LECTURE NOTES ON INTERNET OF THINGS

PREPARED BY :

Miss. PRIYANKA MAHARANA

UNIT- I:-Introduction to Internet of Things (IoT)

Overview of IoT:

Definition: Internet of Things (IoT) is a network of physical devices, vehicles, and appliances embedded with sensors, software, and connectivity, allowing them to collect, share, and act on data autonomously via the internet.

Significance of IoT:

1. **Automation**
   - Reduces manual work by automating routine tasks.
   - Example: Smart lighting and automatic irrigation systems.
2. **Improved Efficiency**
   - Optimizes the use of resources, time, and energy.
   - Example: Smart factories improve production efficiency.
3. **Real-Time Monitoring**
   - Continuously monitors equipment, health, or environmental conditions.
   - Example: Wearable fitness trackers monitor heart rate and activity.
4. **Cost Savings**
   - Reduces operational and maintenance costs through predictive maintenance and efficient resource management.
5. **Better Decision-Making**
   - Collects real-time data that helps individuals and organizations make informed decisions.
6. **Enhanced Safety and Security**
   - Improves security through smart surveillance, fire detection, and remote monitoring systems.
7. **Improved Quality of Life**
   - Makes everyday life more convenient with smart homes, connected healthcare devices, and intelligent transportation.
8. **Support for Smart Cities**
   - Helps manage traffic, waste collection, street lighting, and public services more efficiently.

Historical Evolution of IoT:

1. **1980s – Early Connected Devices**
   - The idea of connecting devices to networks began with experiments like internet-connected vending machines.
2. **1990s – Birth of IoT**
   - The term **Internet of Things (IoT)** was introduced in **1999** by Kevin Ashton.
   - Technologies such as RFID enabled automatic identification and tracking of objects.
3. **2000s – Internet Expansion**
   - Increased internet access and wireless communication made it possible to connect more devices.
   - Smart sensors and embedded systems became more common.
4. **2010s – Rapid Growth**
   - Cloud computing, smartphones, and big data accelerated IoT adoption.
   - Applications expanded to smart homes, healthcare, agriculture, transportation, and industry.

5. **2020s – Intelligent IoT**
   - Integration of Artificial Intelligence (AI), 5G, edge computing, and machine learning has made IoT systems faster, smarter, and more efficient.

Future Prospects:

- **Smart Cities:** Intelligent traffic management, smart lighting, waste management, and public safety.
- **Healthcare:** Remote patient monitoring, wearable devices, and telemedicine.
- **Smart Homes:** Automated lighting, security, and energy-efficient appliances.
- **Industry 4.0:** Smart manufacturing, predictive maintenance, and automated production.
- **Agriculture:** Precision farming, smart irrigation, and crop monitoring using sensors.
- **Transportation:** Connected and self-driving vehicles, smart traffic systems, and improved road safety.
- **Environmental Monitoring:** Air and water quality monitoring, weather forecasting, and disaster management.
- **AI and 5G Integration:** Faster communication, real-time data processing, and support for billions of connected devices.

Applications:

IoT transforms multiple sectors through real-time tracking, automation, and predictive data analysis. Key applications include:

- **Manufacturing (Industrial IoT - IIoT):** Deploys sensors to continuously track machine vibration, temperature, and operating hours. This enables predictive maintenance, which minimizes unplanned equipment downtime and lowers costs.
- **Healthcare & Medical:** Powers remote patient monitoring via wearables that track vitals (like heart rate and glucose) to allow early clinical intervention. Hospitals also use IoT for tracking the real-time location of mobile medical assets (e.g., infusion pumps) and monitoring sensitive pharmaceutical storage environments.
- **Energy & Utilities:** Utilizes smart grids to balance energy generation and distribution in real time. IoT-based smart meters identify faults to prevent power outages, automate building HVAC/lighting for energy conservation, and seamlessly integrate renewable energy sources.
- **Agriculture:** Maximizes yield and minimizes waste using smart irrigation and sensors. Sensors monitor soil chemistry, moisture, and temperature. Systems automatically start and stop water flow based on dryness levels, while RFID chips track livestock vitals.
- **Smart Cities & Transportation:** Employs sensor networks to manage traffic congestion and air pollution in real time. Additionally, connected vehicles use GPS and wireless tech to track fleet logistics, optimize delivery routes, and enable autonomous driving functions.

IoT Architecture and Components:

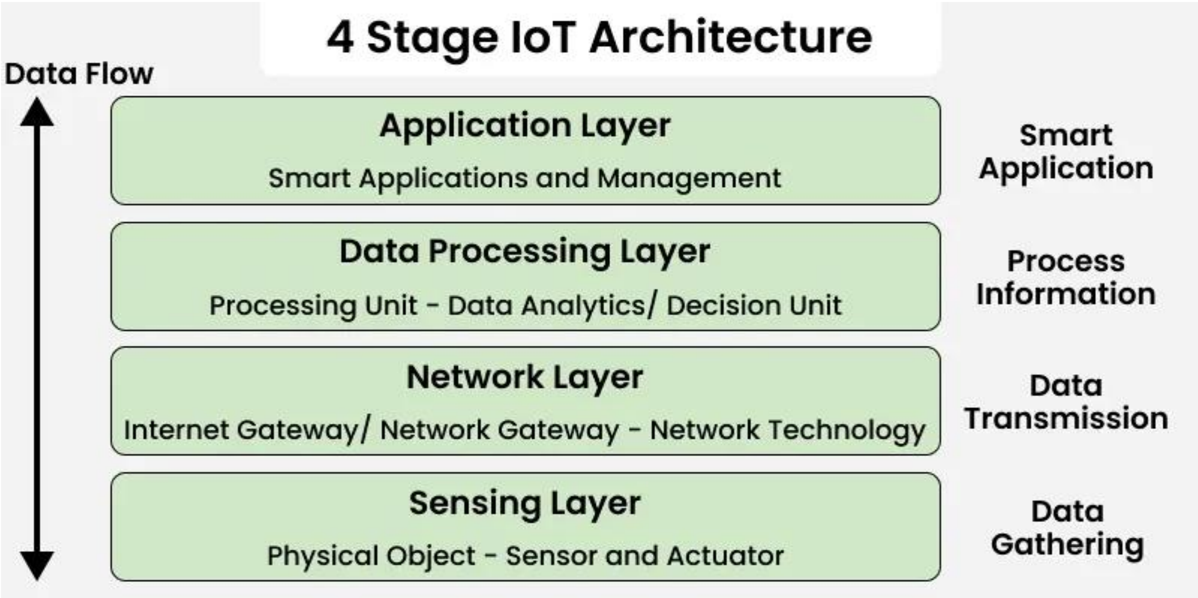
It defines how sensors, networks and cloud systems interact to collect, process and exchange data efficiently.

- The IoT architecture acts as the foundation for all connected devices and applications.
- Each layer has a distinct role, from sensing real-world data to delivering intelligent actions.
- A clear structure ensures scalability, security and smooth device communication.

This architecture forms the backbone of IoT systems, powering everything from smart homes to industrial automation.

Architecture:

The architecture of Internet of Things consists of four different layers i.e. Sensing Layer, Network Layer, Data processing Layer and Application Layer.



1. Sensing Layer

This is the bottom-most layer responsible for detecting physical conditions from the environment.

Functions

- Collects raw data such as temperature, humidity, motion, sound or pressure.
- Senses changes in the surroundings through embedded components.
- Initiates actions using actuators when required.

Components

- Sensors like humidity, gas, infrared, ultrasonic
- Actuators like motors, switches, valves
- Microcontrollers and RFID tags

Communication: Transfers sensed data to the network layer via wired or wireless links.

2. Network Layer

This layer provides connectivity and communication between IoT devices and cloud systems.

Functions

- Transmits collected sensor data to processing platforms securely.
- Supports device-to-device and device-to-server communication.
- Handles addressing, routing and data forwarding.

Technologies

- Wi-Fi, Bluetooth, Zigbee, LoRaWAN
- Ethernet and satellite networks
- Supporting Devices
- Routers and switches

3. Data Processing Layer

This layer analyzes, filters and interprets data received from network devices.

Functions

- Cleans and formats raw sensor data for meaningful insights.
- Applies analytics to detect patterns or abnormalities.
- Stores data for historical analysis or reporting.

Components

- IoT cloud platforms
- Data lakes and warehouses
- Stream processing and machine learning engines

Output

- Predictive alerts and reports
- Anomaly detection signals
- Decision rules for automation

4. Application Layer

This top-most layer interacts directly with end users and business systems.

Functions

- Provides interfaces to monitor and control IoT devices remotely.
- Displays visual analytics through dashboards and charts.
- Triggers automated actions based on processed insights.

Components

- Mobile applications
- Web dashboards and portals
- Visualization and alerting tools

Capabilities

- Remote device management
- Real-time condition monitoring
- Integration with enterprise applications

Advantages:

Some advantages of IoT architecture are:

1. **Scalability:** Supports the integration of additional devices and sensors as business requirements grow without major architectural redesigns.
2. **Resource Efficiency:** Minimizes power consumption and maintenance overhead by optimizing operations through data-driven control.
3. **Real-Time Insights:** Provides instant visibility of ongoing processes using live sensor streams to enable faster responses.
4. **Interoperability:** Allows cross-vendor device communication through open protocols to improve connectivity in diverse environments.
5. **Predictive Analytics:** Forecasts equipment failures and workload fluctuations using AI models to reduce unexpected downtime.

Disadvantages:

Some disadvantages are:

1. **Security Vulnerabilities:** Connected devices are susceptible to cyberattacks, unauthorized access and data breaches due to weak security layers.
2. **High Initial Costs:** Implementing sensors, gateways and communication infrastructure requires significant upfront investment.
3. **Compatibility Challenges:** Different vendor standards and communication protocols create difficulties in integrating heterogeneous systems.

4. **Network Dependency:** Connectivity issues can interrupt data flow and disrupt real-time operations across remote deployments.
5. **Complex Maintenance:** Large-scale IoT deployments require continuous monitoring, regular updates and specialized management tools.

Sensors, Actuators, Connectivity, and Data processing:

This basic IoT framework is a 4-stage system: **Sensors** gather environmental data, **Connectivity** transmits it through networks, **Data Processing** transforms the raw data into actionable intelligence, and **Actuators** execute the physical responses. These stages work together seamlessly to create automated, responsive technological ecosystems.

1. Sensors (The Eyes and Ears)

Sensors are hardware devices that collect real-time data from the physical environment by detecting changes in factors like temperature, pressure, motion, or light.

- **Key Types:** Temperature sensors (HVAC), GPS (tracking), accelerometers (vibration), and proximity sensors (security).

2. Connectivity (The Nervous System)

This layer acts as the bridge that safely and efficiently transfers raw data from the sensors to processing platforms.

- **Technologies:** Wi-Fi, Bluetooth, cellular networks (4G, 5G), Zigbee, and LPWAN.
- **Gateways:** These are critical intermediary devices that collect data from multiple sensors, translate protocols (e.g., MQTT or HTTP), and securely route it over the internet.

3. Data Processing (The Brain)

At this stage, raw data is aggregated, cleaned, and analyzed to uncover patterns or trigger necessary actions.

- **Edge Computing:** Data is analyzed locally near the sensors (on the device or gateway) to reduce latency and save bandwidth.
- **Cloud Computing:** Massive volumes of data are sent to centralized, scalable cloud servers for long-term storage, in-depth machine learning, and historical analysis.

4. Actuators (The Hands and Feet)

Actuators are the components that convert digital processing commands back into physical actions. Based on the insights generated in the data processing stage, the system sends an electrical signal to the actuator to mechanically change or control the environment.

- **Examples:** Electric motors, relays, servos, valves, and switches.
- **Use Case:** A temperature sensor detects an overheated room, the cloud processes this anomaly, and sends a signal to an actuator (valve or switch) to turn on the air conditioner.

Hardware components: microcontrollers (e.g., Arduino, Raspberry Pi):

A microcontroller is a compact, self-contained computer on a single chip. It contains a processor (CPU), memory (RAM and Flash), and programmable input/output (I/O) peripherals. It is designed to read inputs, process data, and control specific tasks or actions.

Arduino

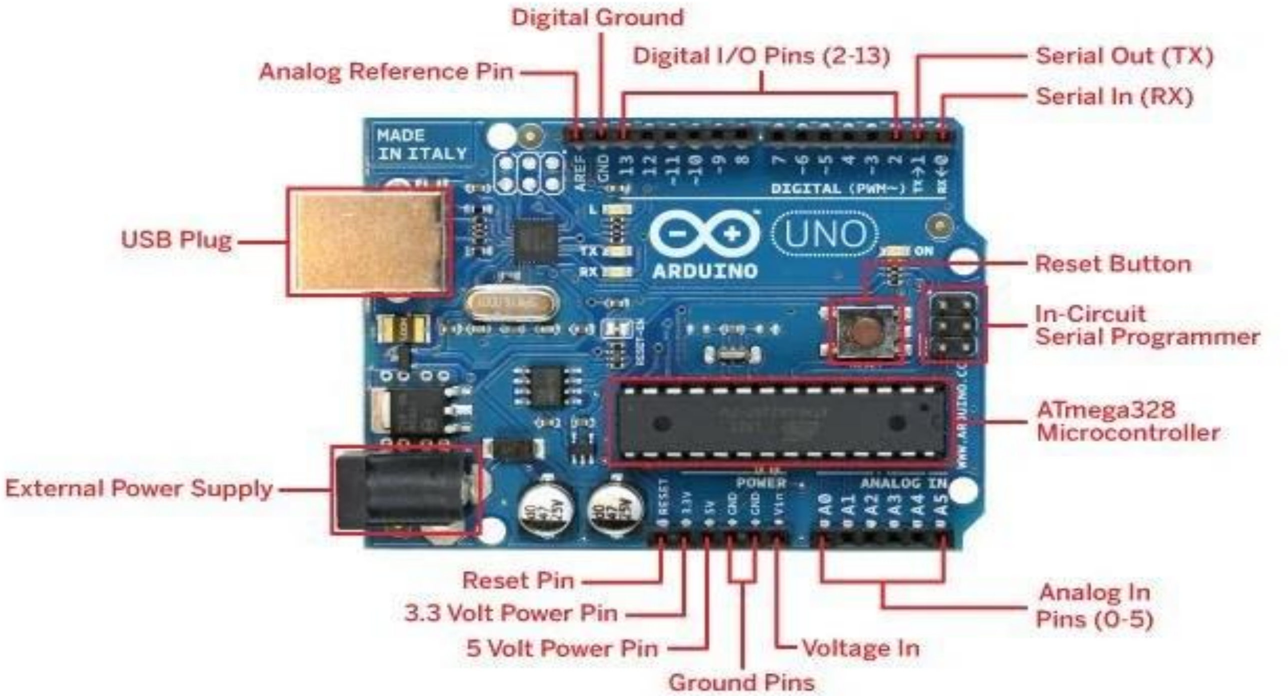
An **Arduino** is an open-source hardware platform featuring a microcontroller, making it easier to build electronic projects. Instead of dealing with bare, complex chips, Arduino boards provide an accessible circuit board with all the necessary support components. An Arduino is actually a microcontroller based kit.

¬ It is basically used in communications and in controlling or operating many devices.

¬ Arduino UNO board is the most popular board in the Arduino board family.

¬ In addition, it is the best board to get started with electronics and coding.

¬ Some boards look a bit different from the one given below, but most Arduino'shave majority of these components in common.
¬ It consists of two memories- Program memory and the data memory.
¬ The code is stored in the flash program memory, whereas the data is stored in the data memory.
¬ Arduino Uno consists of 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.



1.Power USB
Arduino board can be powered by using the USB cable from your computer. All you need to do is connect the USB cable to the USB connection (1).
2.Power (Barrel Jack)
Arduino boards can be powered directly from the AC mains power supply by connecting it to the Barrel Jack (2).
3.Voltage Regulator
The function of the voltage regulator is to control the voltage given to the Arduino board and stabilize the DC voltages used by the processor and other elements.
4.Crystal Oscillator
The crystal oscillator helps Arduino in dealing with time issues. How does Arduino calculate time? The answer is, by using the crystal oscillator. The number printed on top of the Arduino crystal is 16.000H9H. It tells us that the frequency is 16,000,000 Hertz or 16 MHz.
5,17.Arduino Reset
You can reset your Arduino board, i.e., start your program from the beginning. You can reset the UNO board in two ways. First, by using the reset button (17) on the board. Second, you can connect an external reset button to the Arduino pin labelled RESET (5).
6,7,8,9.Pins (3.3, 5, GND, Vin)
• 3.3V (6) − Supply 3.3 output volt
• 5V (7) − Supply 5 output volt

• Most of the components used with Arduino board works fine with 3.3 volt and 5 volt.
• GND (8)(Ground) − There are several GND p used to ground your circuit.
• Vin (9) − This pin also can be used to po source, like AC mains power supply.

10.Analog pins

The Arduino UNO board has six analog input pins A0 through A5. These pins can read the signal from an analog sensor like the humidity sensor or temperature sensor and convert it into a digital value that can be read by the microprocessor.

11.Main microcontroller

Each Arduino board has its own microcontroller (11). You can assume it as the brain of your board. The main IC (integrated circuit) on the Arduino is slightly different from board to board. The microcontrollers are usually of the ATMEL Company. You must know what IC your board has before loading up a new program from the Arduino IDE. This information is available on the top of the IC. For more details about the IC construction and functions, you can refer to the data sheet.

12.ICSP pin

Mostly, ICSP (12) is an AVR, a tiny programming header for the Arduino consisting of MOSI, MISO, SCK, RESET, VCC, and GND. It is often referred to as an SPI (Serial Peripheral Interface), which could be considered as an "expansion" of the output. Actually, you are slaving the output device to the master of the SPI bus.

13.Power LED indicator

This LED should light up when you plug your Arduino into a power source to indicate that your board is powered up correctly. If this light does not turn on, then there is something wrong with the connection.

14.TX and RX LEDs

On your board, you will find two labels: TX (transmit) and RX (receive). They appear in two places on the Arduino UNO board. First, at the digital pins 0 and 1, to indicate the pins responsible for serial communication. Second, the TX and RX led (13). The TX led flashes with different speed while sending the serial data. The speed of flashing depends on the baud rate used by the board. RX flashes during the receiving process.

15.Digital I/O

The Arduino UNO board has 14 digital I/O pins (15) (of which 6 provide PWM (Pulse Width Modulation) output. These pins can be configured to work as input digital pins to read logic values (0 or 1) or as digital output pins to drive different modules like LEDs, relays, etc.

16.AREF

• AREF stands for Analog Reference. It is sometimes, used to set an external reference voltage (between 0 and 5 Volts) as the upper limit for the analog input pins.

Basic Adruino functions are:

digitalRead(pin): Reads the digital value at the given pin.
digitalWrite(pin, value): Writes the digital value to the given pin.
pinMode(pin, mode): Sets the pin to input or output mode.
analogRead(pin): Reads and returns the value.
analogWrite(pin, value): Writes the value to that pin.
serial.begin(baud rate): Sets the beginning of serial communication by setting the bit rate.

Advantages of Arduino Board

1. It is inexpensive
2. It comes with an open source hardware feature which enables users to develop their own kit using already available one as a reference source.
3. The Arduino software is compatible with all types of operating systems like Windows, Linux, and Macintosh etc.
4. It also comes with open source software feature which enables experienced software developers to use the Arduino code to merge with the existing programming language libraries and can be extended and modified.
5. It is easy to use for beginners.
6. We can develop an Arduino based project which can be completely stand alone or projects which involve direct communication with the software loaded in the computer.
7. It comes with an easy provision of connecting with the CPU of the computer using serial communication over USB as it contains built in power and reset circuitry.

Raspberry Pi :

The Raspberry Pi is a very cheap computer that runs Linux, but it also provides a set of GPIO (general purpose input/output) pins that allow you to control electronic components for physical computing and explore the Internet of Things (IoT). Raspberry Pi was basically introduced in 2006. It is particularly designed for educational use and intended for Python. A Raspberry Pi is of small size i.e., of a credit card sized single board computer, which is developed in the United Kingdom(U.K) by a foundation called Raspberry Pi. There have been three generations of Raspberry Pis: Pi 1, Pi 2, and Pi 3. The first generation of Raspberry (Pi 1) was released in the year 2012, that has two types of models namely model A and model B. Raspberry Pi can be plugged into a TV, computer monitor, and it uses a standard keyboard and mouse. It is user friendly as can be handled by all the age groups. It does everything you would expect a desktop computer to do like word-processing, browsing the internet spreadsheets, playing games to playing high definition videos. All models feature on a broadcom system on a chip (SOC), which includes chip graphics processing unit GPU(a Video Core IV), an ARM compatible and CPU. The CPU speed ranges from 700 MHz to 1.2 GHz for the Pi 3 and on board memory range from 256 MB to 1 GB RAM. An operating system is stored in the secured digital SD cards and program memory in either the MicroSDHC or SDHC sizes. Most boards have one to four USB slots, composite video output, HDMI and a 3.5 mm phone jack for audio. Some models have WiFi and Bluetooth.

Several generations of Raspberry Pis have been released. All models feature a Broadcom system on a chip (SoC) with an integrated ARM-compatible central processing unit (CPU) and on-chip graphics processing unit (GPU). Processor speed ranges from 700 MHz to 1.4 GHz for the Pi 3 Model B+ or 1.5 GHz for the Pi 4; on-board memory ranges from 256 MB to 1 GB with up to 4 GB available on the Pi 4 random-access memory (RAM). Secure Digital (SD) cards in MicroSDHC form factor (SDHC on early models) are used to store the operating system and program memory. The boards have one to five USB ports. For video output, HDMI and composite video are supported, with a standard 3.5 mm tip-ring-sleeve jack for audio output.

Lower-level output is provided by a number of GPIO pins, which support common protocols like I^2C. The B-models have an 8P8C Ethernet port and the Pi 3 and Pi Zero W have on-board Wi-Fi and Bluetooth.

Components and Peripherals :

1. **Voltages**: Two 5V pins and two 3V3 pins are present on the board, as well as a number of ground pins (0V). The remaining pins are all general purpose 3V3 pins .A GPIO pin designated as an output pin can be set to high (3V3) or low (0V). A GPIO pin designated as an input pin can be read as high (3V3) or low (0V).
2. **Processor & RAM:** Raspberry based on ARM11 processor. Latest version supports 700MHz processor and 512MB SDRAM. The Central processing unit is the brain of the raspberry pi board and that is responsible for carrying out the instructions of the computer through logical and mathematical operations.
3. **Ethernet:** The Ethernet port of the raspberry pi is the main gateway for communicating with additional devices. The raspberry pi Ethernet port is used to plug your home router to access the internet.
4. **USB Ports**: It has 2 USB ports. USB port provide current upto 100mA. For connecting devices that draw current more than 100mA, an external USB powered hub is required.
5. **Ethernet Port**: It has standard RJ45 Ethernet port. Connect Ethernet cable or USB wifi adapter to provide internet connectivity.
6. **HDMI Output**: It supports both audio and video output. Connect raspberry Pi to monitor using HDMI cable.
7. **Composite video Output**: Raspberry comes with a composite video output with an RCA jack that supports both PAL and NTSC video output.
8. **Audio Output**: It has 3.5mm audio output jack. This audio jack is used for providing audio output to old television along with RCA jack for video.
9. **GPIO Pins**: It has a number of general purpose input/output pins. These pins are used to connect other electronic components. For example, you can connect it to the temperature sensor to transmit digital data.
10. **Display Serial Interface (DSI):** DSI interface are used to connect an LCD panel to Raspberry PI.
11. **Cameral Serial Interface(CSI):** CSI interface are used to connect a camera module to Raspberry PI.
12. **SD Card slot**: Raspberry does not have built in OS and storage. Plug in an SD card loaded with Linux to SD card slot.
13. **Power Input**: Raspberry has a micro USP connector for power input.
14. **Memory:** The raspberry pi model A board is designed with 256MB of SDRAM and model B is designed with 51MB.Raspberry pi is a small size PC compare with other PCs. The normal PCs RAM memory is available in gigabytes. But in raspberry pi board, the RAM memory is available more than 256MB or 512MB
15. **Status LEDs**: Raspberry has 5 status LEDs

Software components: operating systems and middleware:

In the Internet of Things (IoT), software components provide the intelligence and communication needed for connected devices. Two important software components are Operating Systems (OS) and Middleware.

Operating System (OS) in IoT:

An Operating System (OS) is system software that manages the hardware and software resources of an IoT device. It provides an environment for applications to run efficiently.

Functions:

- Manages memory and processor usage.
- Controls input/output devices and sensors.
- Schedules tasks and processes.
- Provides security features.
- Supports communication protocols (Wi-Fi, Bluetooth, Zigbee, etc.).

Examples of IoT Operating Systems:

- FreeRTOS
- Contiki-NG
- Zephyr OS
- RIOT OS
- TinyOS

Features:

- Lightweight and energy-efficient.
- Real-time processing capability.
- Low memory consumption.
- Supports wireless communication.
- Secure and reliable.

Middleware in IoT

Middleware is software that acts as a bridge between IoT devices, operating systems, applications, and cloud services. It simplifies communication and data management.

Functions:

- Connects heterogeneous devices.
- Manages data collection and processing.
- Handles device authentication and security.
- Supports communication between devices and cloud platforms.
- Provides APIs for application development.

Examples of IoT Middleware:

- MQTT brokers (e.g., Mosquitto)
- Eclipse Kura
- AWS IoT Core
- Azure IoT Hub
- ThingsBoard

Features:

- Device management.
- Data storage and analytics.
- Protocol translation.
- Scalability.
- Security and access control.