Reviewer: The IoT in Practice

Lesson 8.1: Hardware, Software, and the Web of Things

The IoT in Practice: Hardware, Software, and the Web of Things

Sensing the World: The "Nerves" of IoT

Sensors convert ***physical parameters*** into ***electrical signals***.

- ***Environmental***: Temperature, Humidity, Air Quality.
- ***Motion/Position***: Accelerometers, Gyroscopes, GPS.
- ***Optical***: Light intensity, Cameras, IR.
- ***Industrial***: Pressure, Flow, Vibration.

Taking Action: The "Muscles" of IoT

Actuators accept ***electrical signals*** and perform ***physical actions***.

- ***Mechanical***: Servo motors, Stepper motors (Robotics).
- ***Switching***: Relays, Solenoids (Smart plugs, locks).
- ***Visual/Audio***: LED displays, Speakers, Buzzers.

Feedback Loop: Often paired with sensors to ***maintain a state*** (e.g., Thermostat).

The Brains: Microcontrollers (MCUs)

Microcontrollers are ***low power*** and designed for ***specific tasks***. They are the core of most ***IoT edge devices*** and run ***without a full OS***.

- ***Arduino***: Great for ***prototyping***, vast community support.
- ***ESP32***: Integrated ***Wi-Fi & Bluetooth***, ***dual-core***, low cost. The ***industry favorite*** for IoT.
- ***STM32***: ***Industrial grade***, ***high performance*** ARM Cortex-M cores.

The Computers: SBCs

Single Board Computers (SBCs) offer ***high processing power***. They are ***full computers*** capable of running ***Linux*** (or Windows IoT).

- ***Use Cases***: ***Gateways***, ***Image Processing***, ***Local Servers***.
- ***Raspberry Pi***: The ***gold standard***. Runs Python scripts, Docker containers, and database servers locally.
- ***Edge AI***: ***Specialized SBCs*** (like ***NVIDIA Jetson***) run ***Machine Learning models*** on-device.

Connectivity: Short Range

Personal Area Networks (PAN) connect devices within a room or building.

- ***Bluetooth Low Energy (BLE)***: ***Ultra-low power***, ubiquitous in wearables.
- ***Zigbee / Z-Wave***: ***Mesh networking*** for ***Smart Homes*** (Lights, Sensors).
- ***NFC***: ***Very short range***, used for ***provisioning*** and ***payments***.

Connectivity: Long Range

- ***Wi-Fi***: ***High bandwidth***, ***power hungry***. Best for mains-powered devices needing ***real-time video*** or large data.
- ***LoRaWAN***: ***Long Range, Low Power***. Perfect for ***agriculture and smart cities*** where sensors are kilometers apart.
- ***Cellular (NB-IoT)***: Uses existing ***mobile towers***. Excellent ***coverage and reliability*** for ***critical logistics*** and ***asset tracking***.

Power Management: The Energy Challenge

Most IoT devices run on ***batteries*** and must last for years. Devices often spend ***99%*** of their time in ***"Sleep Mode"***.

- ***Deep Sleep***: Shutting down ***non-essential circuits*** (Wi-Fi/Radio) when not transmitting.
- ***Energy Harvesting***: ***Solar***, ***piezoelectric*** (vibration), or ***RF harvesting*** to extend life.
- ***Efficient Code***: Writing software that ***minimizes active CPU cycles***.

IoT Operating Systems

- ***Bare Metal***: ***No OS***. Code runs directly on hardware. ***Fastest, simplest***, but hard to manage complex tasks.
- ***RTOS*** (***FreeRTOS, Zephyr***): ***Real-Time Operating Systems*** ensure tasks ***finish deterministically***. Essential for ***time-critical sensing***.
- ***General Purpose***: ***Linux*** (Yocto, Ubuntu Core). Used on ***gateways/SBCs***. ***Multi-threaded***, supports Python/Node.js, but ***power hungry***.

Software Protocols: MQTT

MQTT (***Message Queuing Telemetry Transport***) is the ***de-facto standard*** for IoT.

- ***Pub/Sub Model***: Devices don't talk to each other directly; they talk to a ***"Broker"***.
- ***Lightweight***: ***Small packet overhead***, perfect for ***unstable networks***.
- ***QoS Levels***: ***Quality of Service*** settings ensure message delivery (***Fire & Forget*** vs. ***Confirmed***).

Other Key Protocols

- ***CoAP*** (***Constrained Application Protocol***): Designed to be ***"HTTP for simple devices"***. Uses ***UDP*** instead of TCP for ***lower overhead***. Ideal for ***very constrained sensor nodes***.
- ***HTTP/REST***: The ***standard web protocol***. ***Heavy*** for small devices, but ***widely compatible***. Often used by ***Gateways*** to push ***aggregated data*** to the ***Cloud***.

Cloud Platforms: Managing at Scale

Platforms like ***AWS IoT Core***, ***Azure IoT Hub***, and ***Google Cloud IoT***.

- ***Device Shadows***: ***Virtual JSON documents*** that ***persist device state*** even when offline.
- ***Rules Engines***: ***"If temp > 50, send email"*** logic without writing server code.
- ***Analytics***: ***Storing and visualizing*** massive streams of ***sensor data***.

Edge Computing: Moving Logic Closer

Instead of sending all data to the cloud, process it ***locally*** on the ***Gateway or Device***.

- ***Latency***: ***Instant decisions*** (e.g., stopping a machine) without network delay.
- ***Bandwidth***: Send only the ***"insight"*** (e.g., "Person Detected") rather than the ***full video stream***.
- ***Privacy***: ***Sensitive data stays local***.
- ***Reliability***: ***System works*** even if internet goes down.

W3C WoT Architecture: The Building Blocks

- ***Thing Description (TD)***: The ***core metadata file*** describing a Thing.
- ***Binding Templates***: How to map ***abstract interactions*** to actual protocols (***HTTP, MQTT, Modbus***).
- ***Scripting API***: ***Standardized JavaScript API*** for application logic.
- ***Security & Privacy***: ***Mechanisms*** to ensure ***safe interoperability***.