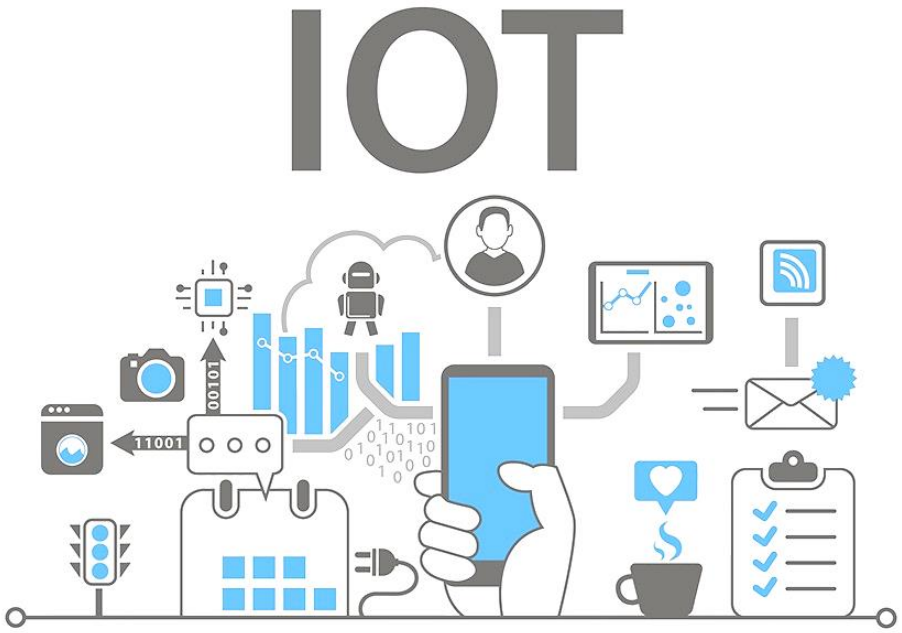
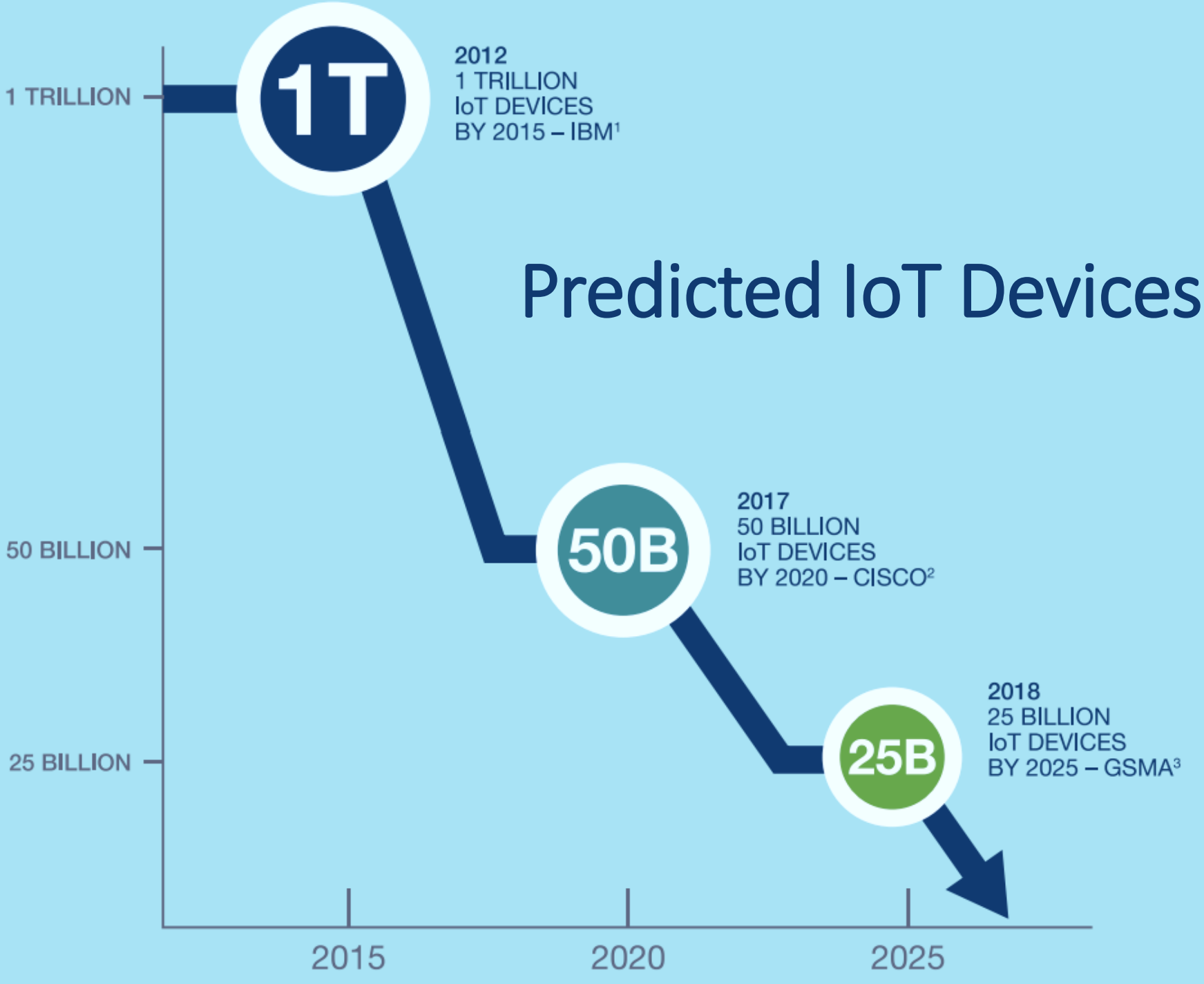
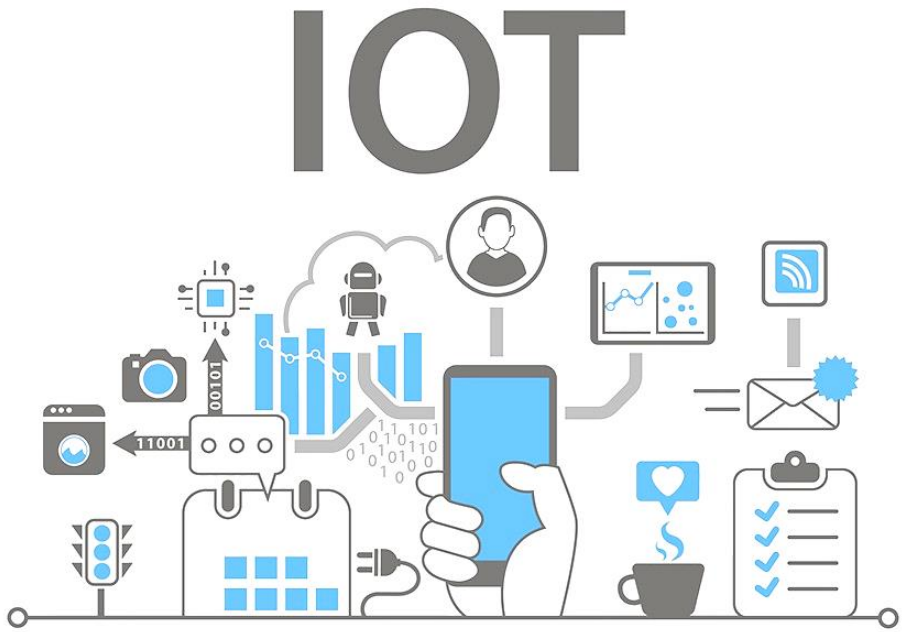


Predicted IoT Devices

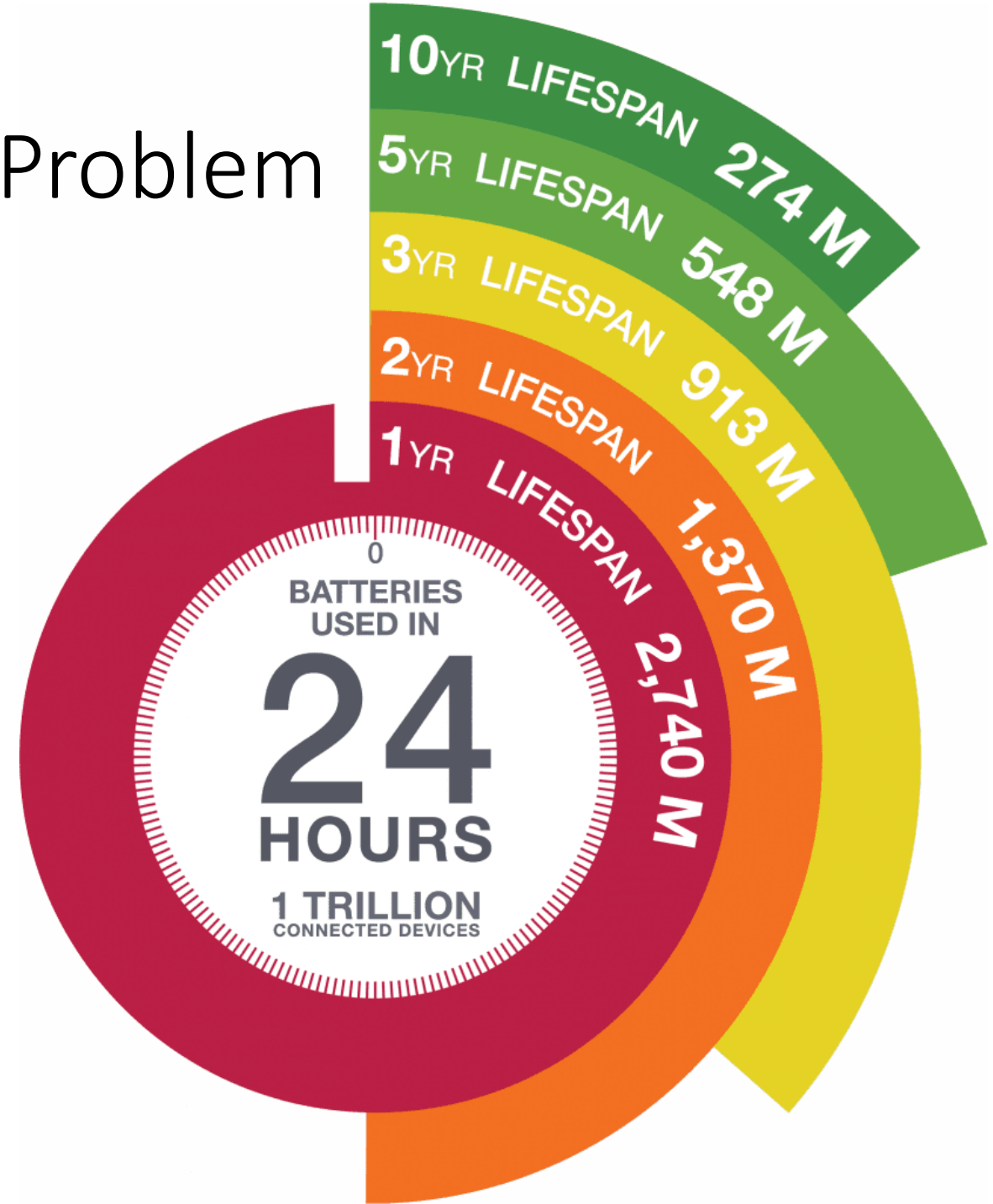


Batteries!



Challenges with batteries in IoT

The Trillion Battery Problem



 Trillion Battery Problem

"The cost of getting to a remote sensor to change a battery is often much higher than the cost of the battery itself"

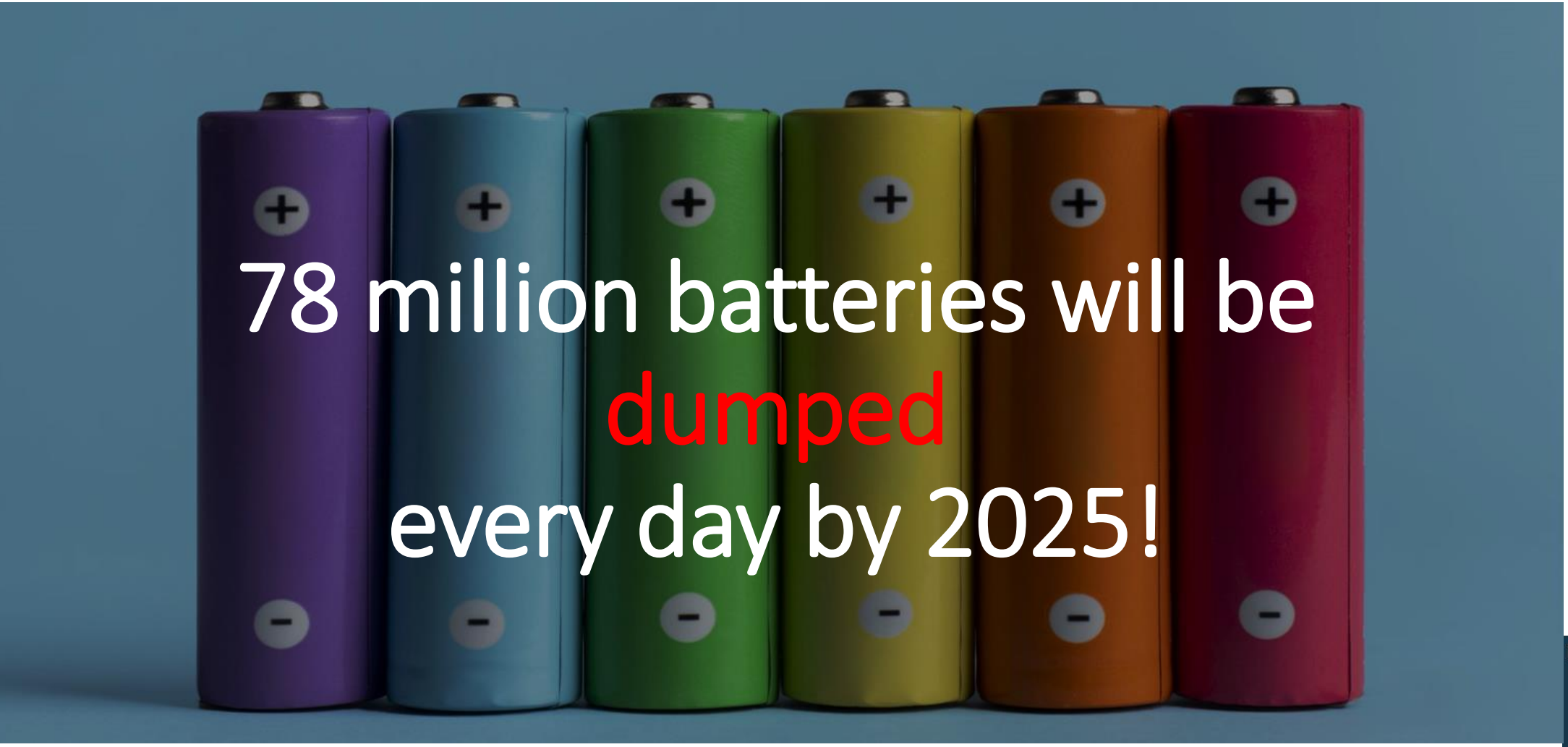
Impractical to Scale and Maintain!

Real costs of batteries

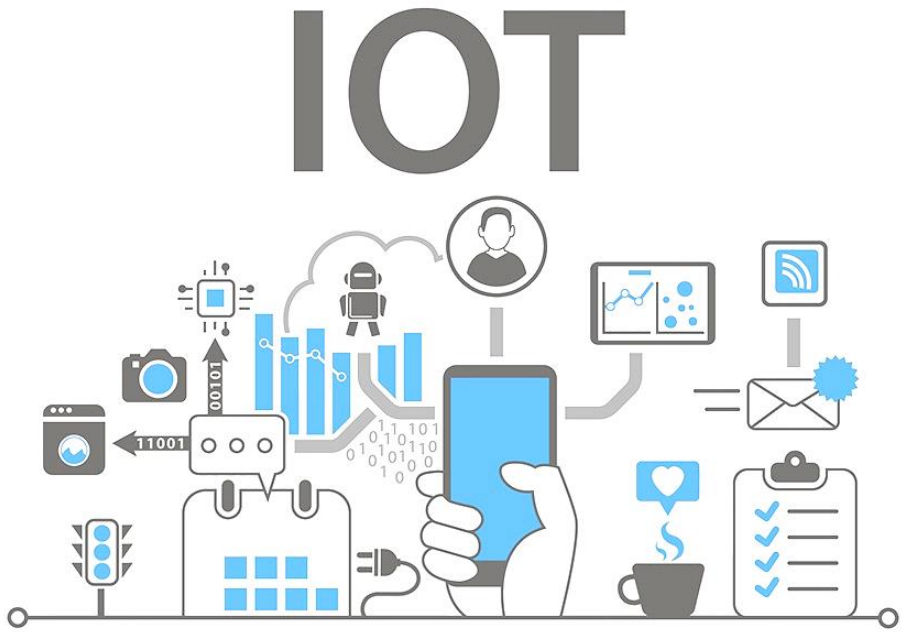
Size Matters!

- Battery limitations restrict device placement and functionality
- To increase lifespan, devices are often configured to transmit data less frequently

Environmental Challenge



 78 million batteries



Solution?

Go Battery-less!

Switch to Battery-less, self-powered IoT using ambient Energy Harvesting

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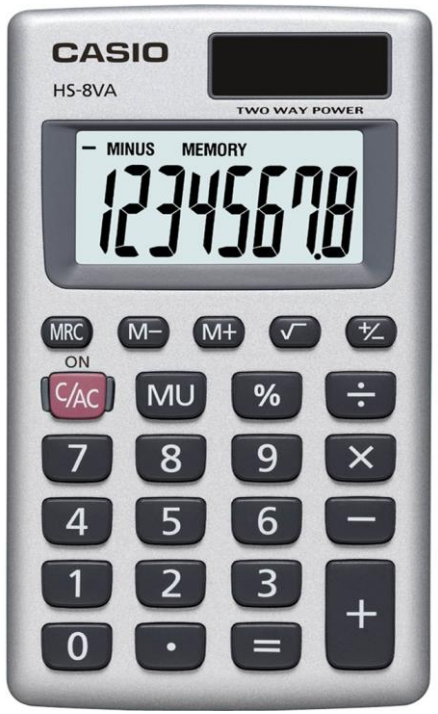
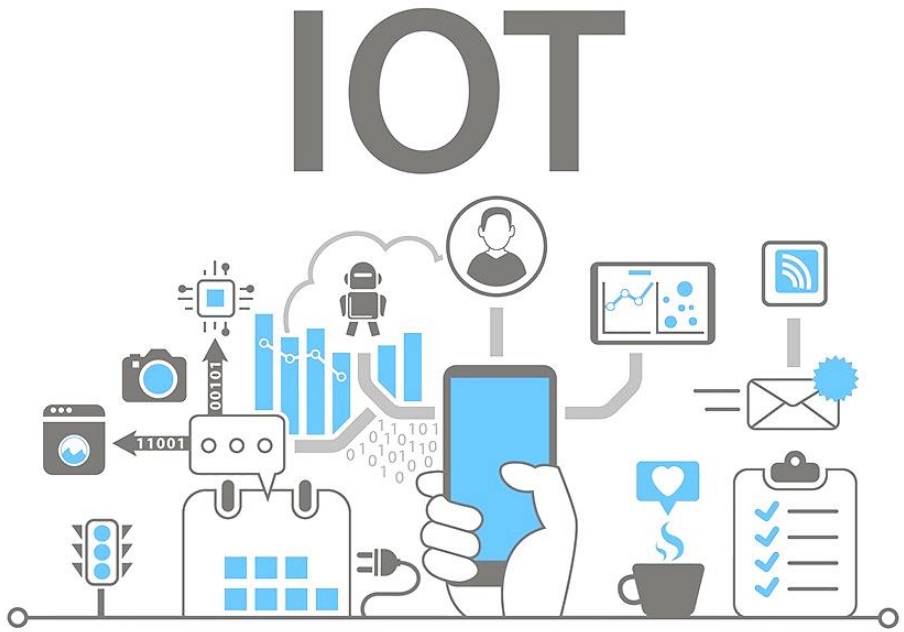
Energy Harvesting?

First observation: 1826!





Energy Harvesting Techniques

Energy Harvesting Techniques

Photovoltaic (PV)

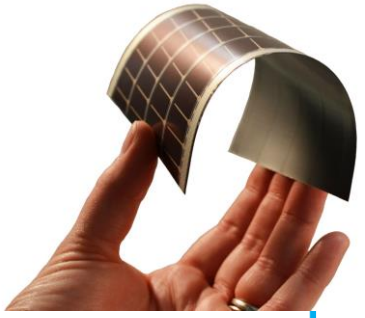
Thermal

Mechanical

Radio Frequency (RF)

Photovoltaic (PV) Harvesting

- Where there is light, there is Energy!
- Many examples in commercial products today – also being added into beacons, sensors, and tags for IoT applications
- PV is not just about silicon anymore - new technologies like dye-sensitized and organic materials are viable options
- Features like flexible substrates and custom form factors make adding PV to existing applications easier



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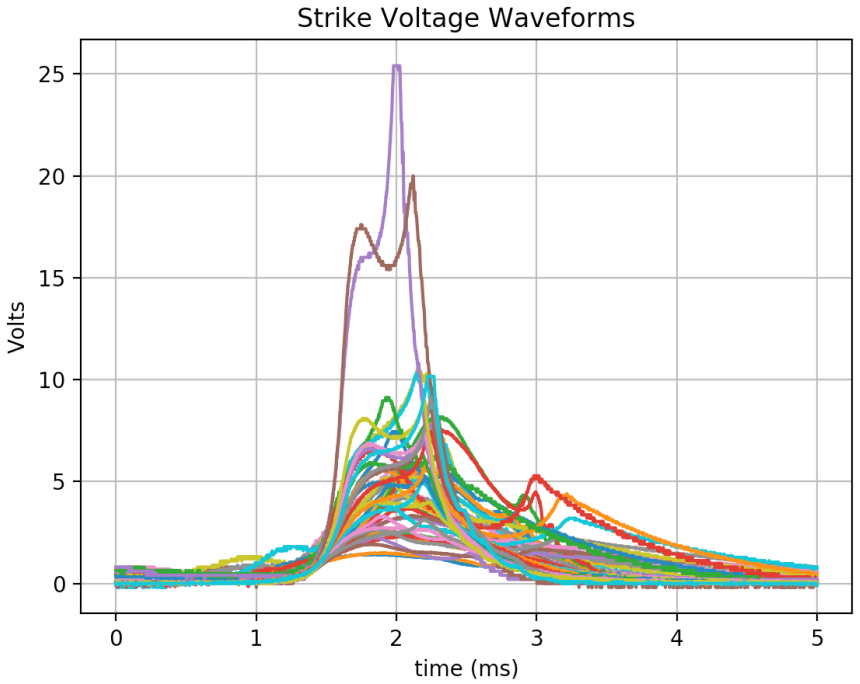
How much energy can you harvest?

Light Level (lux)	**Harvested Energy** ($\mu W/cm^2$)	**Conditions**
100	3-10	Dim Indoor
200	7-20	Residential
500	20-45	Office
1000	35-90	Bright Office, Retail, Overcast day
20K	2-4K	Full Daylight
100K	15-20K	Direct Sunlight

Energy harvested varies based on PV cell technology and optimal performance range

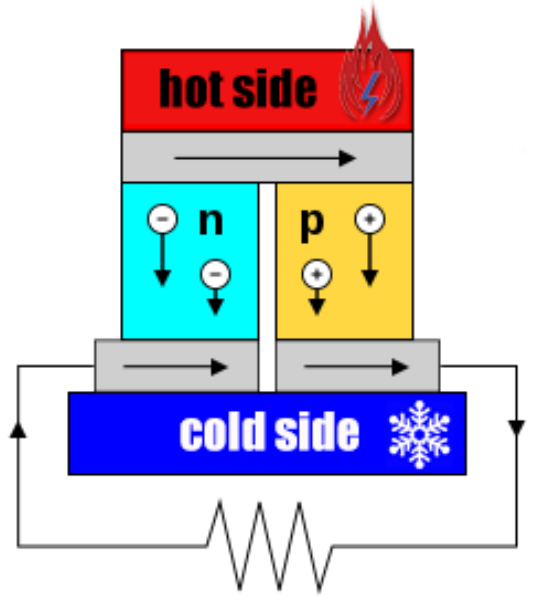
Mechanical Harvesting

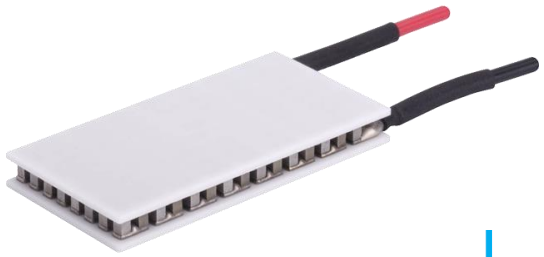


- Mechanical energy harvesting rely on either piezoelectricity or electromagnetism to create a burst of energy
- IoT Wireless switches use the motion of a magnet through a coil to convert mechanical to electrical energy
- Actual amount of energy harvested is in 100s of µW – enough power for multiple wireless transmissions

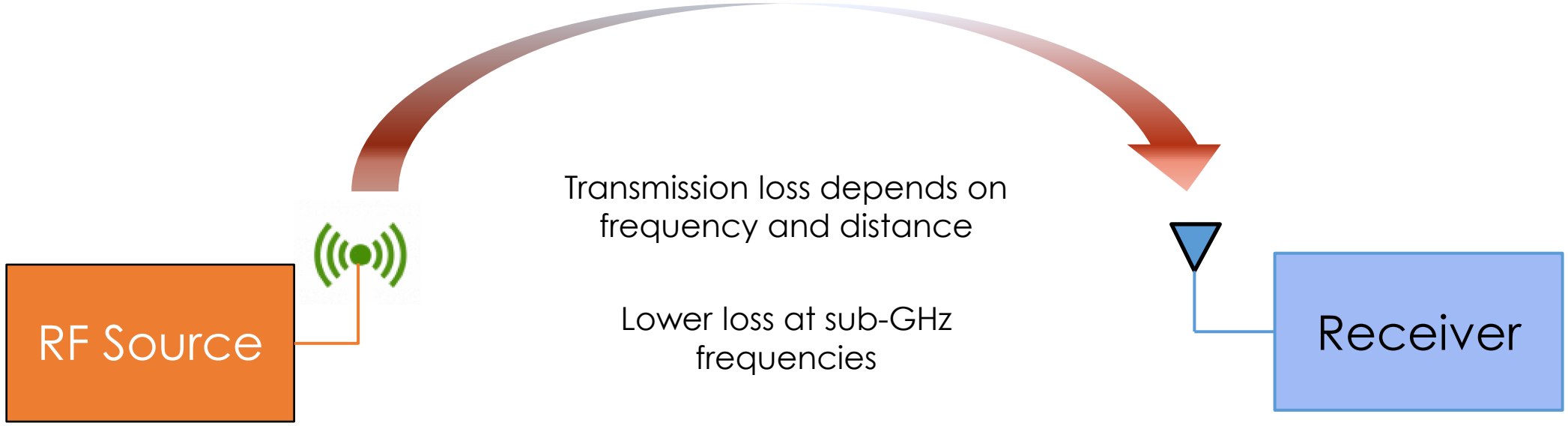
Thermal Harvesting

- Thermo-Electric Generator (TEG) requires a temperature gradient to generate electricity
  - Heated electrons to flow from hot to cold side of the TEG
  - Heat sinks increase cold side thermal dissipation
- Thermal sources may be human body, HVAC Air Flow, Machinery
  - Amount of energy generated based on TEG size and temperature gradient
  - 0.25 in^2 TEG generates ~100 µW from finger touch (+5 $\Delta T\ ^oC$)
- Applications
  - Fitness Bands and Smart Watches
  - Wearables/Tracking Beacons
  - Remote Sensing/Environmental Monitoring





RF Harvesting

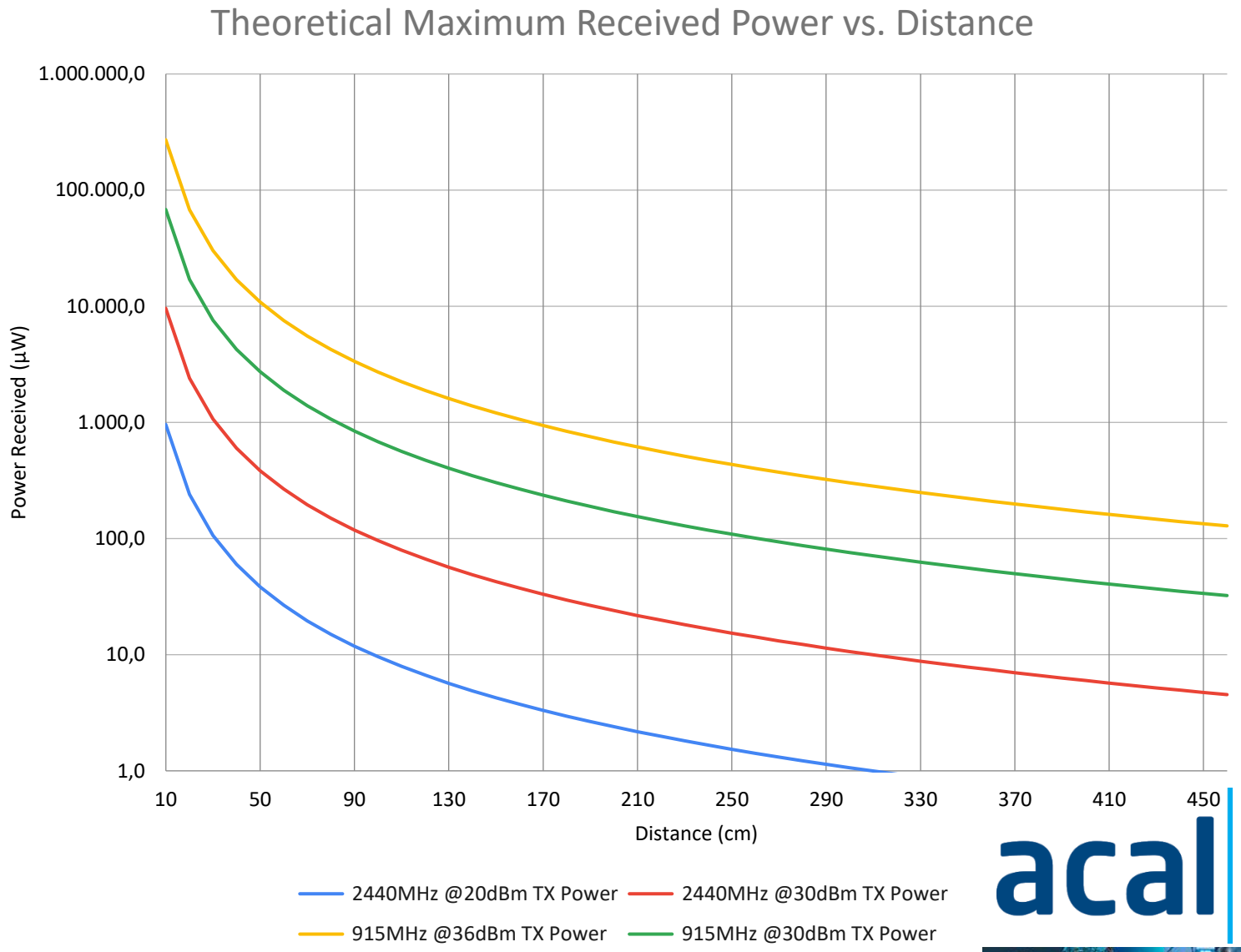


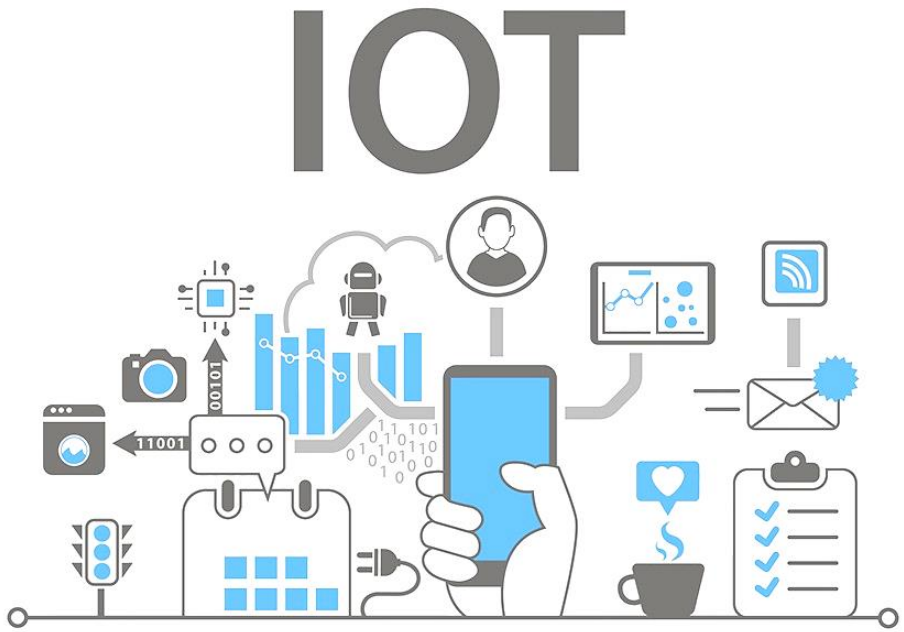
Regulatory considerations define available frequency bands and maximum output power

Harvested power available depends on sensitivity of receiver, efficiency of both harvester and energy storage

RF Harvesting

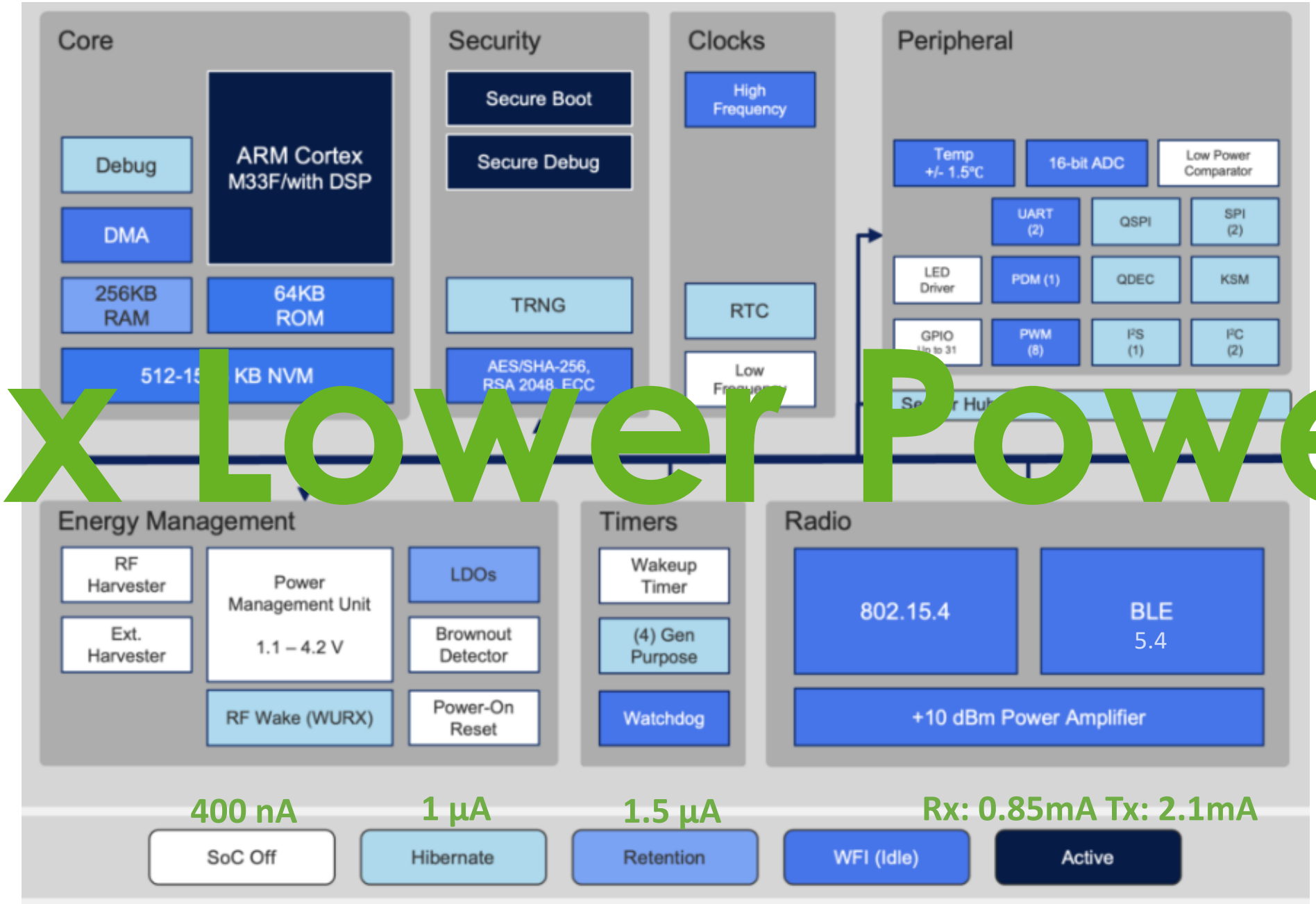
- For 2.4 GHz, not much energy (<100µW) available beyond 1m
- Sub GHz bands provide energy out past 2-3m





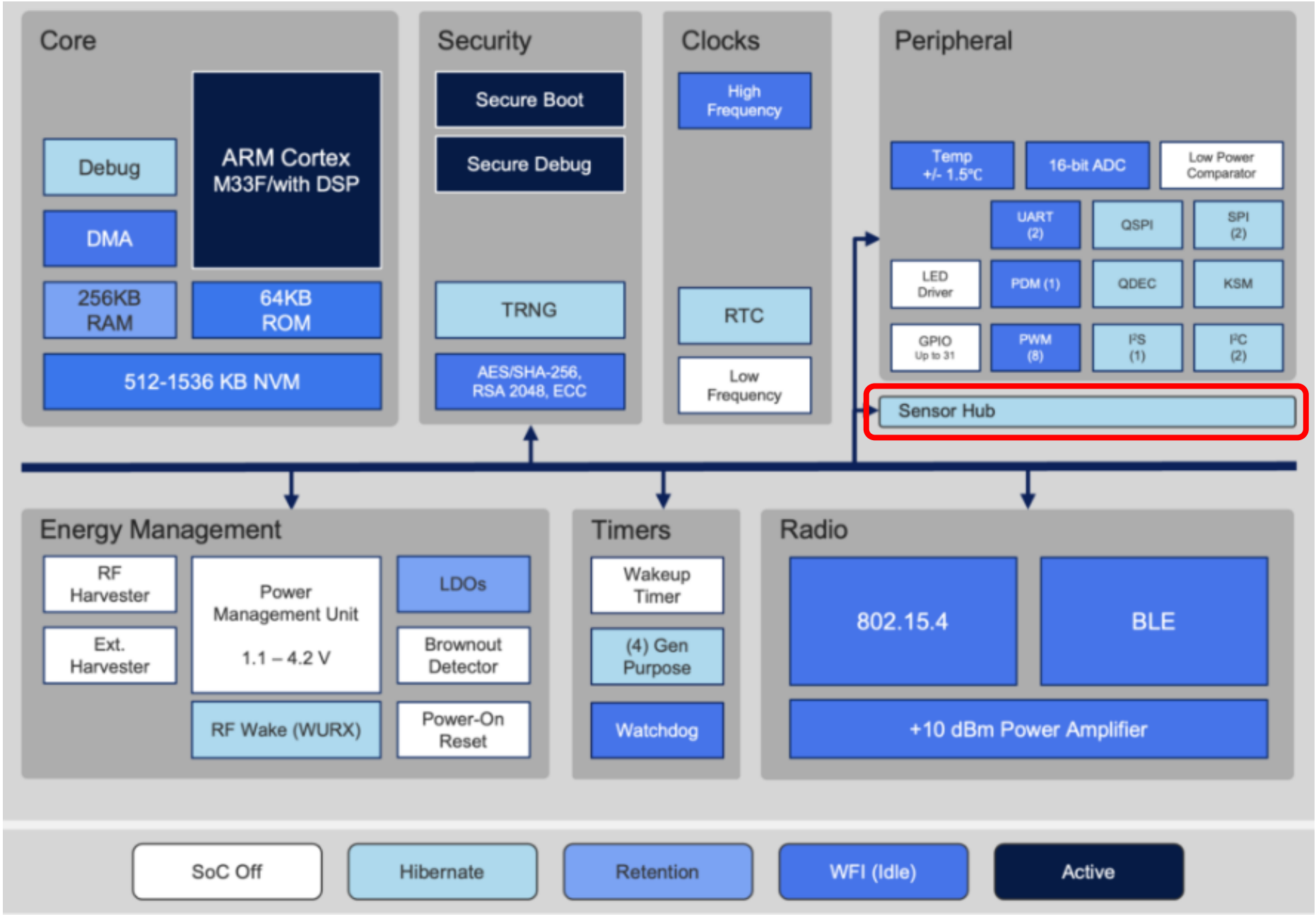
Ultra-low Power Consumption SoC

Architecture BLE SoC

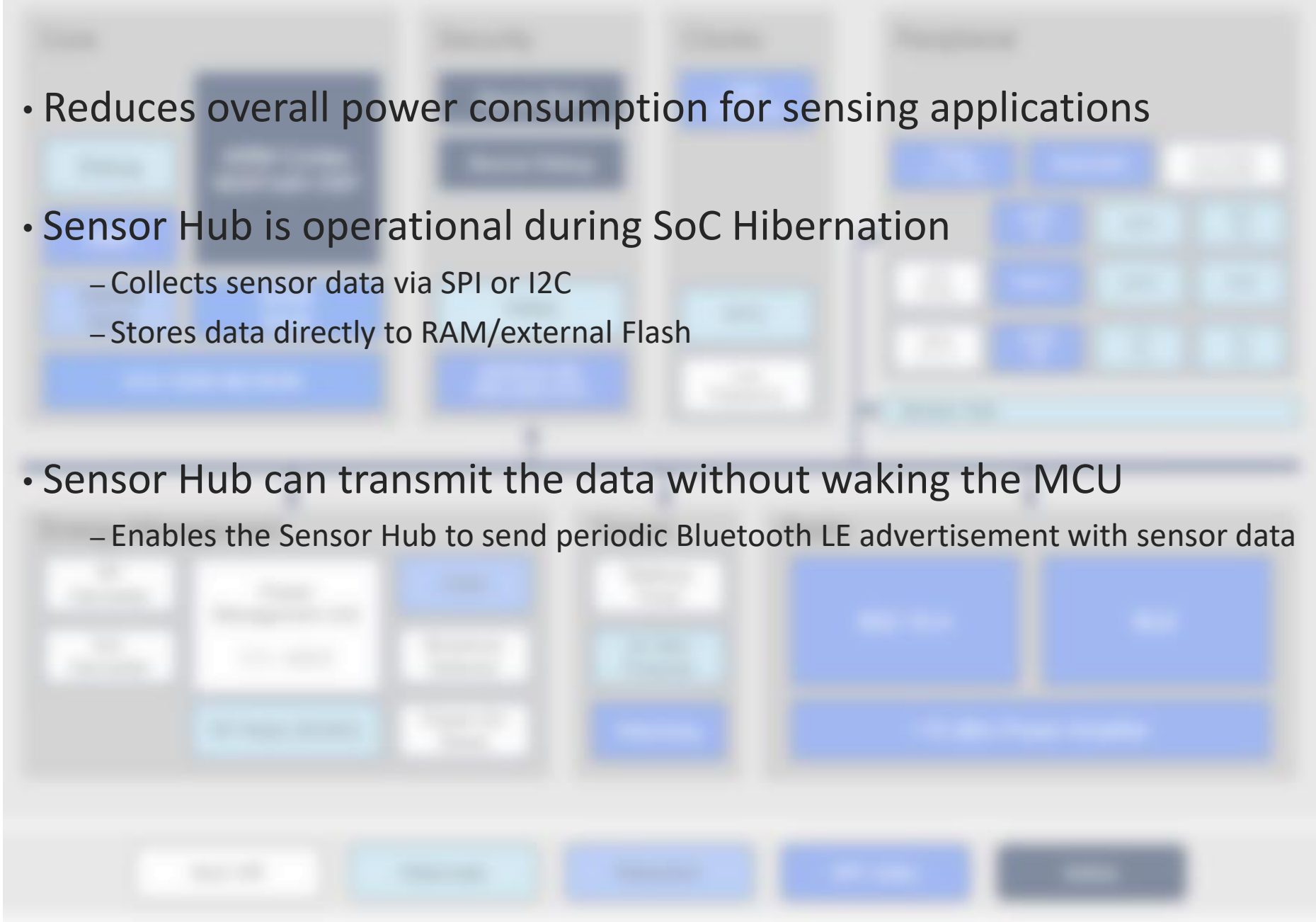


4x Lower Power!

Sensor Hub

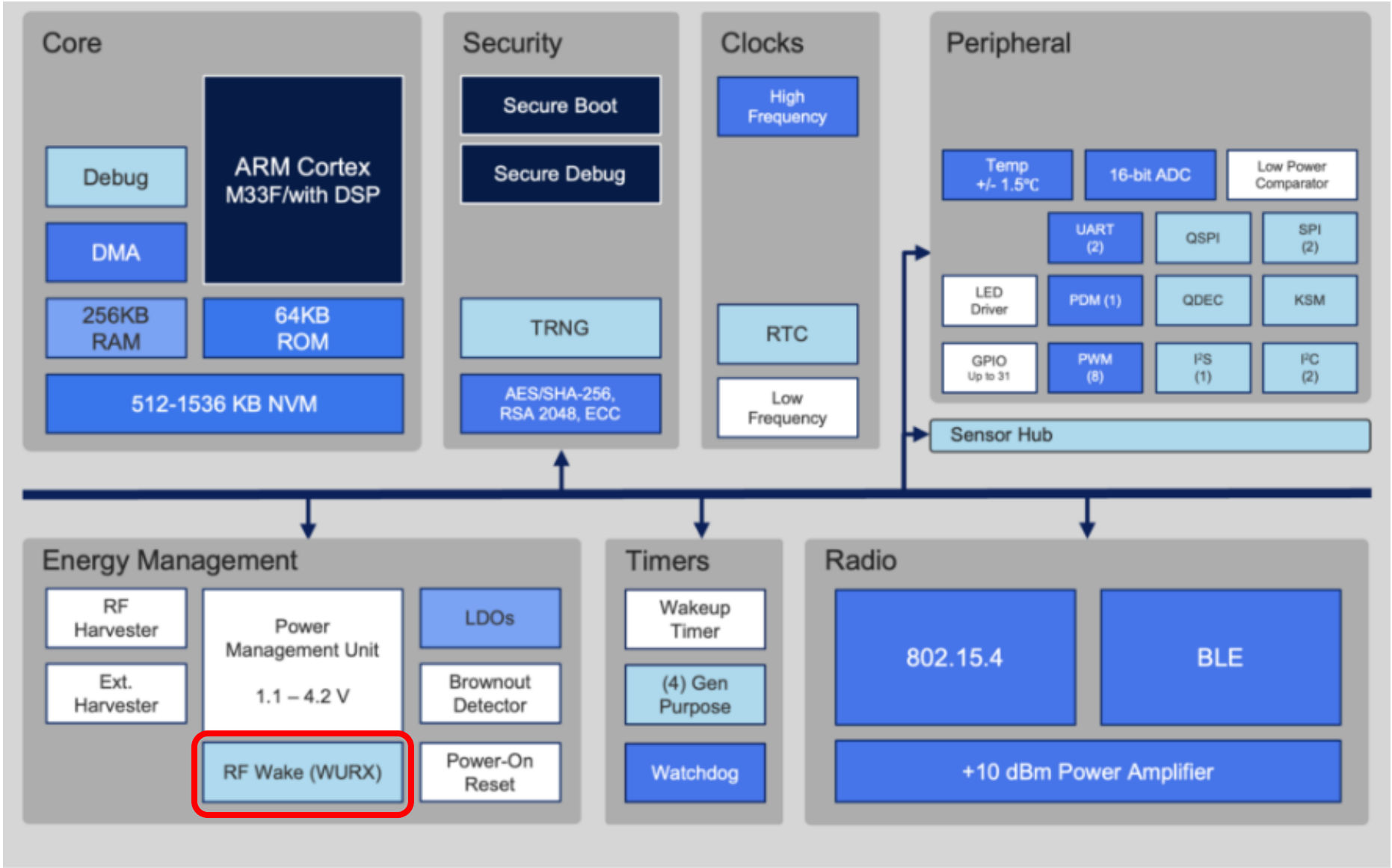


Sensor Hub



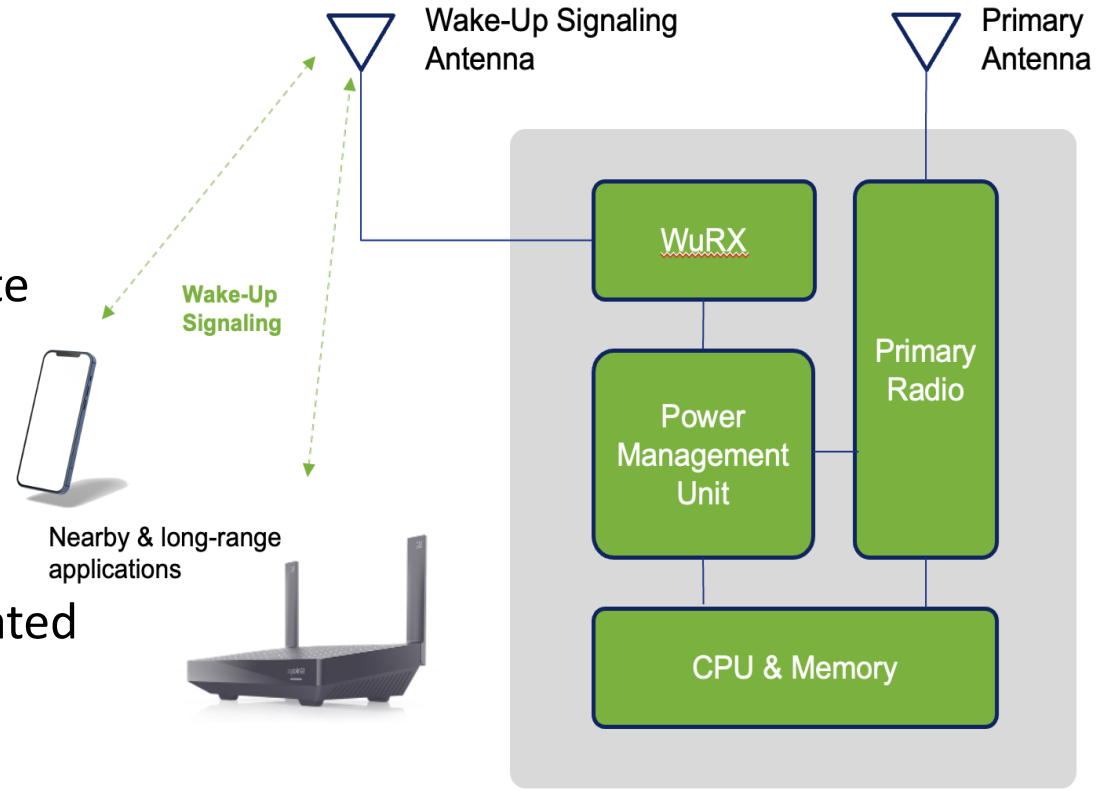
- Reduces overall power consumption for sensing applications
- Sensor Hub is operational during SoC Hibernation
  - Collects sensor data via SPI or I2C
  - Stores data directly to RAM/external Flash
- Sensor Hub can transmit the data without waking the MCU
  - Enables the Sensor Hub to send periodic Bluetooth LE advertisement with sensor data

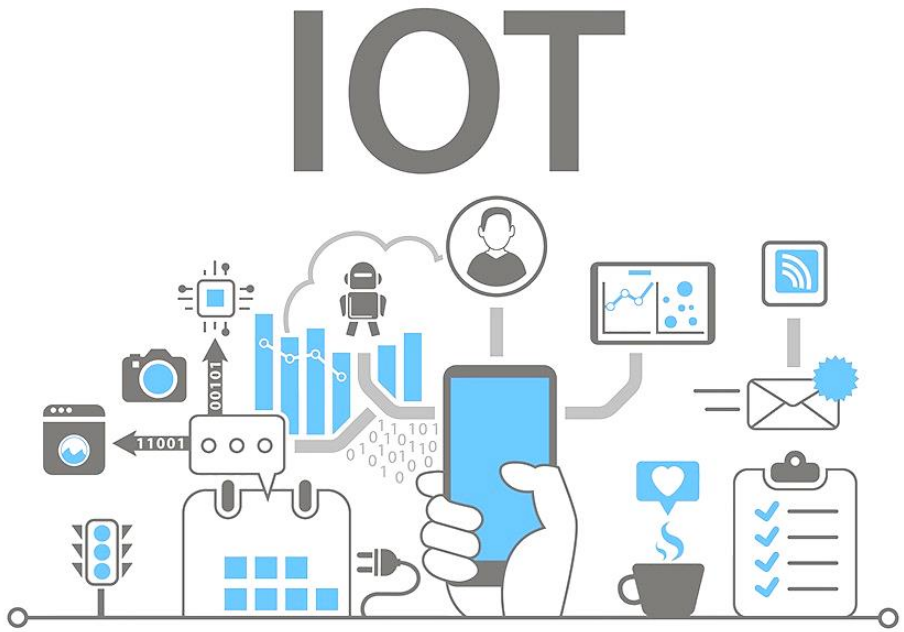
Wake on RF



Wake on RF

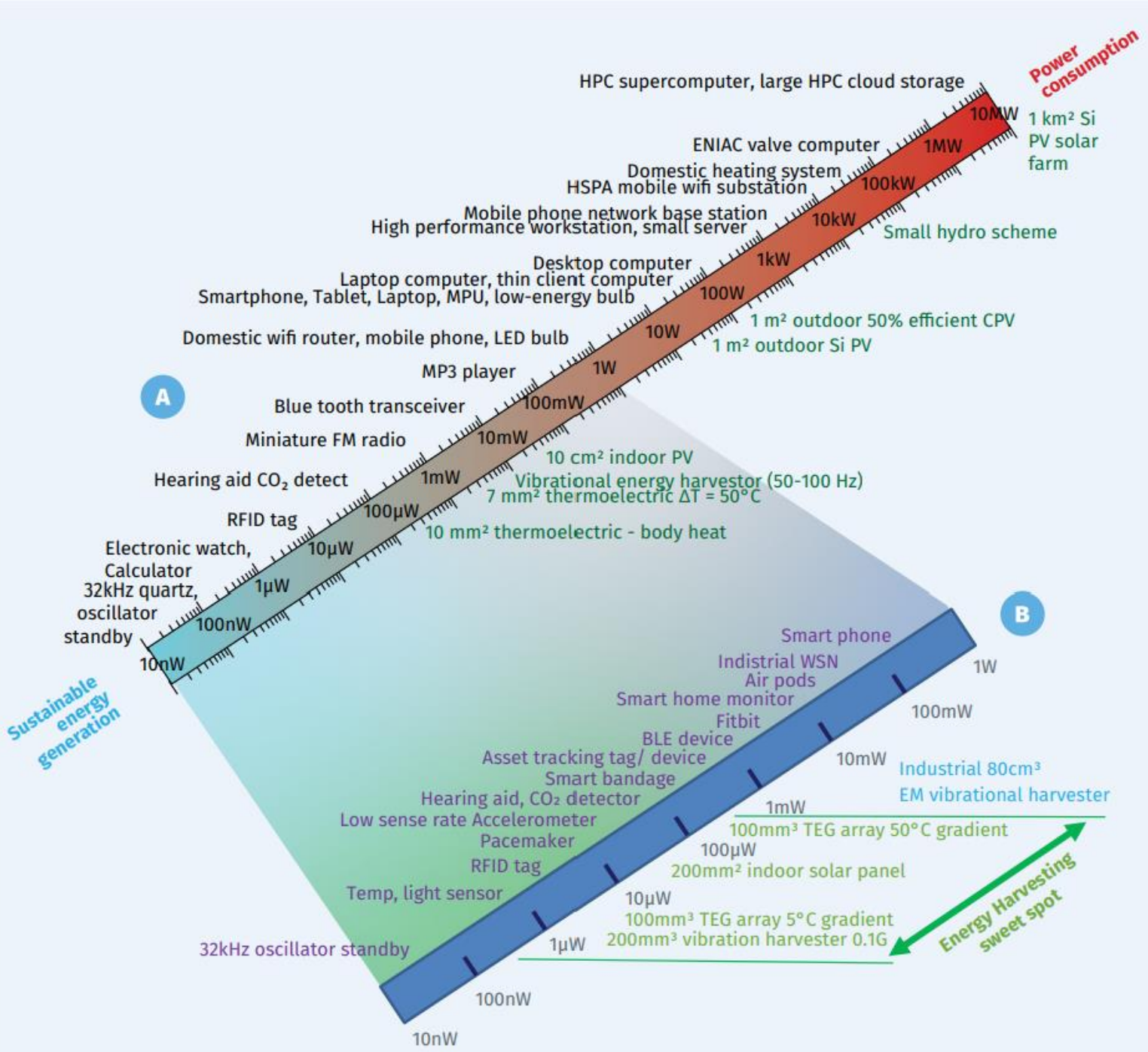
- Facilitates on-demand or infrequent wakeup applications
- Separate wideband receiver enabled while chip is in hibernate
  - Input frequency 400 MHz to 2.5 GHz
  - Consumes only 300nA additional power
- Wakeup signal from mobile phone, tablet, gateway, or dedicated hardware
  - Use BT (inquiry), iBeacon, or non-BLE signaling
  - OOK detection in receiver
  - Individual device or group addressing supported





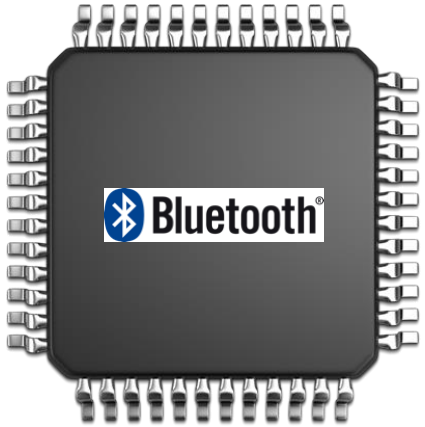
Outcome

Sweet Spot



Changing the Power Equation

ULTRA–LOW POWER



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ENERGY HARVESTING

ENERGY STORAGE

YOUR PRODUCT

+	Capacitor	=	**Battery Free**
+	Standard Battery	=	**Extended Battery Life**
+	Rechargeable Battery	=	**Batteries Last Forever**

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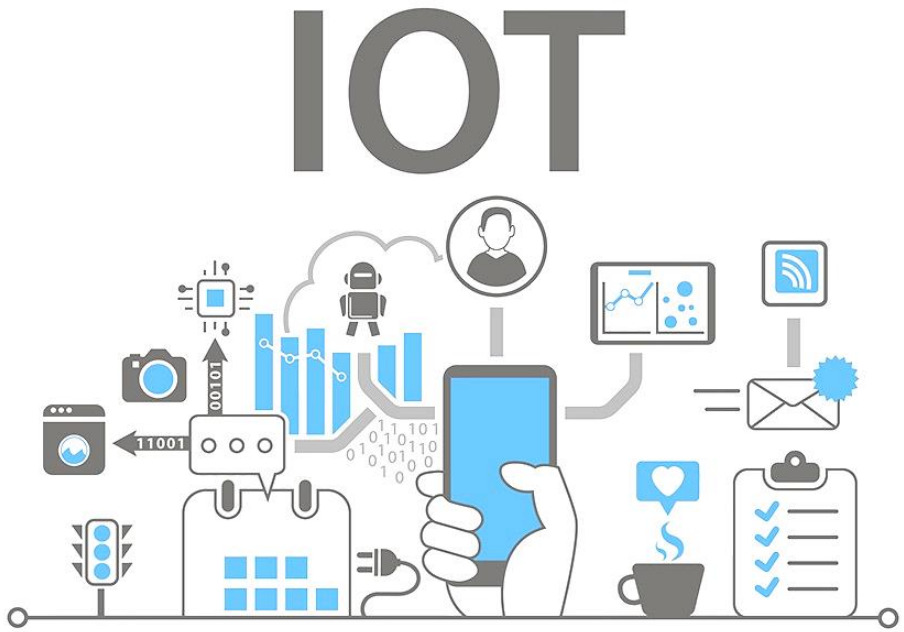


Applications

Energy Harvesting Methods and Applications

RF

Asset Tracking/Tags

TV Remote

Keyboard

ESL

Beacons

Sensing

Wearables

Light

Switch/Control

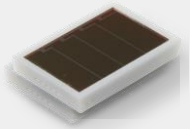
Motion

Thermal

Applications

Remote Controls

Tags and Tracking



Electronic Shelf Labels

Human Interface Devices

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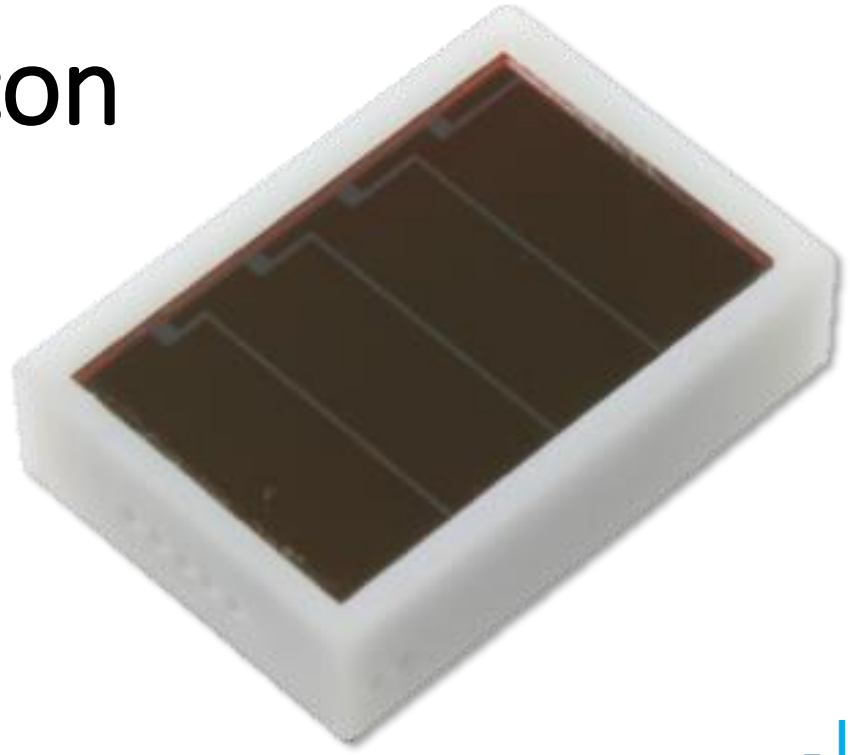
Demo: Battery-less PV BLE Beacon

To demonstrate how the energy harvesting capabilities can use indoor lighting conditions to implement fully battery-free beacon designs.



Acal BFi: Stand 15

Thank you

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