2 Days Training on

IoT Architecture and Simulation using ns-3

CHAPTER 3 – Sensors, Endpoints and Power Systems

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Introduction

- The Internet of Things (IoT) begins with sources of data or devices that perform an action.
- These we call endpoints, and they are the things associated with the internet.
- These sources are sensors outputting a stream of time-correlated data that must be transmitted securely, possibly analyzed, and possibly stored.
- For an architect, it is critical to understand the data as well as how the data is interpreted.

Sensing Devices

- Thermocouples and Temperature sensing.
  - Thermocouples
  - Resistance Temperature Detectors
  - Thermistor

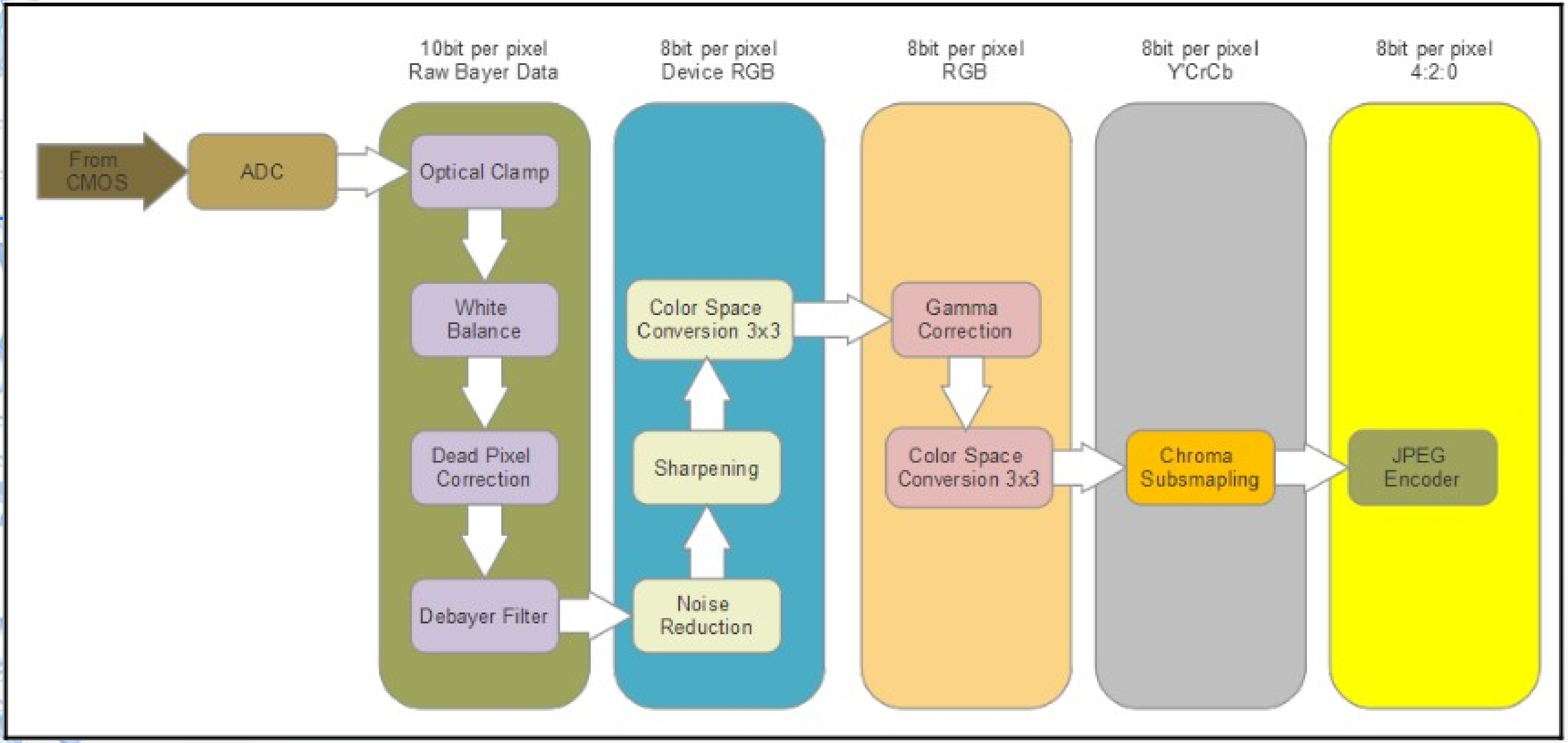
Category	Thermocouples	Resistance Temperature Detectors	Thermistors
Temperature Range (degrees Celsius)	-180 to 2,320	-200 to 500	-90 to 130
Response Time	Fast (microseconds)	Slow (seconds)	Slow (seconds)
Size	Large (~1 mm)	Small (5 mm)	Small (5 mm)
Accuracy	Low	Medium	Very high

Sensing Devices(2)

- Hall Effect Sensor and Current Sensors
- Photoelectrics Sensors
- Photoelectric Infrared (PIR) Sensor
- LiDAR & Active Sensing Systems
- MEMS Sensors
  - MEMS Accelerometers Gyroscopes
  - MEMS Microphones
  - MEMS Pressure Sensors

Smart IoT Endpoints

- Vision System
  - CCD, CMOS



Smart IoT Endpoints(2)

- Sensor Fusion
  - Sensor fusion is the process of combining several different kinds of sensor data to reveal more about context than a single sensor can provide
- A single thermal sensor has no notion of what causes a rapid temperature change.
- With time-correlated data from multiple sensors (edge and cloud), processing can make better decisions based on more data
  -

Smart IoT Endpoints(3)

- There are two modes of sensor fusion:
  - Centralized: Where raw data is streamed and aggregated to a central service and fusion occurs there (cloud-based, for example)
  - De-centralized: Where data is correlated at the sensor (or close to it)
  -

Other Input Devices

- Gas Sensors
- Humidity Sensors
- Radiation Sensors
- Smoke Sensors
- Ultrasonics Sensors

Output Devices

- Output devices in the IoT ecosphere can be just about anything, from a simple LED to a full video system.
- Other types of output include actuators, stepper motors, speakers and audio systems, industrial valves, and so on.
- In general, output systems can require substantial energy to convert to mechanical movement, thermal energy, or even light.

Functional Example – TI SensorTag CC2650

- The Texas Instruments CC2650 SensorTag is a good example of an IoT sensor module for development, prototyping, and design. SensorTag has the following features and sensors in the package:
- Sensor Input:
  - Ambient light sensor (TI Light Sensor OPT3001)
  - Infrared temperature sensor (TI Thermopile infrared TMP007)
  - Ambient temperature sensor (TI light sensor OPT3001)
  - Accelerometer (Invensense MPU-9250)
  - Gyroscope (Invensense MPU-9250)
  - Magnetometer (Bosch SensorTec BMP280)
  - Altimeter/Pressure sensor (Bosch SensorTec BMP280)

Functional Example – TI SensorTag CC2650(2)

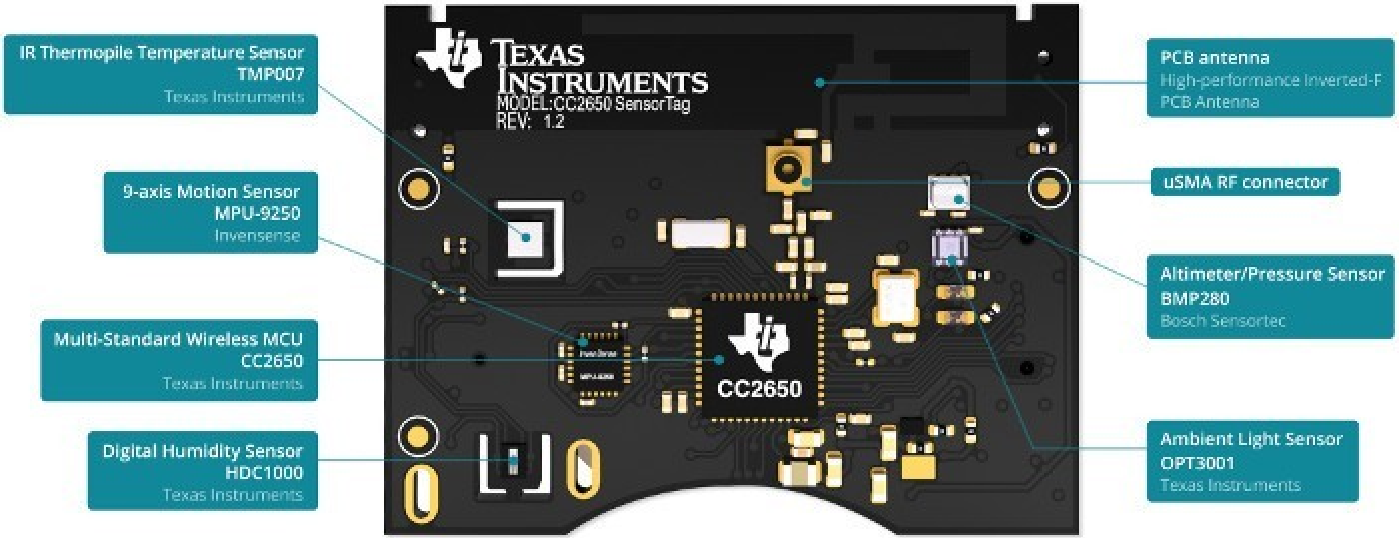
- Sensor Input:
  - Humidity sensor (TI HDC1000)
  - MEMS microphone (Knowles SPH0641LU4H)
  - Magnetic sensor (Bosch SensorTec BMP280)
  - 2 Push-button GPIOs
  - Reed relay (Meder MK24)

Functional Example – TI SensorTag CC2650(3)

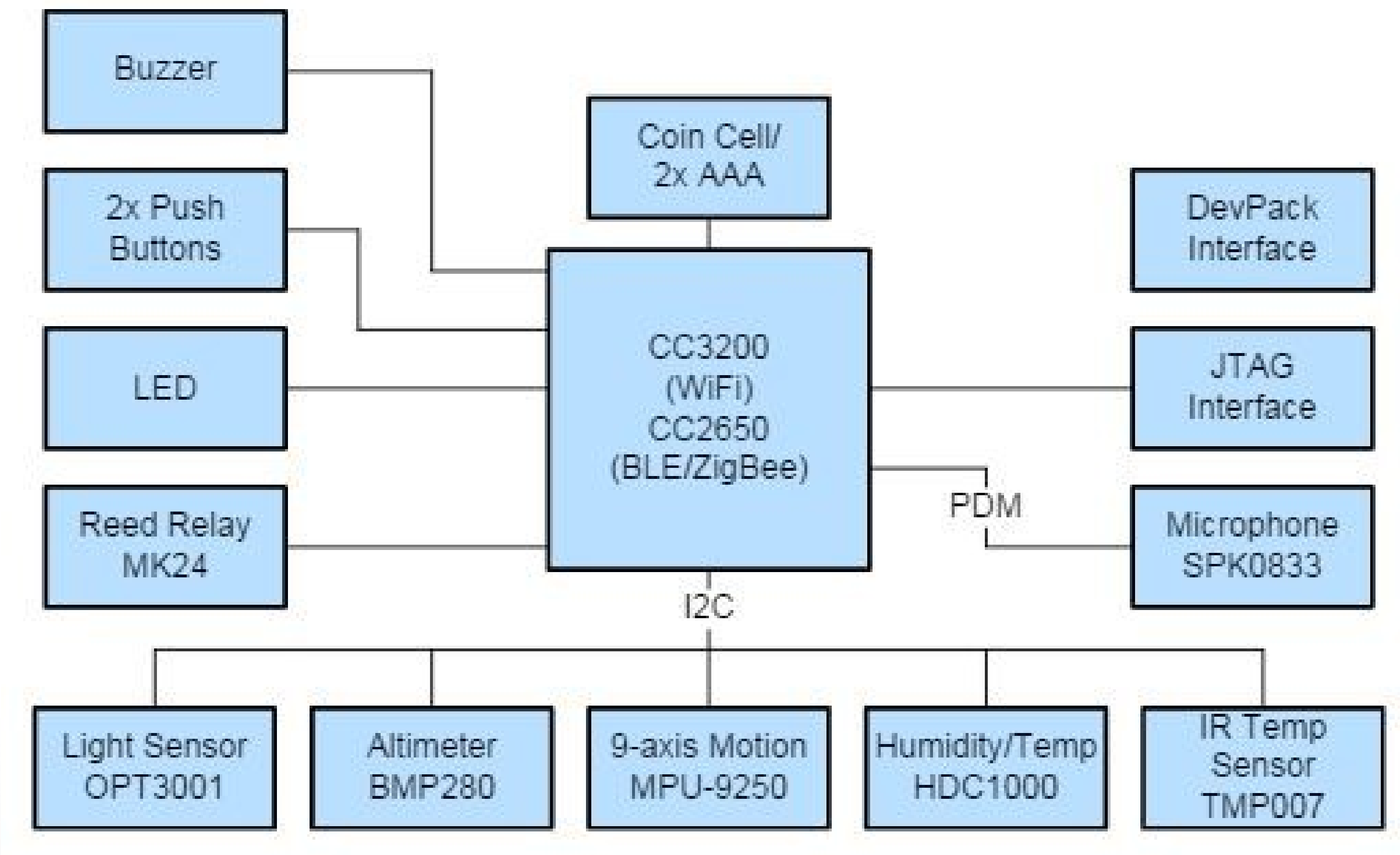
- Output devices
  - Buzzer/speaker
  - 2 LEDs
- Communications
  - Bluetooth Low Energy (Bluetooth Smart)
  - Zigbee
  - 6LoWPAN

Functional Example – TI SensorTag CC2650(4)

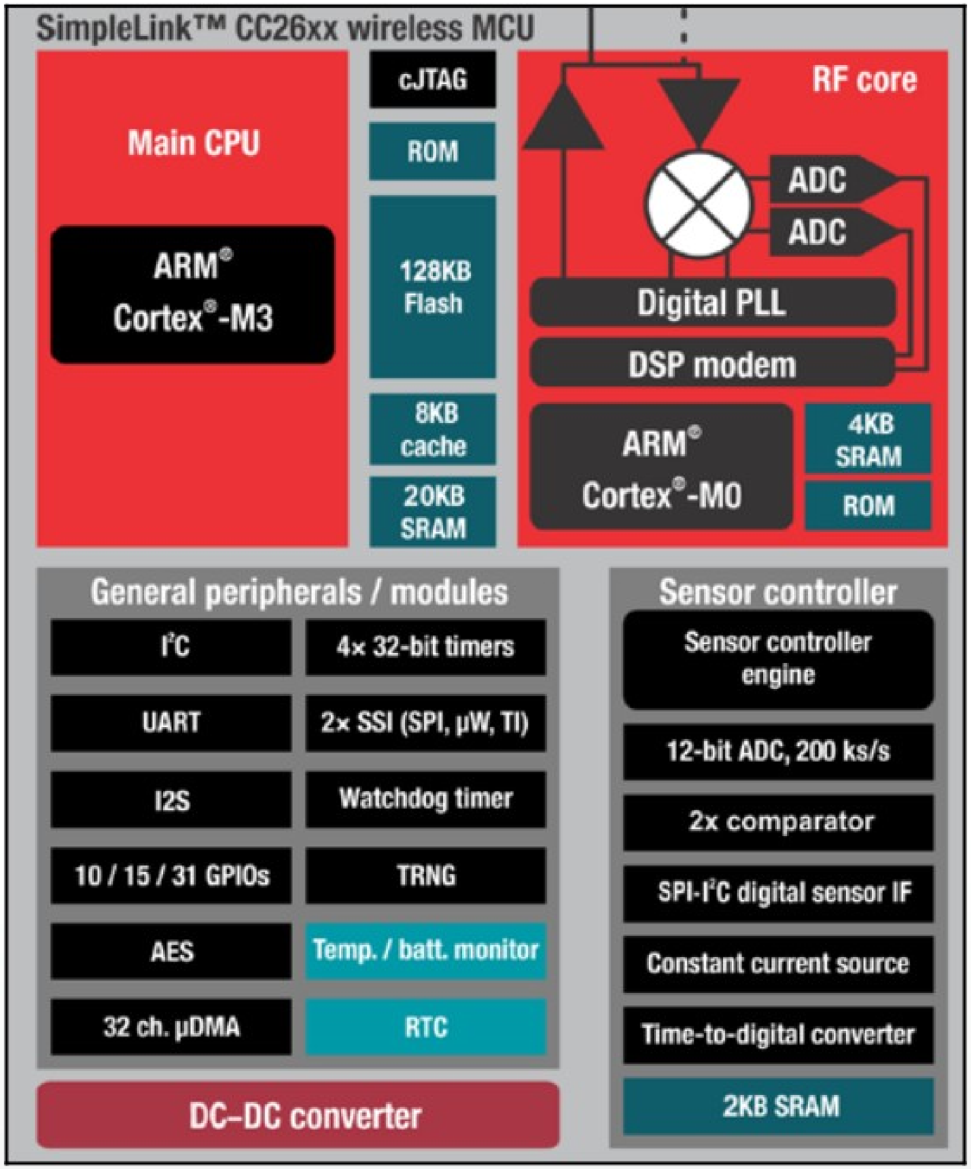
Functional Example – TI SensorTag CC2650(5)



Functional Example – TI SensorTag CC2650(6)



Functional Example – TI SensorTag CC2650(7)



Sensor to Controller

- In many of the preceding examples for sensing components, the signal will require amplification, filtering, and calibration before going anywhere.
- Typically, the hardware will need an analog-to-digital converter of some resolution.
- The output can then be raw pulse-modulated data, or a serial interface such as I 2 C, SPI, or UART to a microcontroller or digital signal processor.

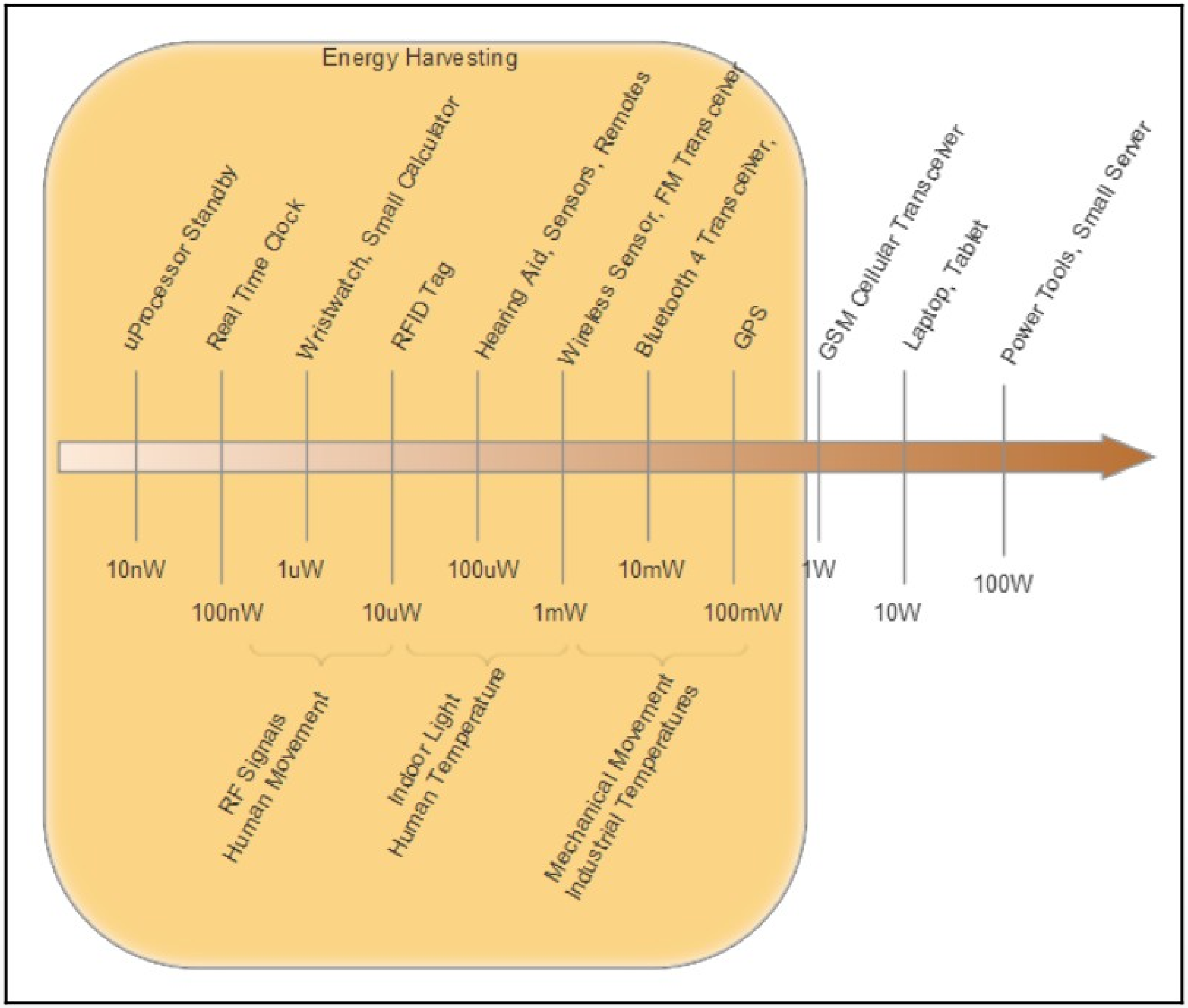
Power Management

- The architect must build a power budget for the edge device, which includes:
  - Active sensor power
  - Frequency of data collection
  - Wireless radio communication strength and power
  - Frequency of communication
  - Microprocessor or microcontroller power as a function of core frequency
  - Passive component power
  - Energy loss from leakage or power supply inefficiency
  - Power reserve for actuators and motors

Power Management(2)

- For example, the TI SensorTag C2650 has the following power characteristics:
  - Standby mode: 0.24 mA
  - Running with all sensors disabled: 0.33 mA
  - LEDs
  - All sensors on at 100 ms/sample data rate and broadcasting BLE: 5.5 mA:
    - Temperature sensor: 0.84 mA
    - Light sensor: 0.56 mA
    - Accelerometer and gyros: 4.68 mA
    - Barometric sensor: 0.5 mA

Energy Harvesting



Typical energy consumption for various devices.

Types of Energy Harvesting

- Solar Harvesting
- Piezo-mechanical harvesting
- RF Energy Harvesting
- Thermal Harvesting
  - **Thermoelectric**: Direct conversion of thermal energy into electrical energy
  - **Thermionic**: Also known as thermotunneling. Electrons are ejected from an electrode that is heated, and into an electrode that is cool.

Energy Storage

- When considering the architecture for sensor power, one must consider several aspects.
  - Volume allowance for a power subsystem. Will a battery even fit?
  - The battery energy capacity.
  - Accessibility. If the unit is embedded in concrete, limited forms of energy regeneration can be used, and the difficulty of replacing batteries can be costly.
  - Weight. Is the unit intended to fly as a drone, or float on water?
  - How often will the battery be recharged?
  - Is the renewable form of energy constantly available, or intermittent, as in solar?
  - The battery power characteristics. How the battery's energy will vary over time as it's discharged.
  - Is the sensor in a thermally constrained environment that can affect battery life and reliability?
  - Does the battery have a profile that guarantees minimum current availability?

Energy Storage(2)

Category	Li-ion Battery	Supercap
Energy density	200 Wh/kg	8-10 Wh/kg
Charge-discharge cycles	Capacity drops after 100 to 1,000 cycles	Nearly infinite
Charge-discharge time	1 to 10 hours	Milliseconds to seconds
Operational temperature	-20°C to +65°C	-40 degrees Celcius to +85 degrees Celsius
Operational voltage	1.2 V to 4.2 V	1 V to 3 V
Power delivery	Constant voltage over time	Linear or exponential decay
Charge rate	(Very slow) 40 C/x	(Very fast) 1,500 C/x
Operational life	0.5 to 5 years	5 to 20 years
Form factor	Very small	Large
Cost ($/kWh)	Low ($250 to $1000)	High ($10,000)

Summary

- This chapter summarized several different sensors and endpoints used in IoT deployments.
- The essence of IoT is connecting the analog world to the digital.
- Things and devices previously unconnected now have the opportunity to collect information and communicate it to other devices.
- Powering such systems is also critical, and must be understood by architects. A poorly designed system can lead to too short a battery life, which will end in substantial costs to remediate.