21ES614 – Internet of Things

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Syllabus

Unit 1

Introduction to IoT - Definitions, frameworks and key technologies. Functional blocks of IoT systems: hardware and software elements- devices, communications, services, management, security, and application. Challenges to solve in IoT

Unit 2

Basics of Networking & Sensor Networks - Applications, challenges - ISO/OSI Model, TCP/IP Model, Sensor network architecture and design principles, IoT technology stack, Communication models. Communication Protocols - Overview of protocols in each layer, Application protocols for the transfer of sensor data, Infrastructure for IoT: LoRa-Wan, 6LoWPAN, 5G and Sigfox.

Unit 3

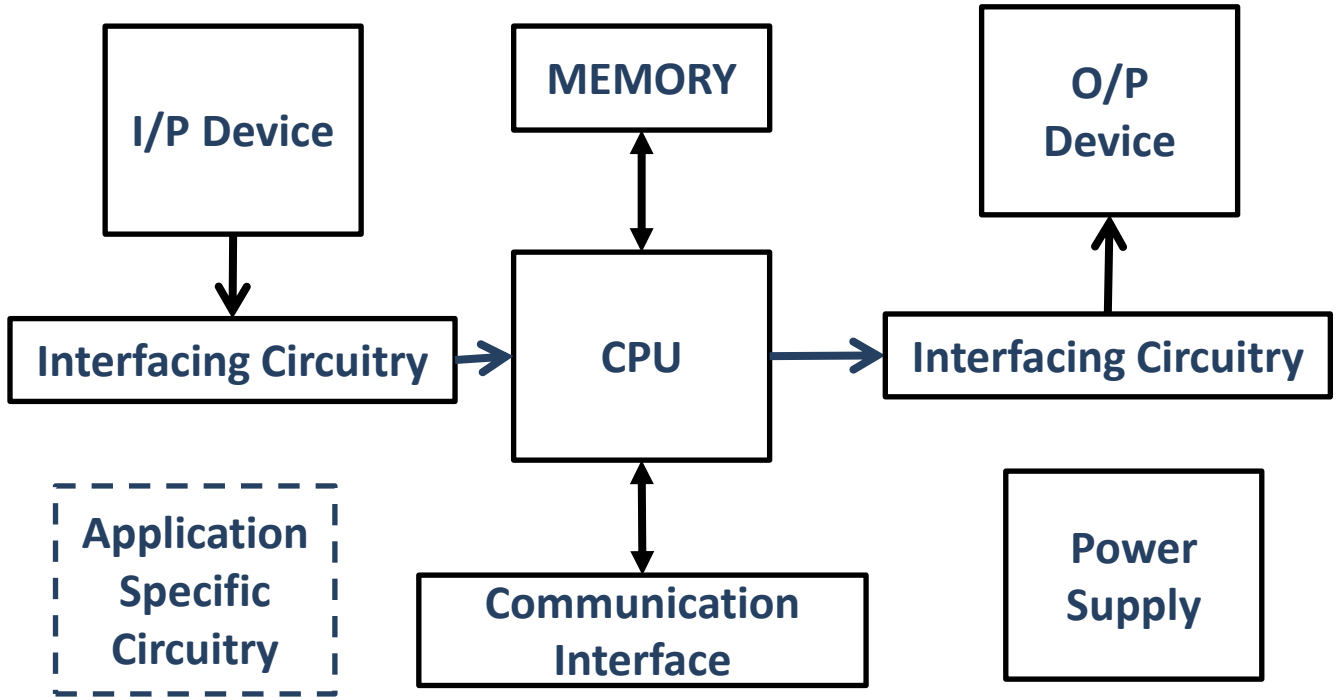
Introduction to Cloud, Fog and Edge Computing. Modern trends in IoT – Industrial IoT, Wearable. Applications of IoT - Smart Homes/Buildings, Smart Cities, Smart Industry, and Smart Medical care, Smart Automation etc.

IoT Devices

- End Devices
  - Sense, Actuate & Communicate
  - Minimal processing
- Edge Devices
  - Distributed Processing - Processing in network, Data aggregation
  - Protocol Conversion
  - Optional Sensing and Actuation
- Servers/Cloud
  - Services Platform, Data Storage, Intelligent Decision Making
  - Major Processing, Data Analytics, Visualization

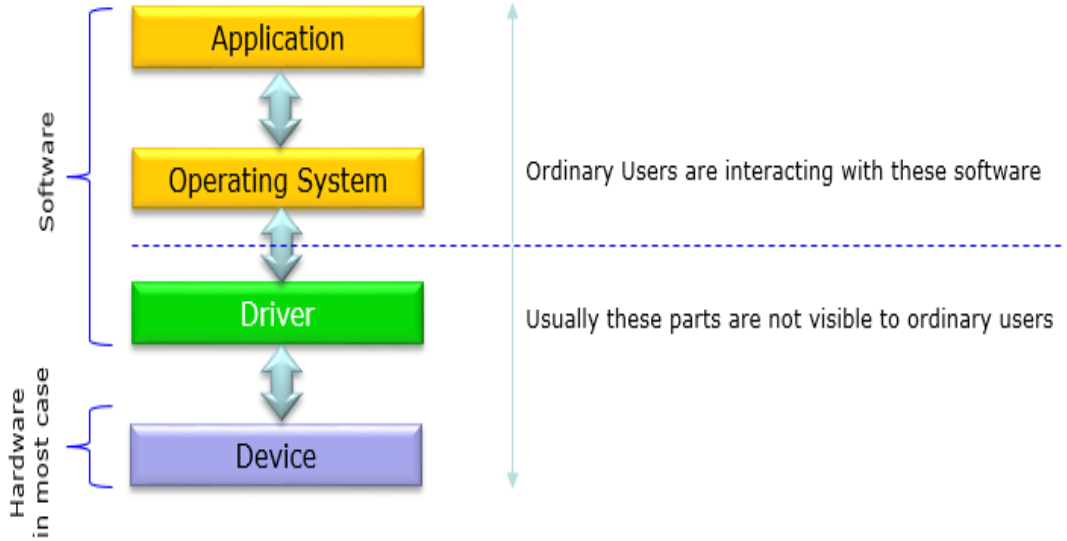
Functional blocks of IoT End Device - Hardware

- Input Devices
- CPU
- Output Devices
- Interfacing circuitry
- Memory
- Power Supply
- Communication Interface
- Application specific circuitry, and
- Other peripheral devices…



Functional blocks of IoT End Device - Software

- Application Software
  - Sensing
  - Processing
  - Actuation
- System Software
  - Protocol Stack – APIs for communication
  - Device Management – APIs for application software
    - Device Drivers
    - RTOS



Sensors & Actuators - Fact file

- Depends on the application / Suitable for the environment
- Sensors - First step of being Intelligent, Awareness of the surroundings
- Sensor should not disturb the physical quantity it measures
- Actuators – Action step of implementing intelligence
- Size, cost and ease of operation
- Means of device/solution to interact to the environment
- Isolated from noise

Classification of Sensors

- Proprioceptive sensors
  - Measure values internally to the system (for e.g., robot)
  - E.g. motor speed, wheel load, heading of the robot, battery status, joint angles
  - Position sensor, tilt sensor, speed sensor
- Exteroceptive sensors
  - Information from the robots environment
  - Extract meaningful environmental features
  - Distances to objects, intensity of the ambient light, unique features, sound amplitude
  - Ultrasonic, Infrared, Camera

Continued…

- Passive sensors
  - Measure environmental energy entering the sensor
  - E.g.: temperature probes, microphones
- Active sensors
  - Emit their proper energy and measure the reaction
  - Better performance, but some influence on environment
  - Eg: optical encoders, ultrasonic sensors

Continued…

- Analog
  - Requires a A/D converter to connect to a microcontroller
  - Less complex
  - E.g. analog compass, microphone, analog infrared distance sensor.
- Digital
  - More complex
  - More accurate
  - Output interface – parallel, serial and synchronous serial

Actuators

- Soft
- Hydraulic
- Pneumatic
- Electric
- Electromechanical
- Thermal
- Magnetic

- Display
- LED
- Relay
- Motors
- Buzzer
- Solenoid
- Valve

Characteristics

- **Dynamic Range**: The ratio of maximum recordable input amplitude to minimum input amplitude.
- **Sensitivity**: The ratio between the change in the output signal to a small change in input physical signal. Slope of the input-output fit line.
- **Resolution:** The smallest increment of measure that a device can make.
- **Accuracy:** Ratio between the result of a measurement and the true value being measured.
- **Repeatability/Precision**: The ability of the sensor to output the same value for the same input over a number of trials
- **Response Time:** Time required to observe change in output as a result of change in input

Errors

- Systematic errors: deterministic
  - Caused by factors that can be modeled and predicted
  - e.g. unequal wheel diameters or uncertainty about the exact wheelbase
- Random errors: non-deterministic
  - No prediction possible
  - However, they may be described probabilistically
  - e.g. interaction of the floor with the wheels, e.g., wheel slippage or bumps and cracks, non-returning echoes in ultrasonic sensors, etc.

Finding the Right Sensor/Actuator

- Right measurement/actuation technique
- Right size and weight
- Right operating temperature range
- Power consumption
- Cost
- Data Transfer
  - CPU Initiated (Polling)
  - Sensor Initiated (Interrupt)

Continued…

- Sensor's Output Interface
  - Binary signal (0 or 1) - Tactile sensor
  - Analog signal (e.g. 0..5V) - Inclinometer
  - Timing signal (e.g. PWM) - Gyroscope
  - Serial link (RS232 or USB) - GPS module
  - Parallel link - Digital camera
- Actuator Interface
  - Analog (Plotter)
  - Digital Pulse (Motor Driver, Relay, etc.)
  - Digital Data (Numeric Devices, Smart Actuators, etc.)

Interfacing Systems for Input Devices

- Conditioning of output signals from sensors
  - —Voltage and power level
  - —Noise reduction
- Handling analog signals
  - — Polarity
  - — Analog to digital conversion
- Handling digital interfaces
- Associated circuitry for sensor modules

Interfacing Systems for Output Devices

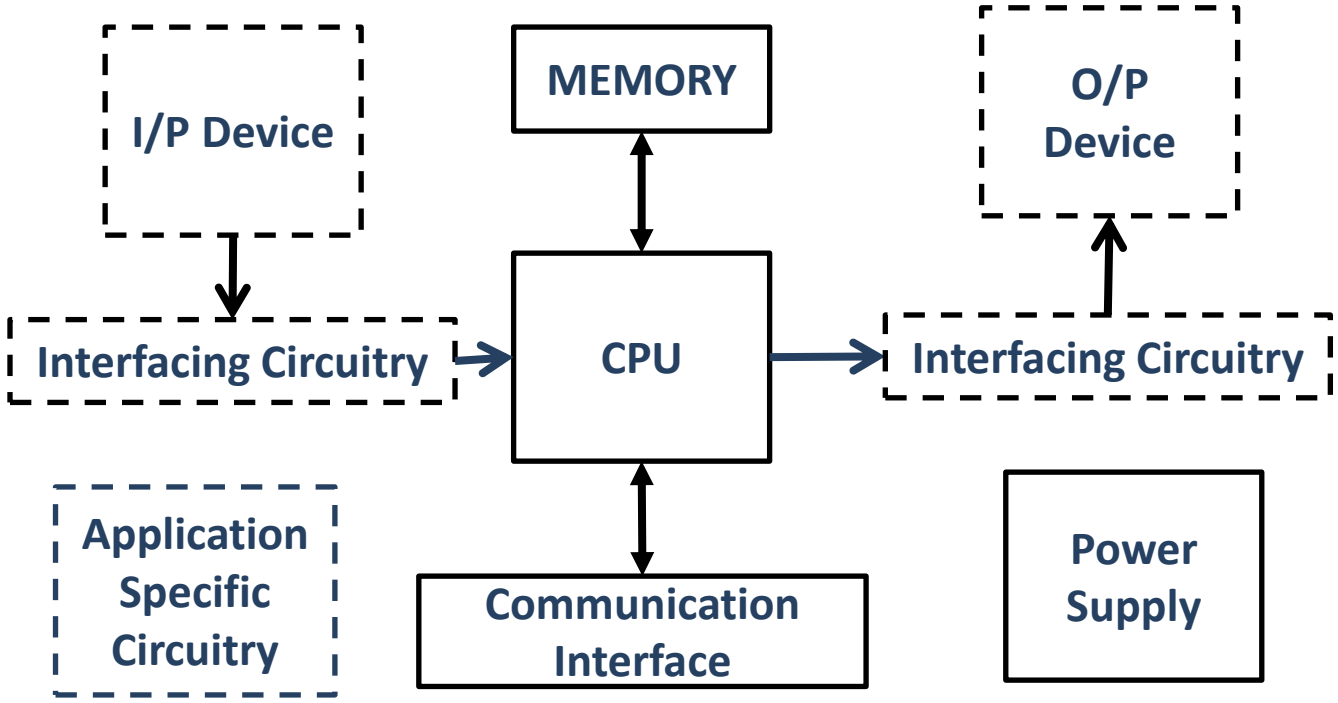
- Conditioning of input signals for actuation devices
  - —Voltage and power level
  - —Sequencing and timing
- Handling digital signals
  - —ON/OFF, Pulses
  - —Digital to analog conversion
- Handling digital interfaces
- Associated circuitry for actuator modules

Interfaces

- GPIO
- UART/USART
- SPI, SSP
- I2C, I2S
- CAN
- USB
- PWM
- DAC
- ADC
- Many more

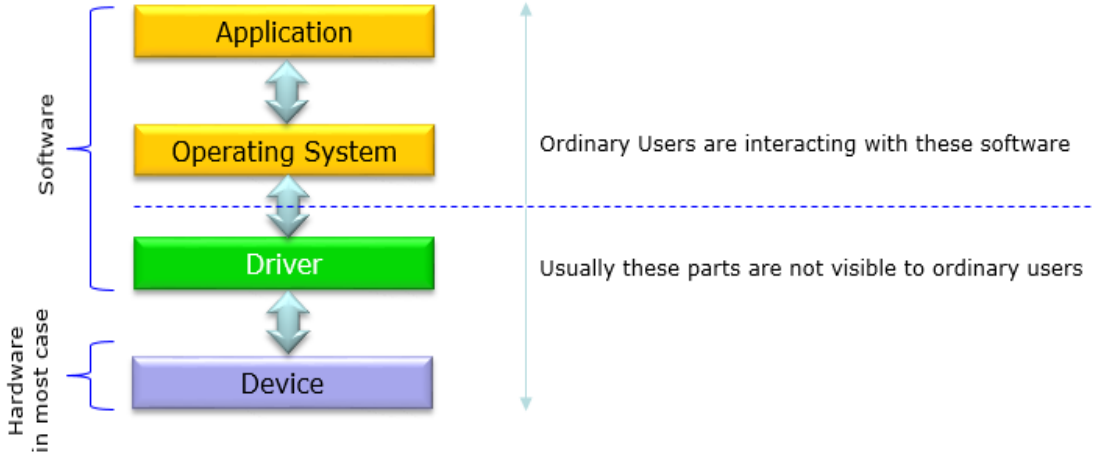
Functional blocks of IoT Edge Device - Hardware

- CPU
- Memory
- Power Supply
- Communication Interface
- Input Devices
- Output Devices
- Interfacing circuitry
- Application specific circuitry, and
- Other peripheral devices…



Functional blocks of IoT Edge Device - Software

- Application Software
  - Optional Sensing/ Actuation
  - Edge Computing
  - Protocol Conversion

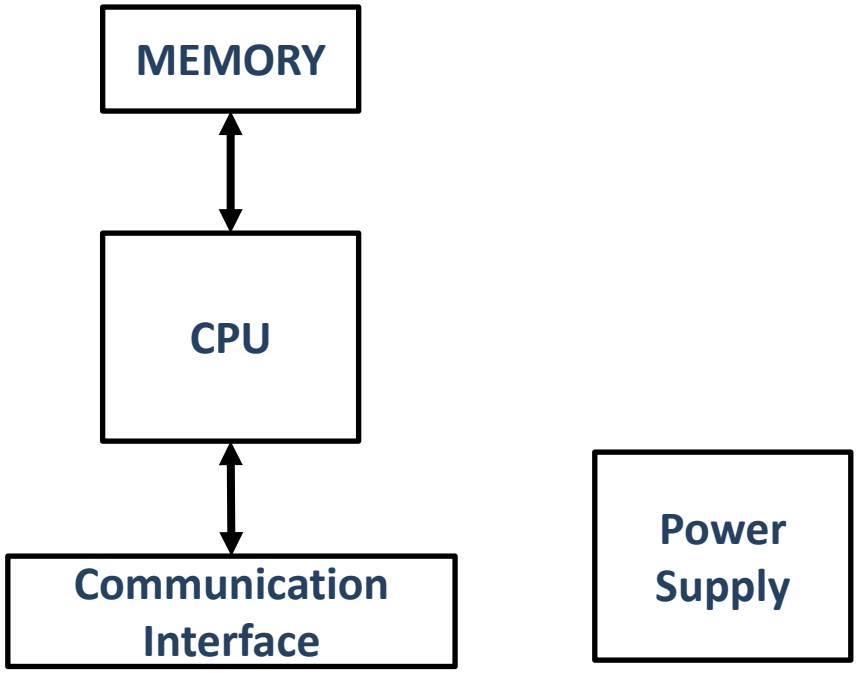


- System Software
  - Protocol Stack – APIs for communication & Protocol Conversion
  - Device Management – APIs for computing & optional operations
    - Device Drivers
    - RTOS

Functional blocks of IoT Servers - Hardware

- CPU/GPU/Distributed Processors
- Memory/Data Centers
- Power Supply
- Communication Interface

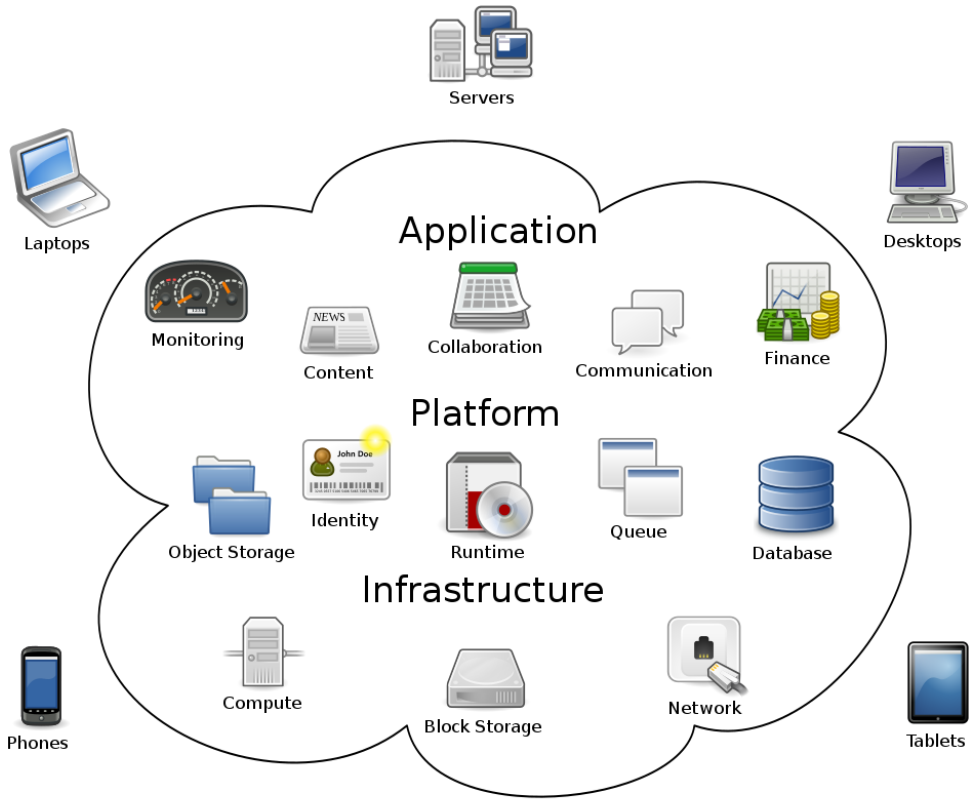
- Cloud/Networked



Functional blocks of IoT Servers - Software

- Application Software
  - Intelligent Decision Making
  - Data Analytics
  - Visualization (UIs for all stake holders)
  - Storage
- System Software
  - Protocol Stack – Server Management
  - Device Management – APIs for data & Network management
    - Device Drivers
    - OS/Network OS/RTOS

Cloud Computing

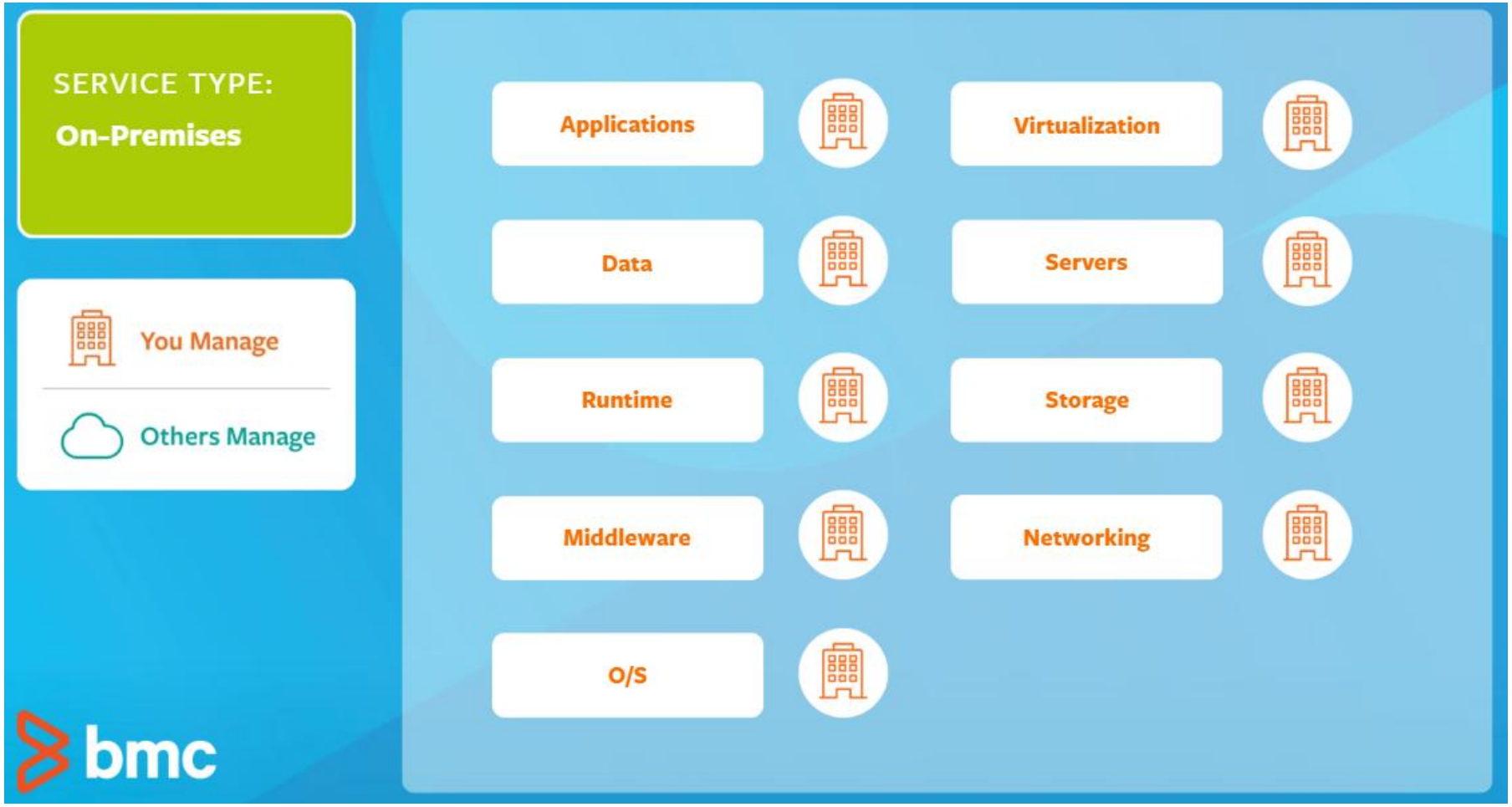


On-Premise	IaaS	PaaS	SaaS
Application	Application	Application	Application
Data	Data	Data	Data
Runtime	Runtime	Runtime	Runtime
Middleware	Middleware	Middleware	Middleware
O/S	O/S	O/S	O/S
Virtualization	Virtualization	Virtualization	Virtualization
Servers	Servers	Servers	Servers
Storage	Storage	Storage	Storage
Networking	Networking	Networking	Networking

BLUE - consumers are managing the service
ORANGE - cloud providers are managing the service

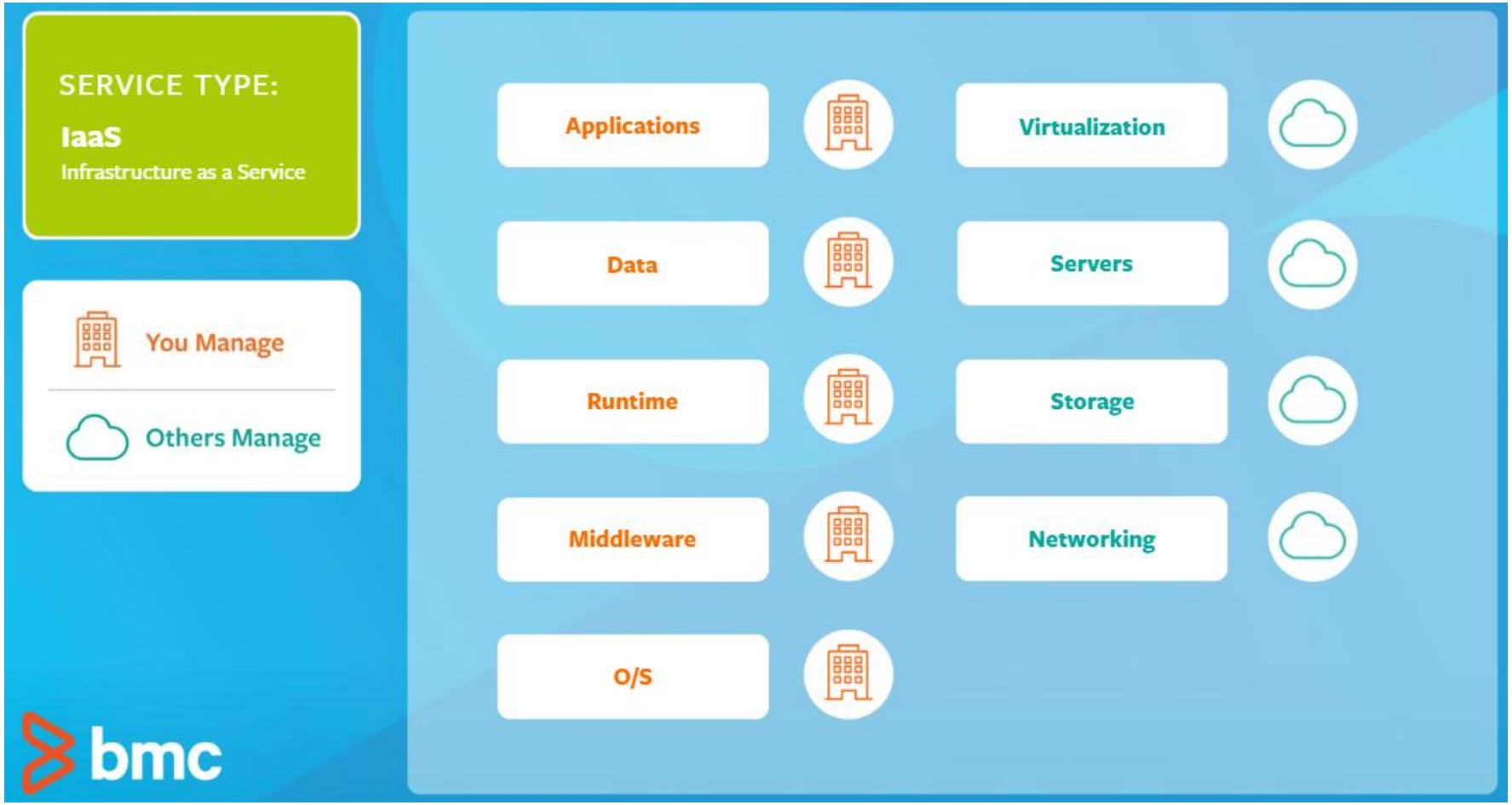
Courtesy: https://en.wikipedia.org/wiki/Cloud_computing
https://study-ccna.com/cloud-service-models-iaas-paas-saas/

On Premise



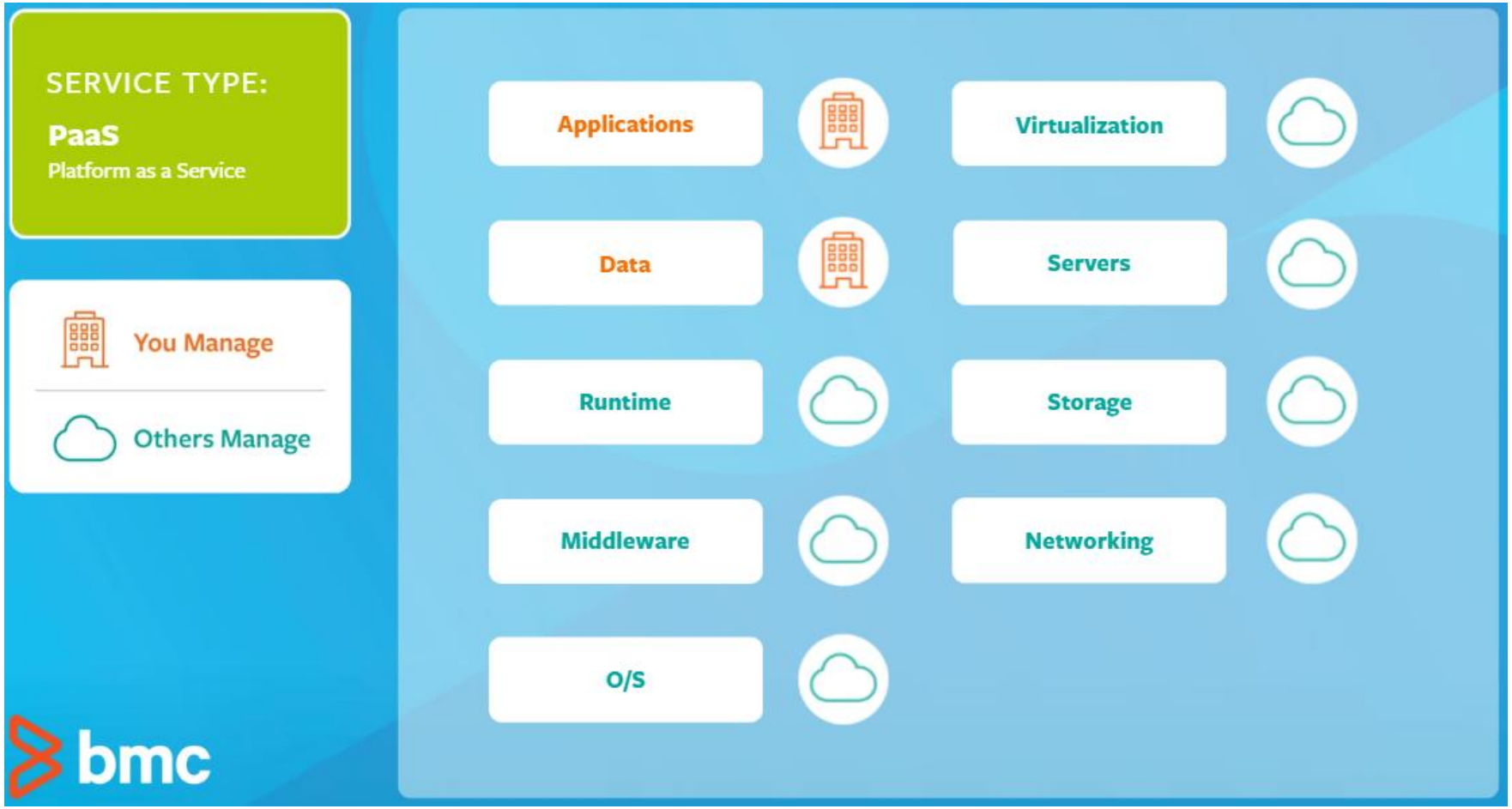
Courtesy: https://www.bmc.com/blogs/saas-vs-paas-vs-iaas-whats-the-difference-and-how-to-choose/

Infrastructure as a Service (IaaS)



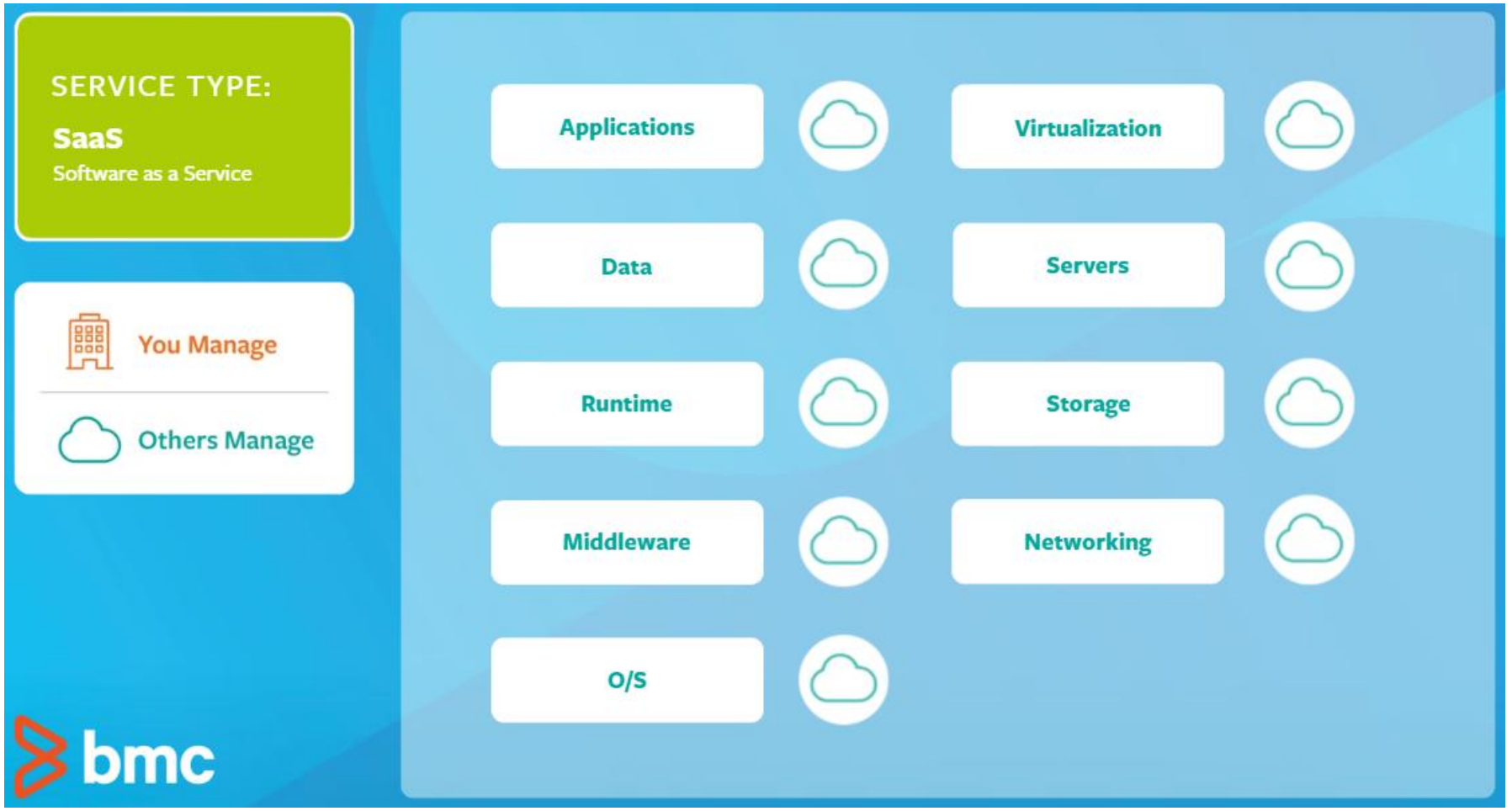
Courtesy: https://www.bmc.com/blogs/saas-vs-paas-vs-iaas-whats-the-difference-and-how-to-choose/

Platform as a Service (PaaS)



Courtesy: https://www.bmc.com/blogs/saas-vs-paas-vs-iaas-whats-the-difference-and-how-to-choose/

Software as a Service (SaaS)



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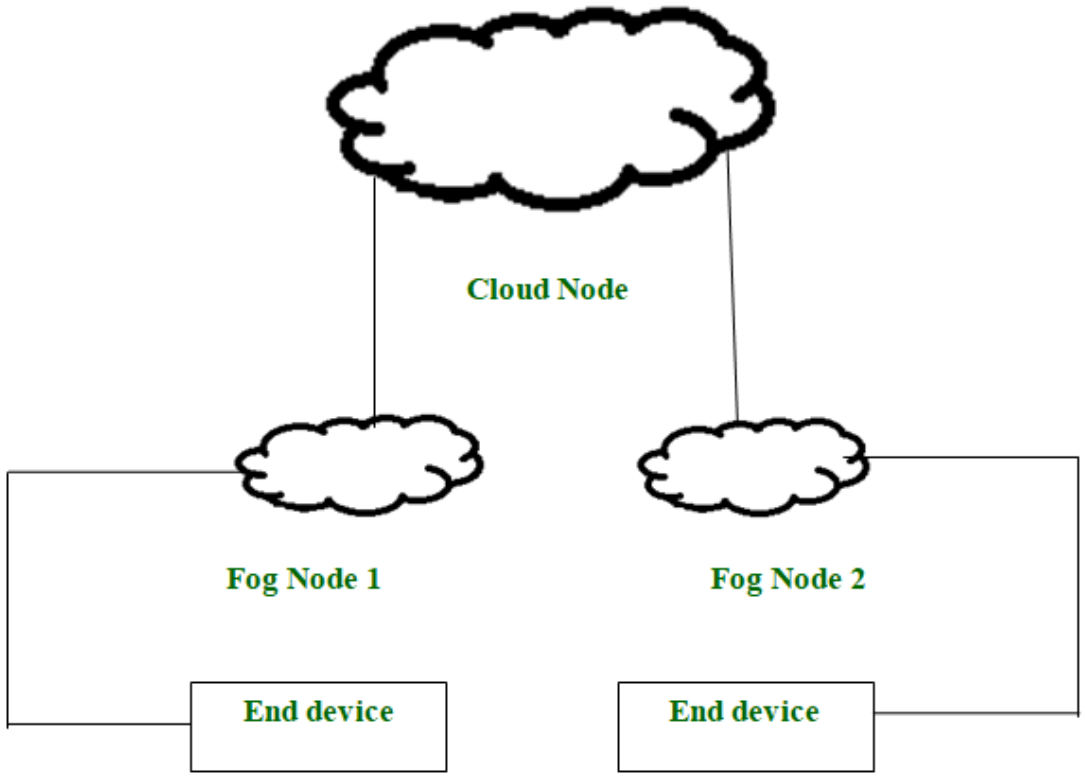
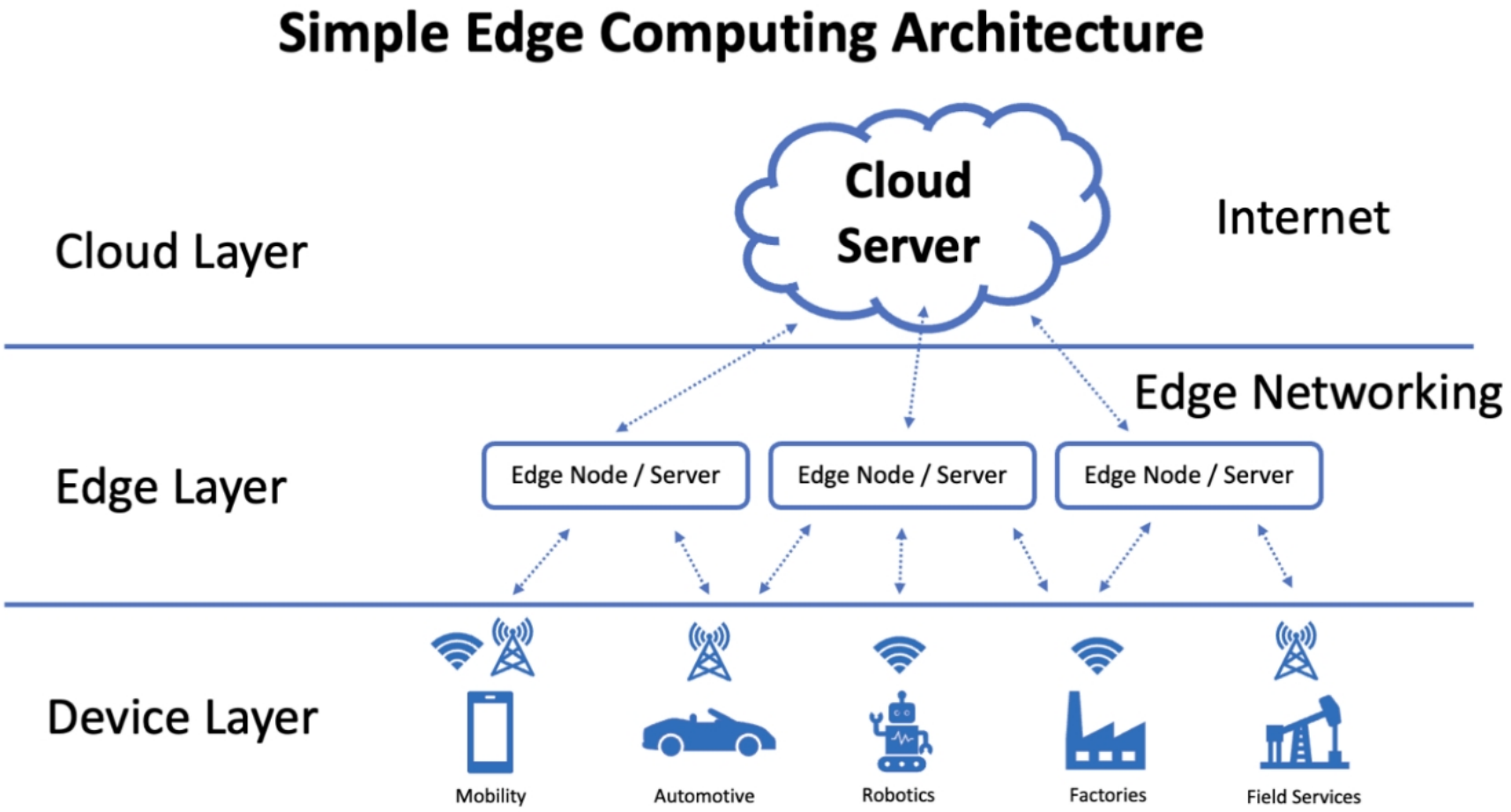
Fog Computing



Fog Computing Architecture

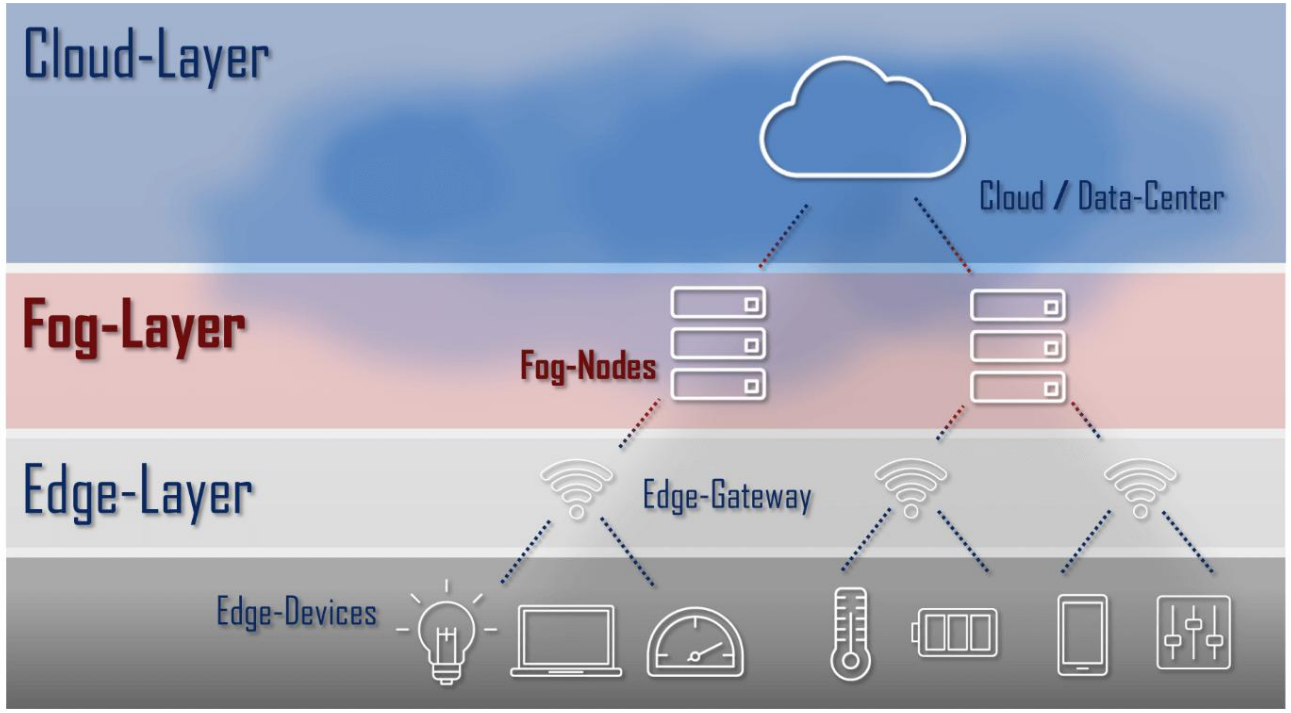
Courtesy: https://www.geeksforgeeks.org/fog-computing/
https://www.eccouncil.org/cybersecurity-exchange/ethical-hacking/fog-computing-everything-to-know/

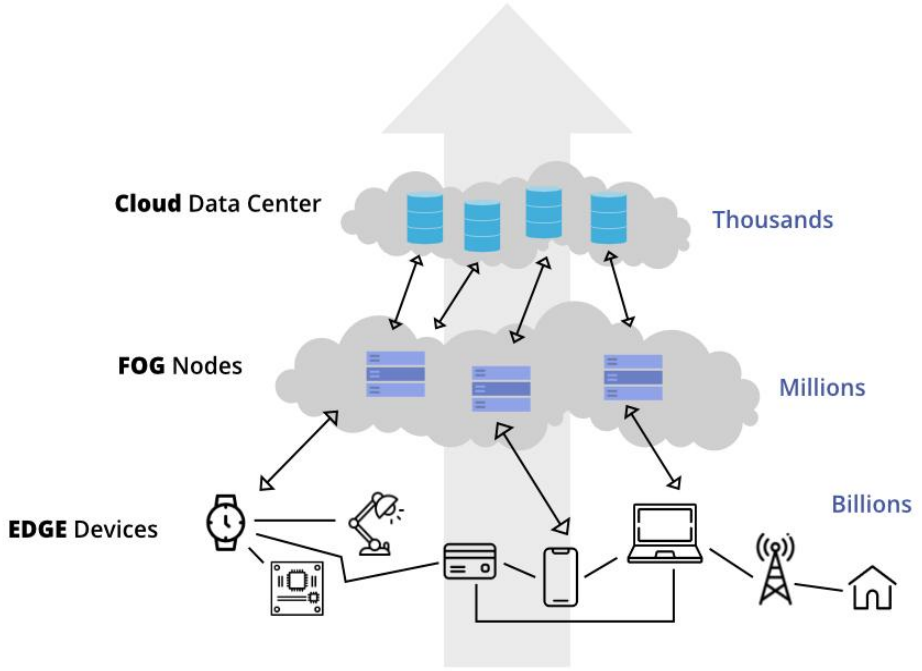
Edge Computing



Courtesy: https://www.wipro.com/infrastructure/edge-computing-understanding-the-user-experience/
https://innovationatwork.ieee.org/real-life-edge-computing-use-cases/

Fog vs Edge Computing





Courtesy: https://www.ionos.com/digitalguide/server/know-how/fog-computing/
https://www.geeksforgeeks.org/difference-between-edge-computing-and-fog-computing/

IoT Communication

- Hierarchical
- End Nodes – Edge Nodes – Cloud/Servers
  - Network Devices, Intermediate nodes
- Medium & Technology
- Options – Ethernet (Base T, Broadband, Base F, PLCC), Wi-Fi, WiMAX, BLE, ZigBee, Z-Wave, HART, Wireless HART, LoRaWAN, 6LoWPAN, Wavenis, LTE (4G/5G), NFC,

Communication Technologies

Wired

- 4-20 mA
- Ethernet
  - Twister Copper Cables
  - Coaxial Cables
  - Fiber Optic Cables
  - Power Line Conductors
- DSL
- HART
- Insteon
- Many more

Wireless

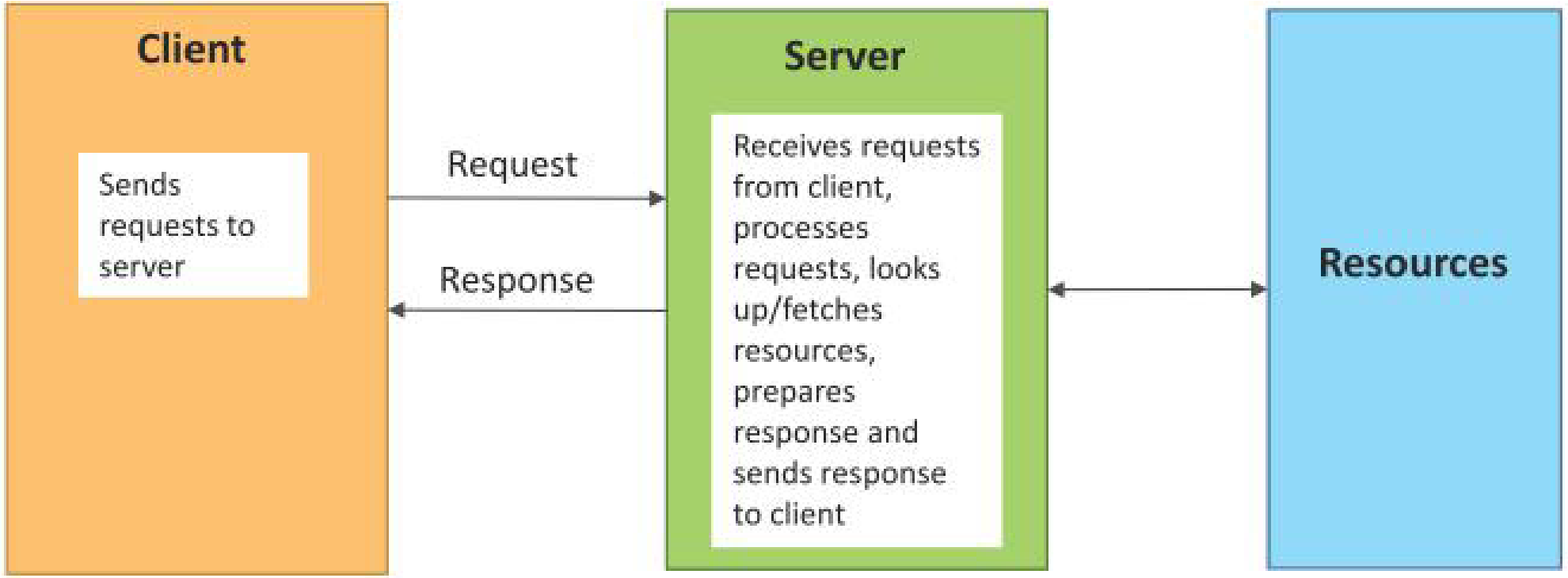
- Wi-Fi
- WiMAX
- LTE/5G
- ZigBee
- Z-Wave
- LoRA
- 6LoWPAN
- Wireless HART
- Insteon
- NFC
- Infrared
- RF
- Satellite
- AM Radio
- FM Radio
- HAM Radio
- Li-Fi
- Visible Light
- IR
- Ultrasound
- Bluetooth
- Many more

IoT Communication Models

- Request – Response
- Publish – Subscribe
- Push – Pull
- Exclusive Pair

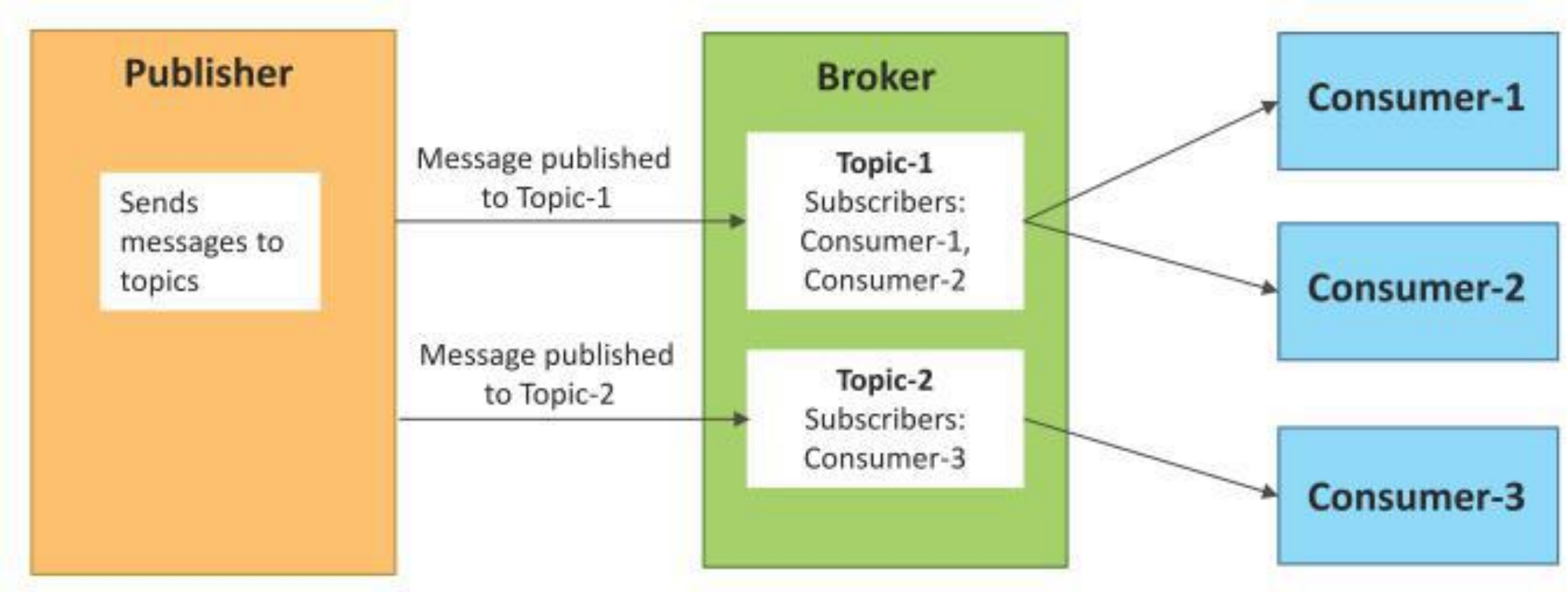
Ref: https://gyansanchay.csjmu.ac.in/wp-content/uploads/2022/08/iot-communication-model.pdf
https://www.geeksforgeeks.org/communication-models-in-iot-internet-of-things/

Request-Response Communication Model



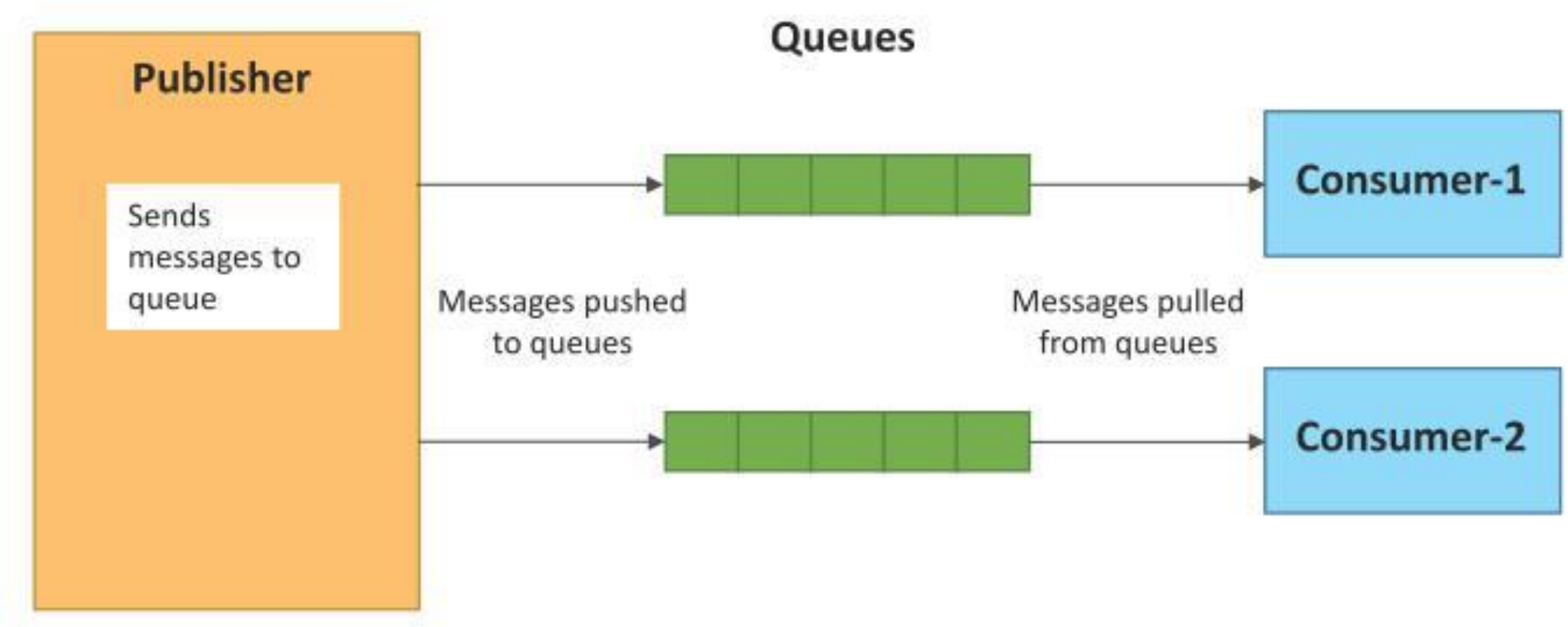
Ref: Arshdeep Bahga and Vijay Madisetti, “Internet of Things: A Hands-on Approach”, Universities Press, 2015.

Publish-Subscribe Communication Model



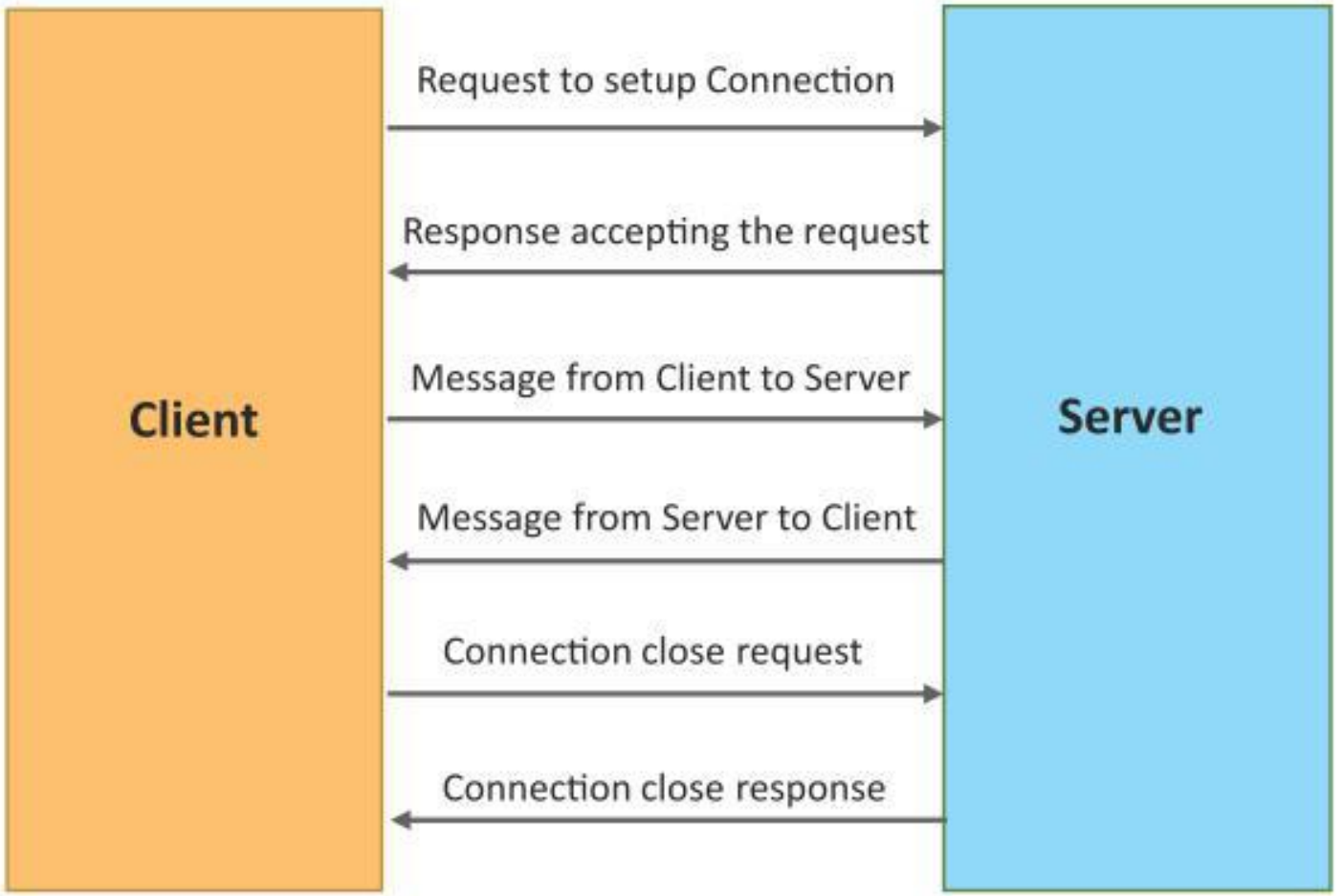
Ref: Arshdeep Bahga and Vijay Madisetti, “Internet of Things: A Hands-on Approach”, Universities Press, 2015.

Push-Pull Communication Model



Ref: Arshdeep Bahga and Vijay Madisetti, “Internet of Things: A Hands-on Approach”, Universities Press, 2015.

Exclusive Pair Communication Model



Ref: Arshdeep Bahga and Vijay Madisetti, “Internet of Things: A Hands-on Approach”, Universities Press, 2015.

IoT Services – What?

- Computing
- Data Analytics
- Intelligence
- System wide state awareness
- Matured Decision making
- And many more…

IoT – Management

- Node Management
- Network Management
- Services Management
- Application Management

IoT – Security

- Security – Device, Data & Network
- Confidentiality, Integrity, Availability, Authenticity
- Unauthorized access, Malicious software, etc.
- Cryptography, Digital Signatures, Authentication protocols, Privacy
- Intruders, Denial of Service, Viruses, etc.
- Web Security, Transport layer security, Firewalls, Firmware security, etc.

Ref: https://www.balbix.com/insights/addressing-iot-security-challenges/;
https://www.peerbits.com/blog/biggest-iot-security-challenges.html
https://www.kaspersky.com/resource-center/preemptive-safety/best-practices-for-iot-security

IoT – Applications

- Industrial (IIoT) - Smart Infrastructure, Surveillance, Security, etc.
- Healthcare - Smart Hospitals, Body area networks, etc.
- Agricultural – Smart Infrastructure, Precision agriculture, etc.
- Vehicular – V2X networks, Smart Transportation, etc.
- Smart grid – WAMPAC, AMI, etc.
- Smart city - Smart Infrastructure, e-services, etc.
- Robotics – IoD, Robotic Surgery, Collaboratory robots, etc.
- And many more…

IoT – Challenges

- Design – Interoperability, Scalability, Power Consumption
- Ease of Integration – Connectivity, Software & Hardware
- Reliability and Quality – Constraints, Performance metrics
- Security – Device, Data, Network & Privacy
- Costs – Cost vs Performance, Time to market, Features
- Development Skillset
- Deployment – Cross platform capability, Heterogeneity
- Data handling & Infrastructure

Ref: https://www.geeksforgeeks.org/challenges-in-internet-of-things-iot/
https://bytebeam.io/blog/top-8-challenges-in-iot-development/

Thank You…