UNIVERSITÀ DEGLI STUDI DI BERGAMO | Department of Engineering and Applied Sciences

From IoT to LoRAWAN: Fundamentals for Industrial Applications

Industrial IoT

Department of Ingineering and Applied Sciences

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Objectives

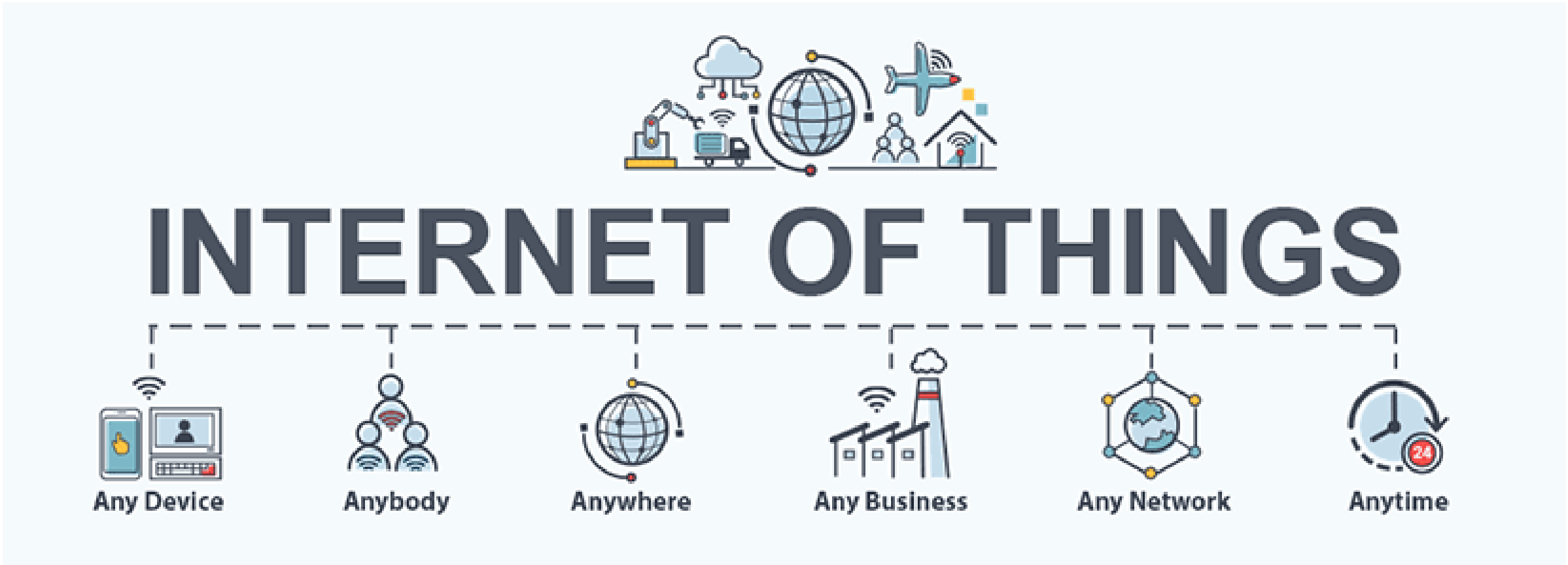
- Contextualize IoT
- Review the OSI model
- LPWAN Technologies
- Explain the LoRa physical layer
- Describe the LoRaWAN protocol
- Present the ecosystem of tools
- Prepare the laboratory

Index

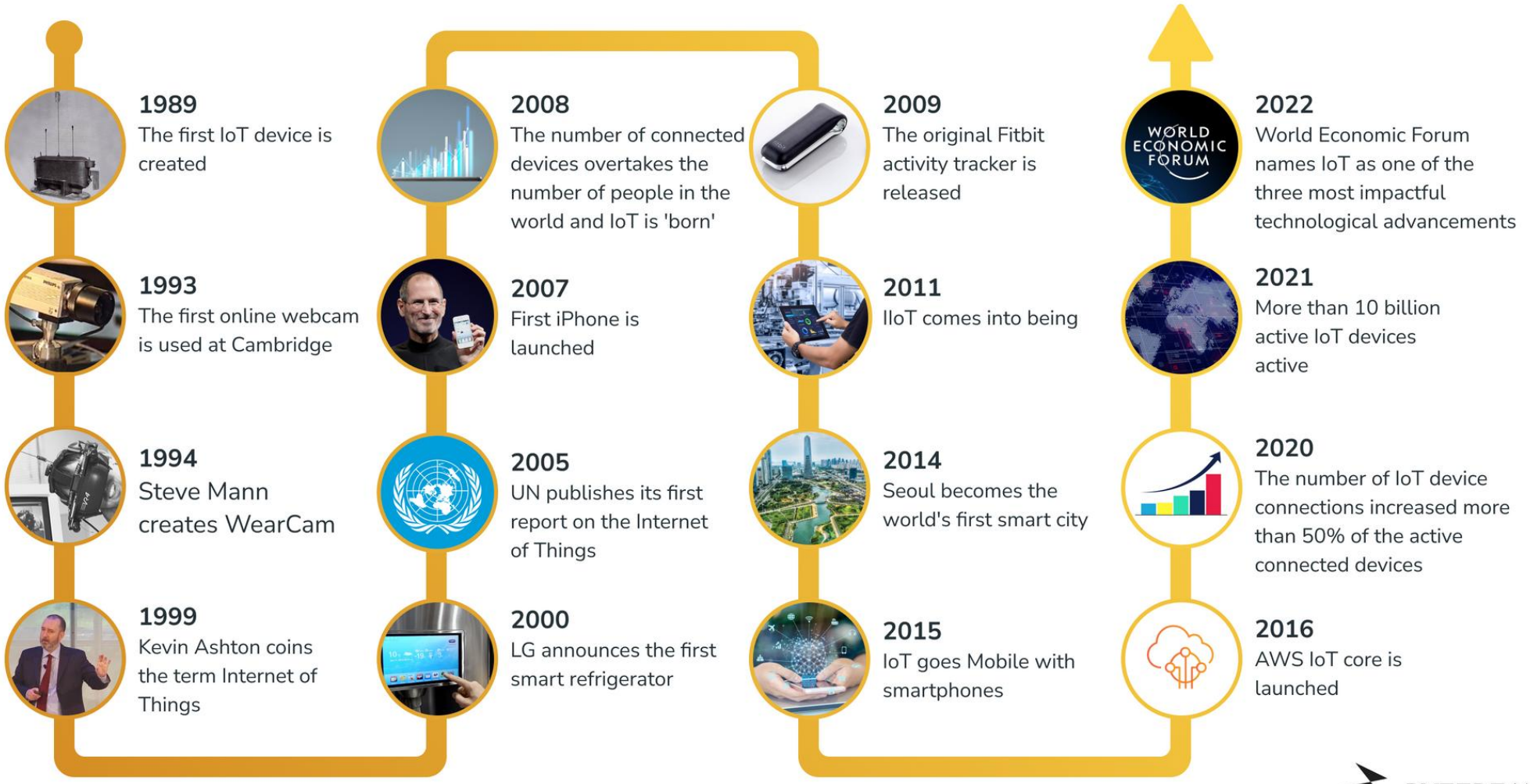
- Introduction to IoT
- OSI Model
- LPWAN
- LoRa
- LoRaWAN
- Integration & Data-Pipeline Tools
- Conclusions & Takeaways
- Hands-On Exercise

Introduction to IoT

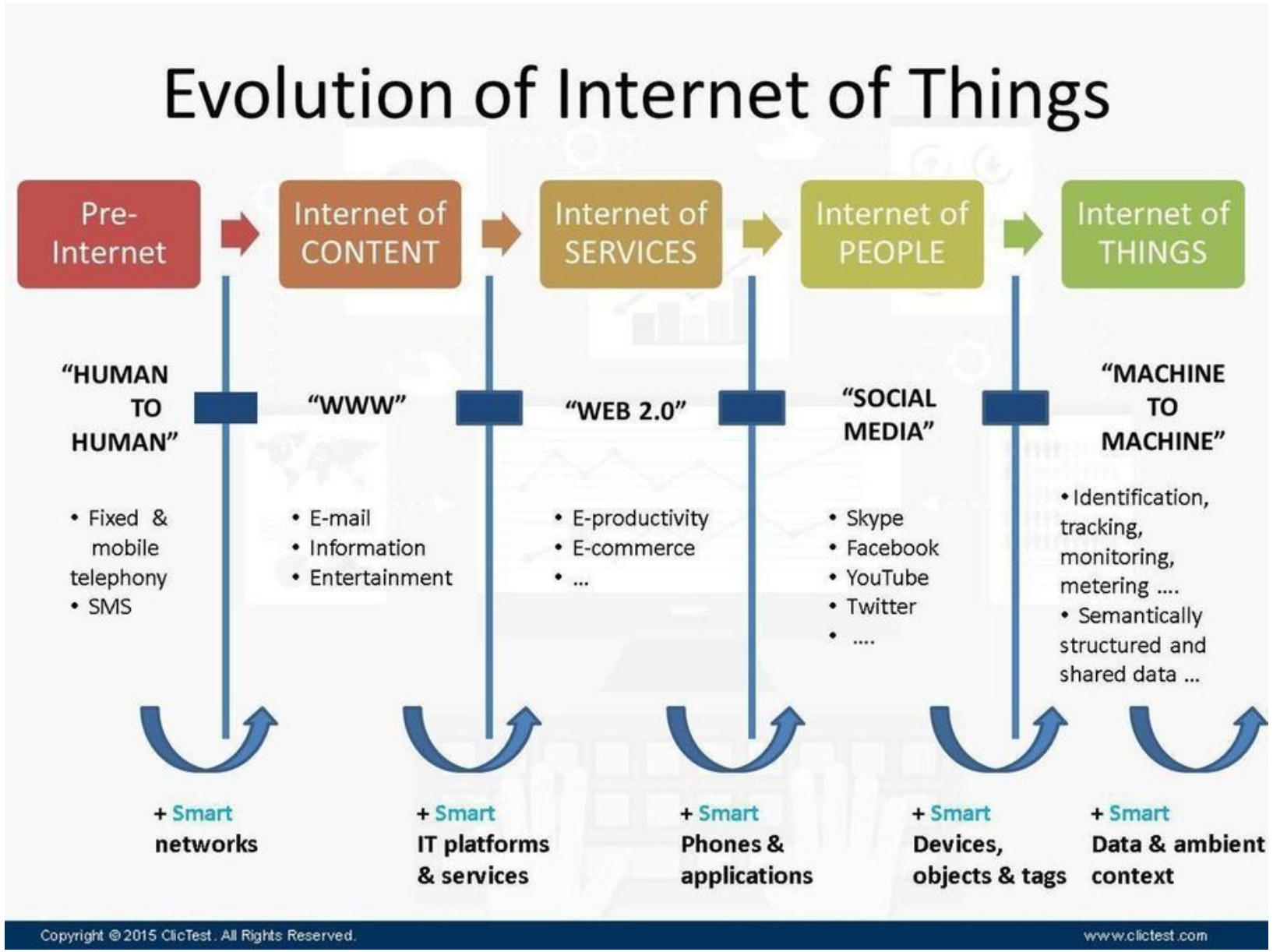
"Everything is connected at all times, anywhere, using any means"



IoT timeline



BYTEBEAM


Evolution of Internet of Things
Pre-Internet
Internet of CONTENT
Internet of SERVICES
Internet of PEOPLE
Internet of THINGS
"HUMAN TO HUMAN"
• Fixed & mobile telephony
• SMS
"WWW"
• E-mail
• Information
• Entertainment
"WEB 2.0"
• E-productivity
• E-commerce
• ...
"SOCIAL MEDIA"
• Skype
• Facebook
• YouTube
• Twitter
• ....
"MACHINE TO MACHINE"
• Identification, tracking, monitoring, metering ....
• Semantically structured and shared data ...
+ Smart networks
+ Smart IT platforms & services
+ Smart Phones & applications
+ Smart Devices, objects & tags
+ Smart Data & ambient context
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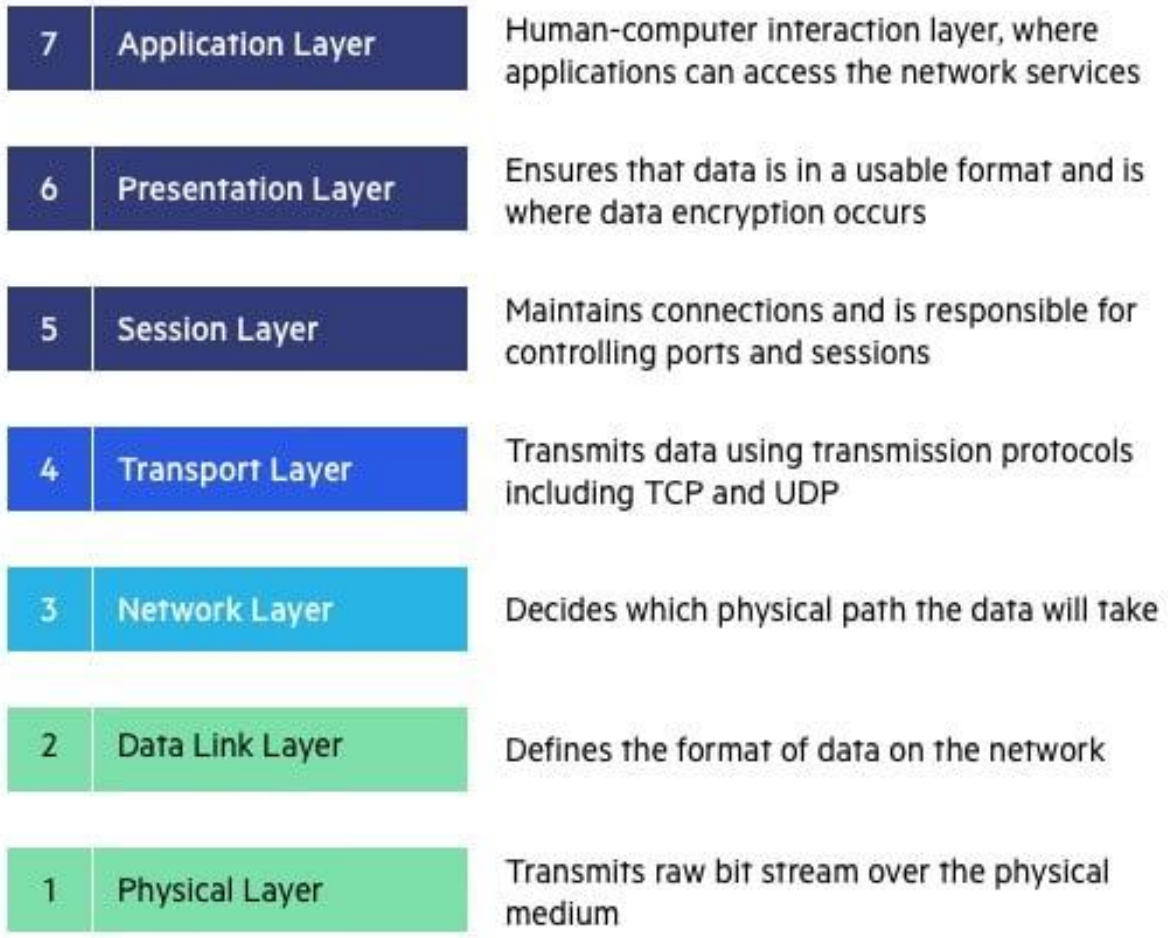
OSI/ISO Model

- The OSI model (Open Systems Interconnection) is a reference model for computer networks developed by ISO (International Organization for Standardization)

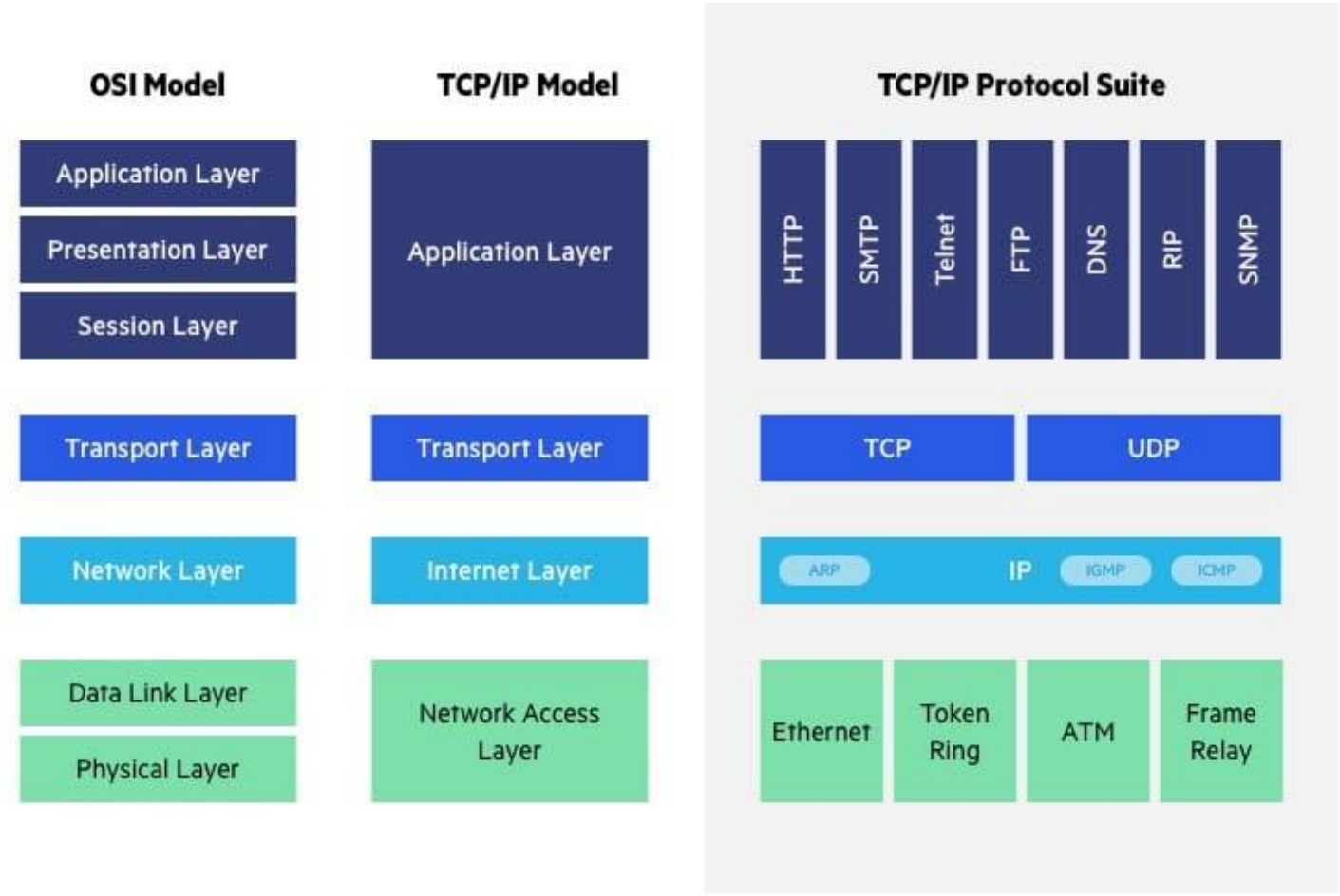


Why was the OSI/ISO model created?

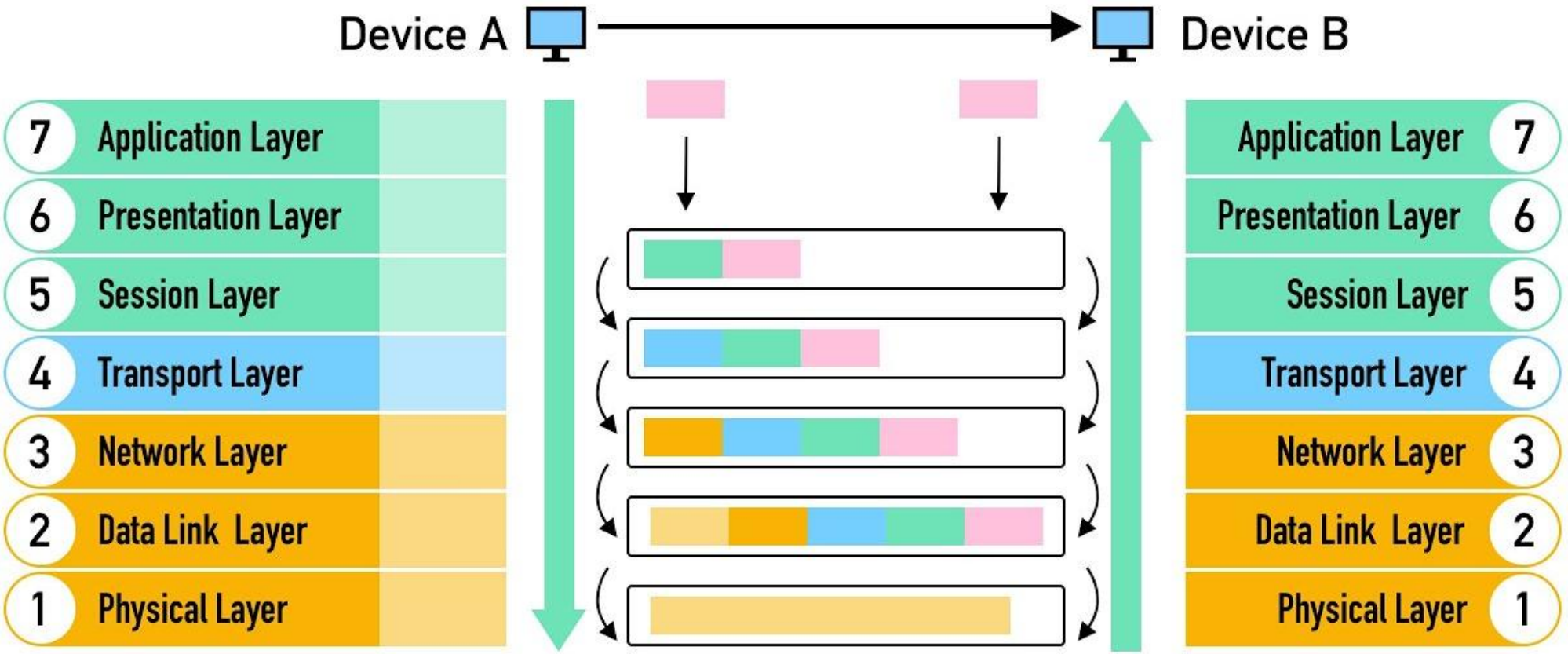
R – Standardization and Interoperability

TCP/IP x OSI Model

- The IP and TCP protocols were created before the OSI model.
- That's why there is a TCP/IP model.
- The OSI model is more abstract, while TCP/IP is more practical.

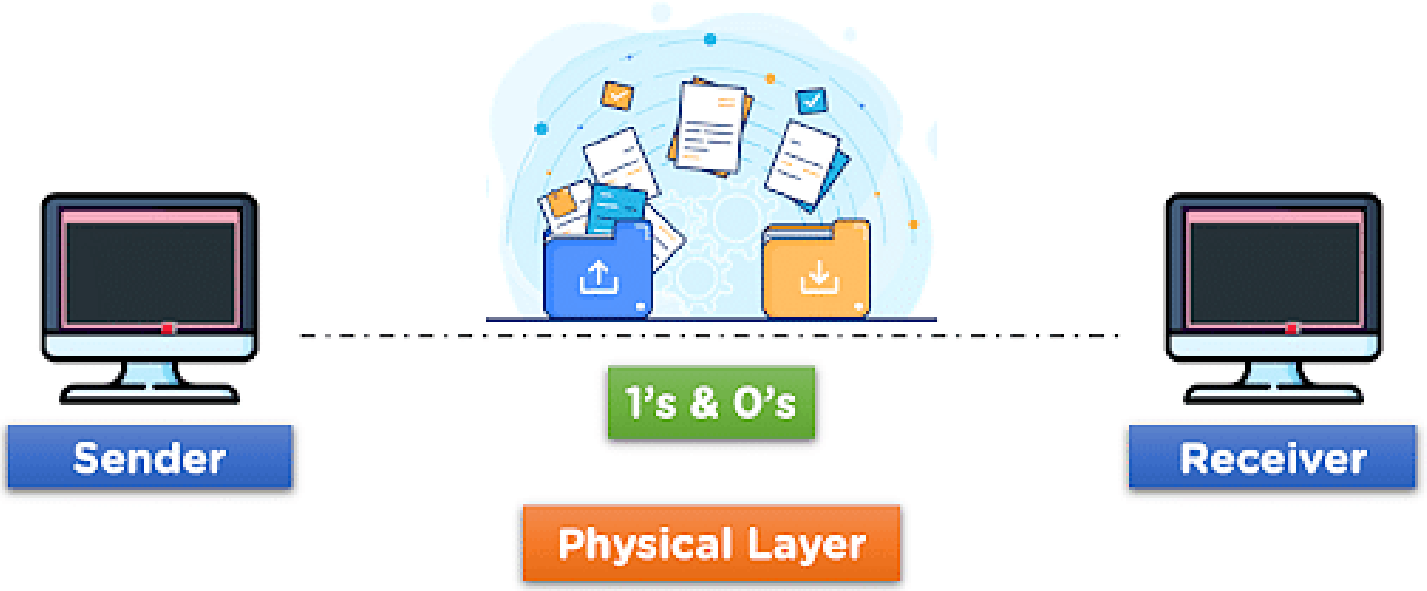


Communication between OSI/ISO model layers



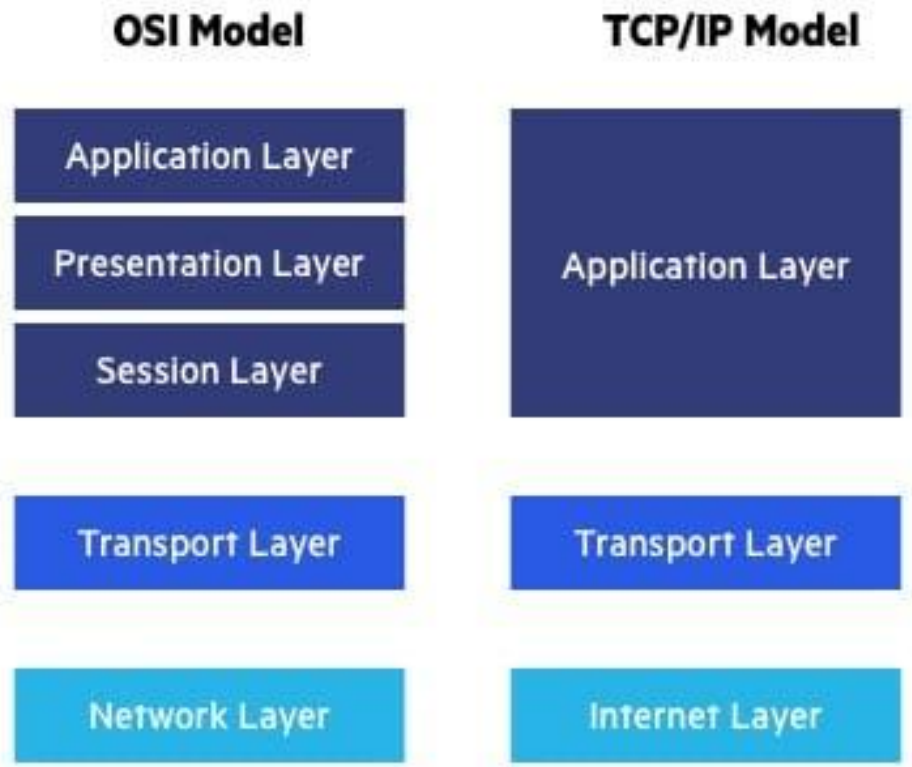
The Physical Layer

- It is responsible for:
  - Transmission and reception.
  - Specifications of the physical medium and physical interface.
  - Signals, encoding, and bit synchronization.
  - Transmission rate.



Data Link Layer

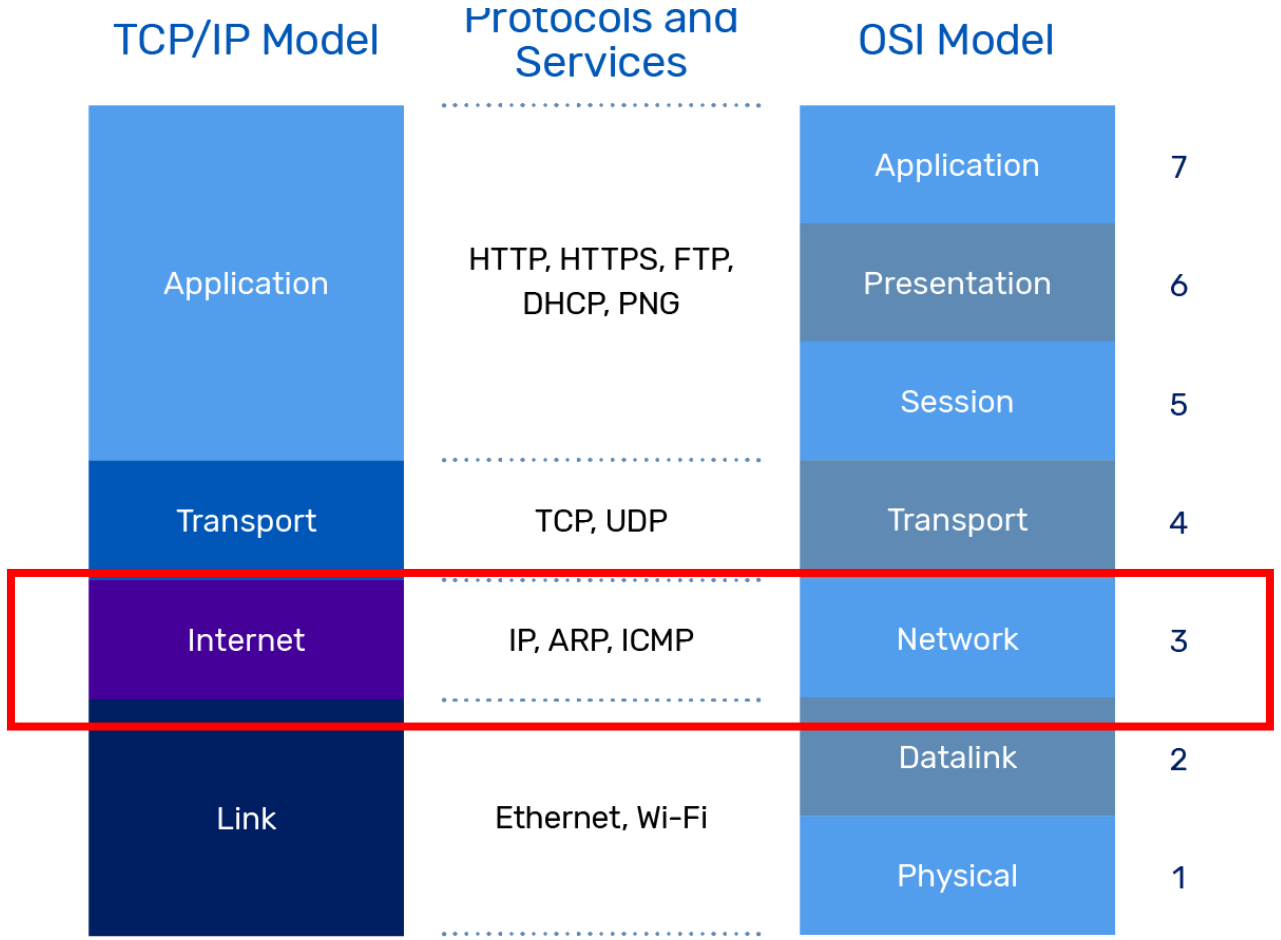
- The Data Link layer includes protocols like Ethernet (IEEE 802.3), WiFi (IEEE 802.11), NB-IoT, Bluetooth, LoRaWAN, etc.
- These protocols also define the access method to the communication medium.



NB-IoT Bluetooth LoRaWAN Wi Fi ETHERNET

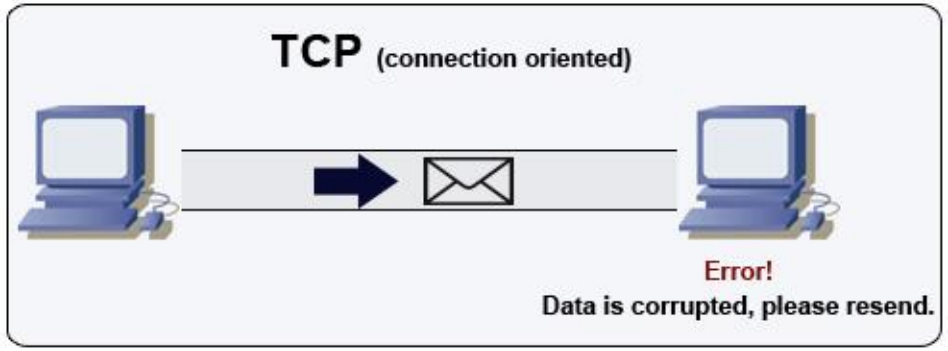
Network Layer

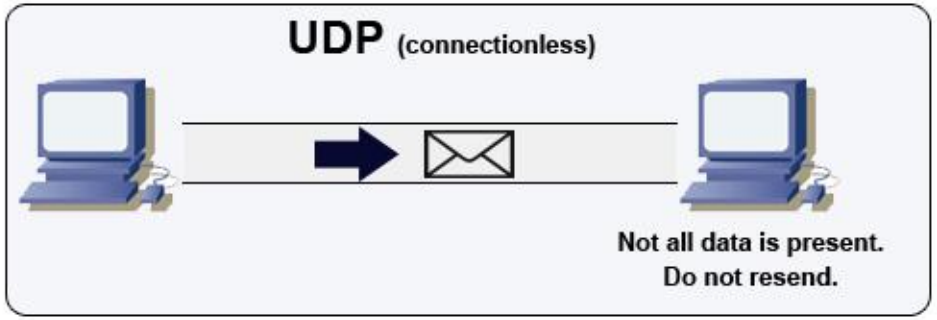
- This is the third layer of the OSI model.
- It is responsible for transmitting datagrams across different networks.
- The protocol used at this layer is the Internet Protocol (IP – IPv4 and IPv6).

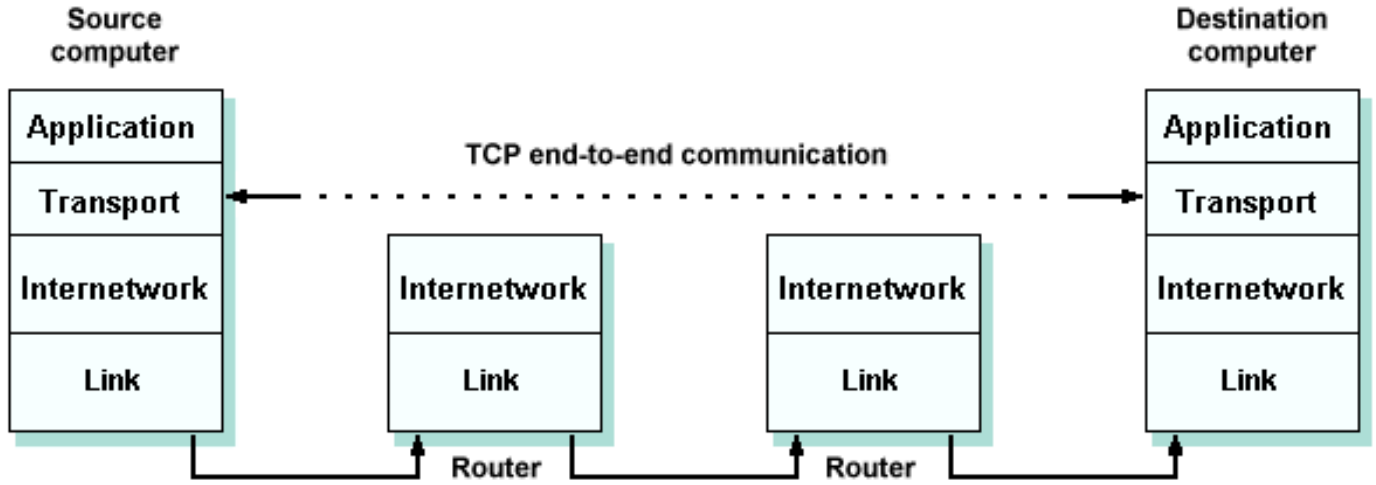


Transport layer

- It is the fourth layer of the OSI model.
- Responsible for end-to-end communication between devices.
- The two main protocols are UDP and TCP.

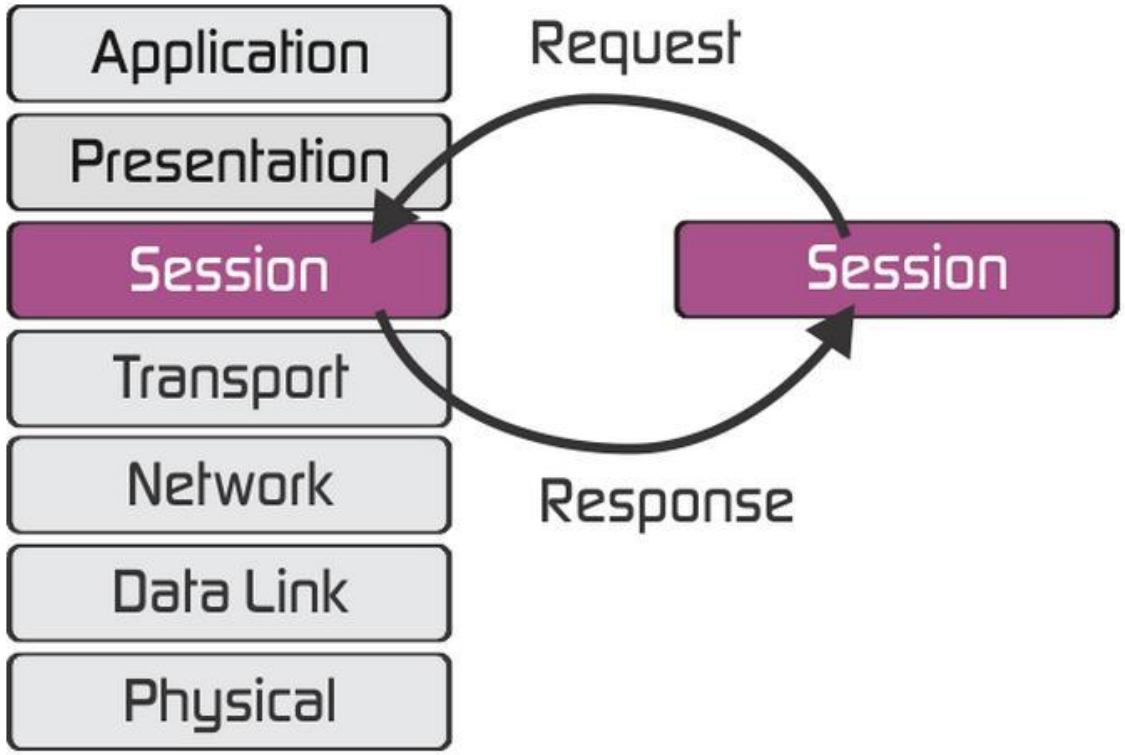






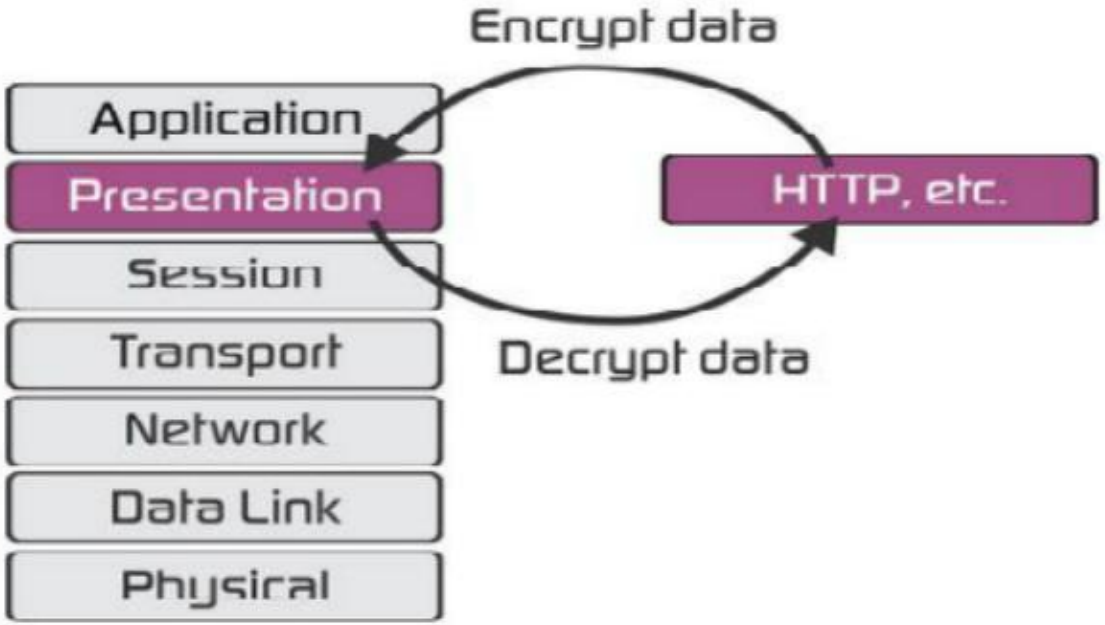
Session Layer

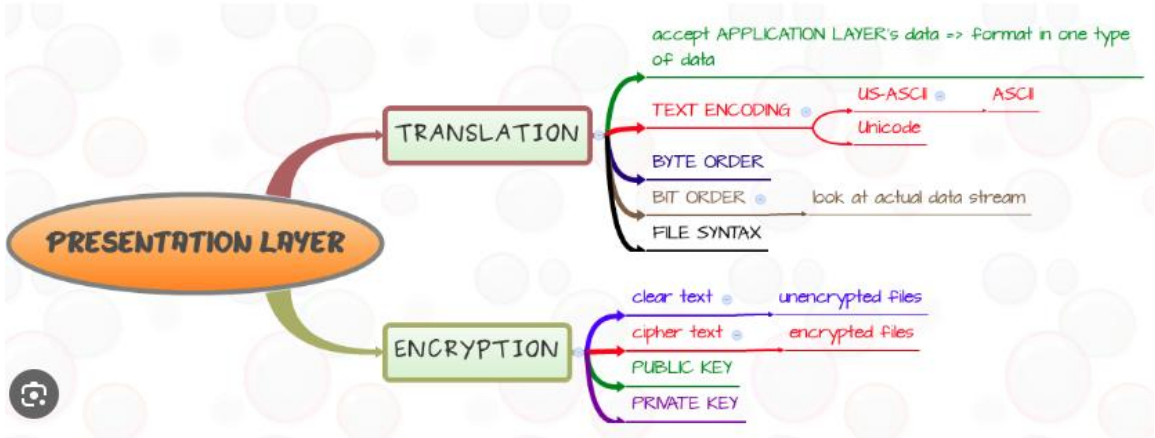
- The Session layer is the fifth layer of the OSI model (usually abstracted within the application layer).
- It is used for session control (dialog between an application on two different devices).



Presentation Layer

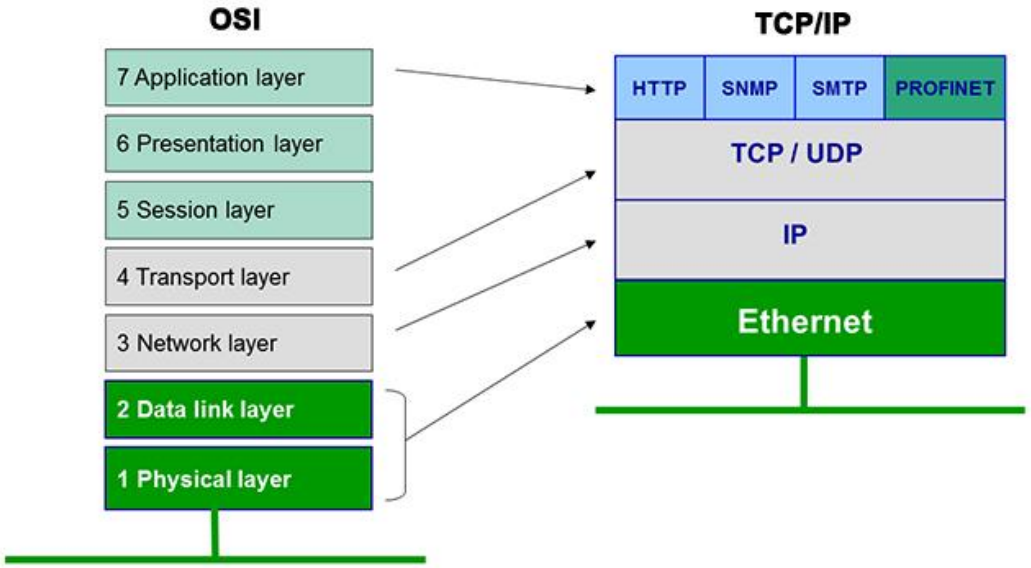
- It is the sixth layer of the OSI model (usually abstracted within the application layer).
- It handles: encryption, translation, data formatting, and compression.

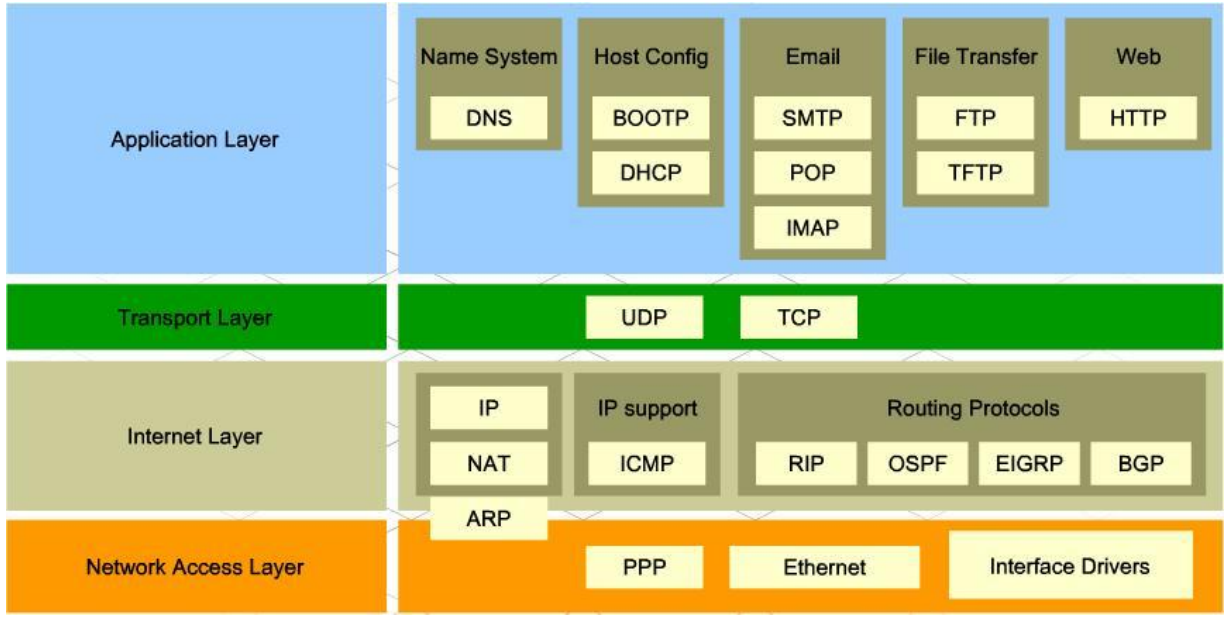




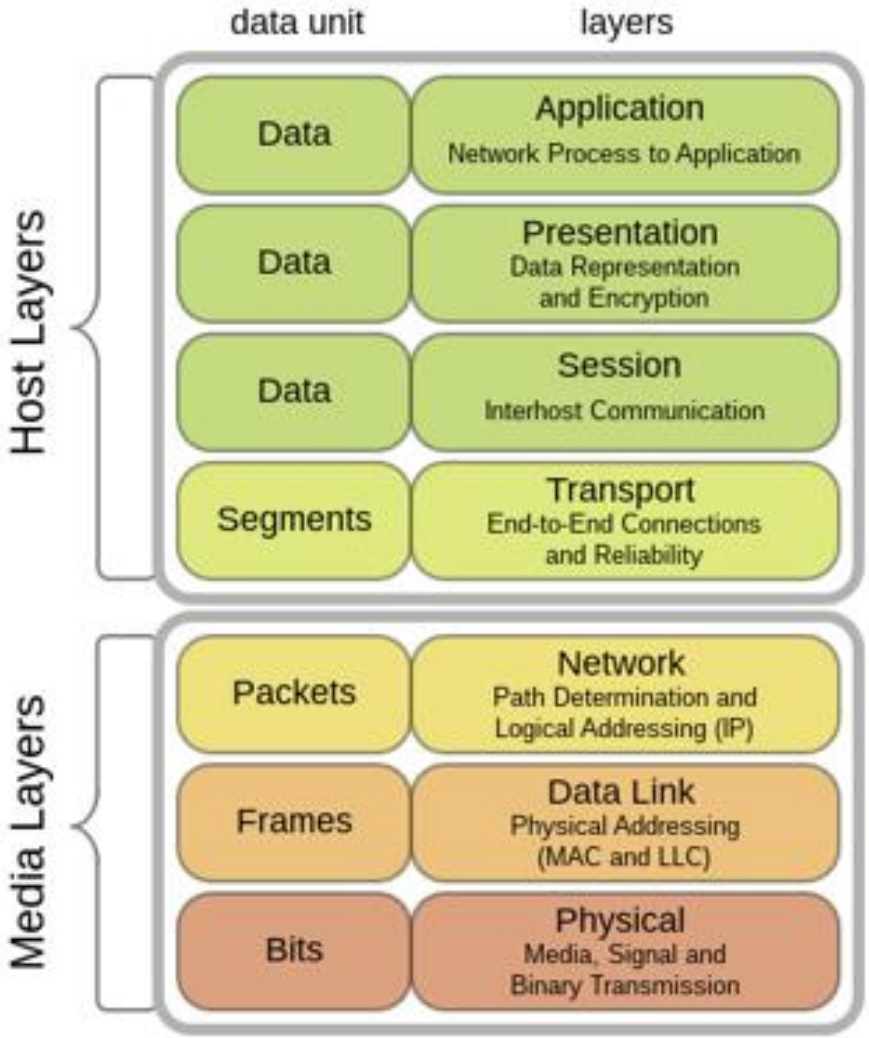
Application Layer

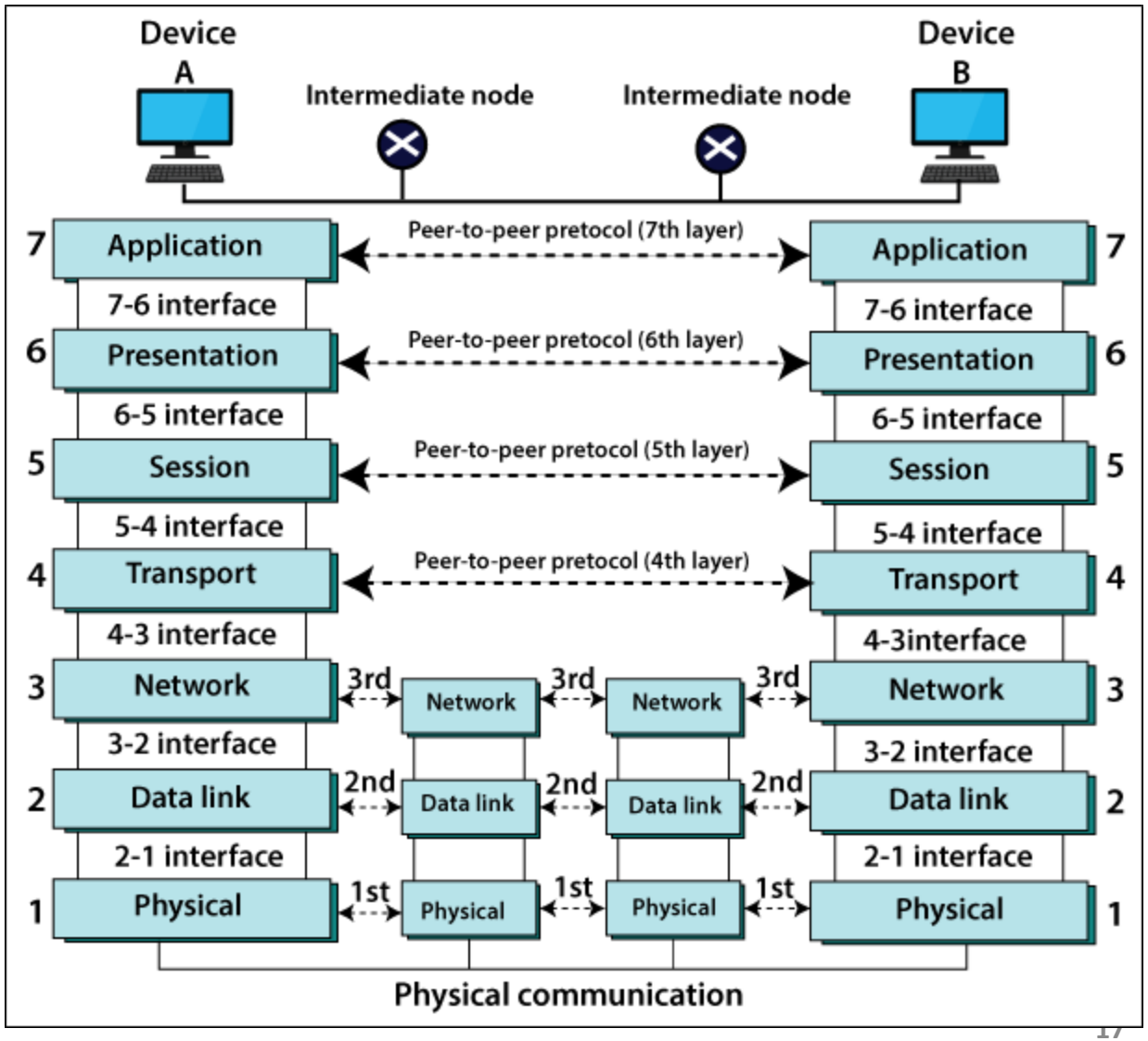
- The seventh layer of the OSI/ISO model.
- This is where you find network services used by end users.



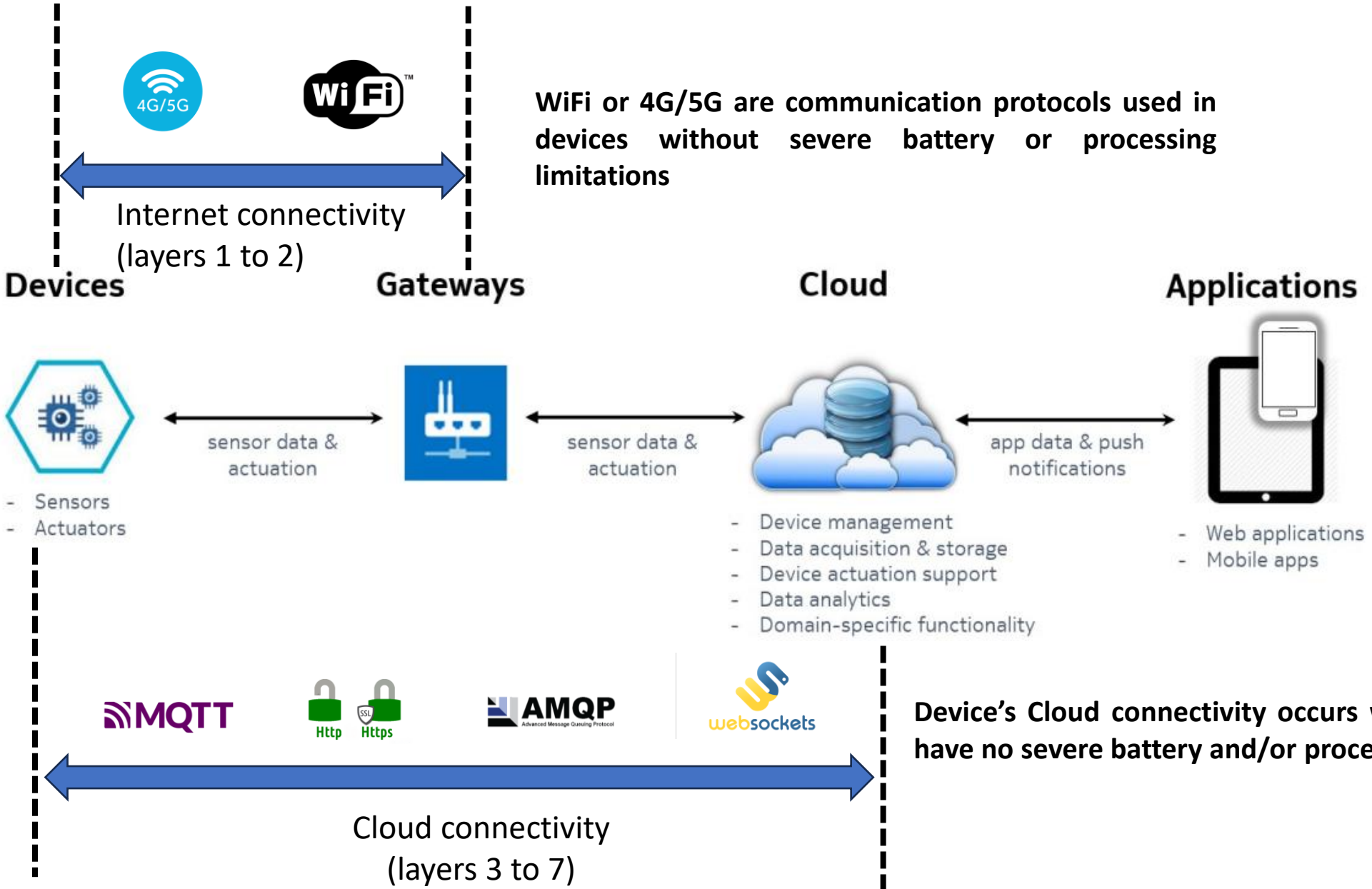


OSI/ISO Model Stack Overview





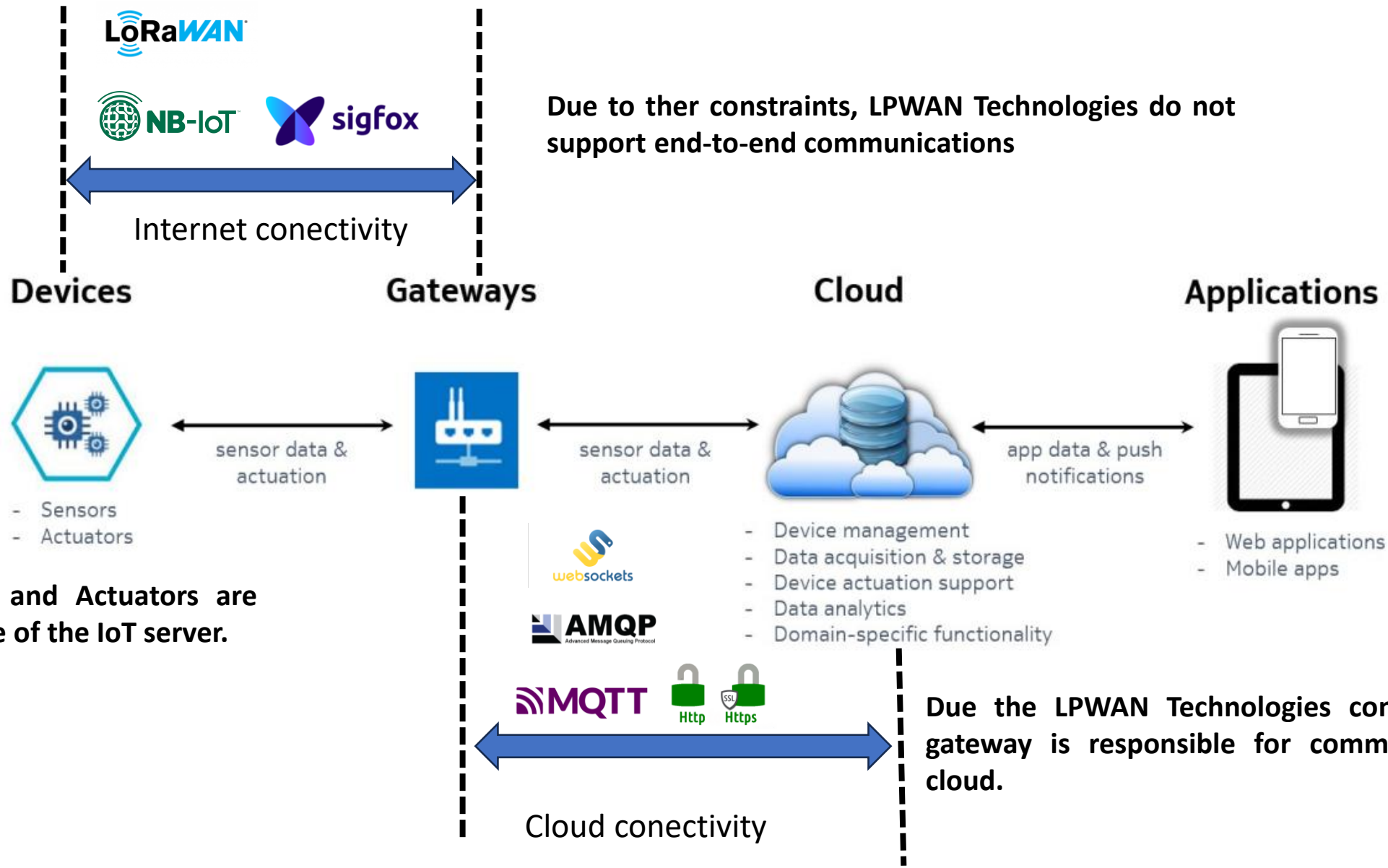
IoT Network Architecture using WiFi/4G/5G inside OSI Model



WiFi or 4G/5G are communication protocols used in devices without severe battery or processing limitations

Device's Cloud connectivity occurs when IoT devices have no severe battery and/or processing constraints.

IoT Arquitecture using LPWAN inside OSI Model



Due to ther constraints, LPWAN Technologies do not support end-to-end communications

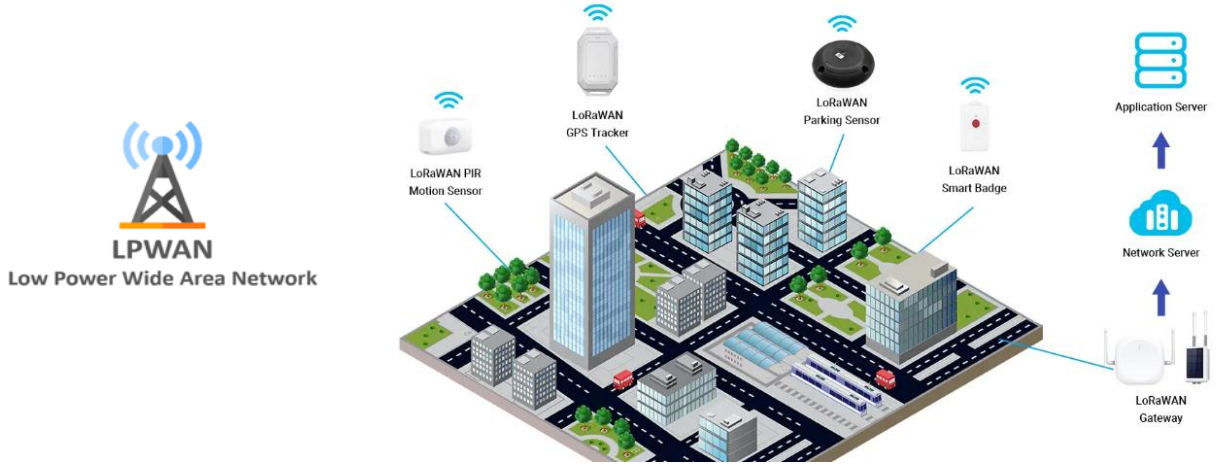
Sensors and Actuators are unaware of the IoT server.

Due the LPWAN Technologies constraints, the IoT gateway is responsible for communication to the cloud.

Internet Conectivity (layers 1 and 2 of OSI Model Stack)

- **Wi-Fi**: Common in residential environments, offering a good combination of range and speed.

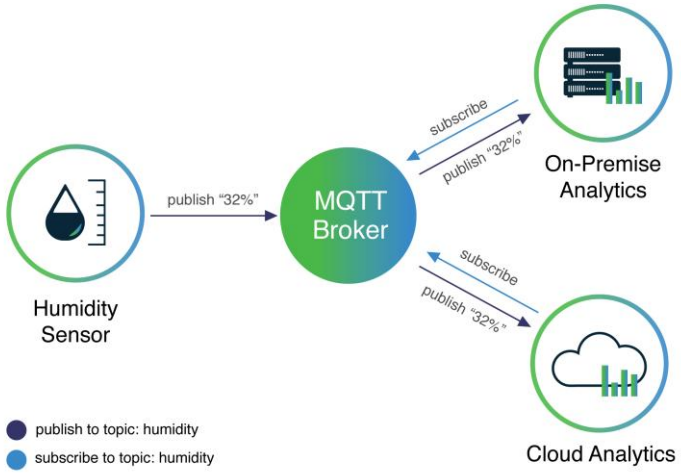
- **LPWAN (Low Power Wide Area Network)**: designed for devices that need to send small amounts of data over long distances, optimizing energy usage



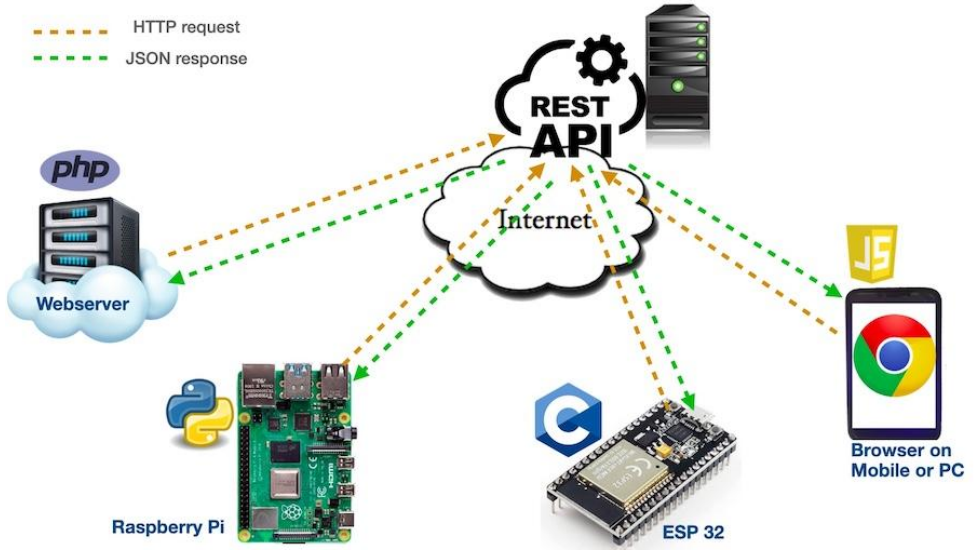
- **Cellular** technologies (4G/LTE and 5G): provide wide coverage and mobility, suitable for IoT devices that operate across different locations or while moving

Cloud conectivity (layers 3 to 7 of OSI Model Stack)

- **MQTT**: lightweight, publish/subscribe-based, designed for low-bandwidth connections and resource-constrained devices.



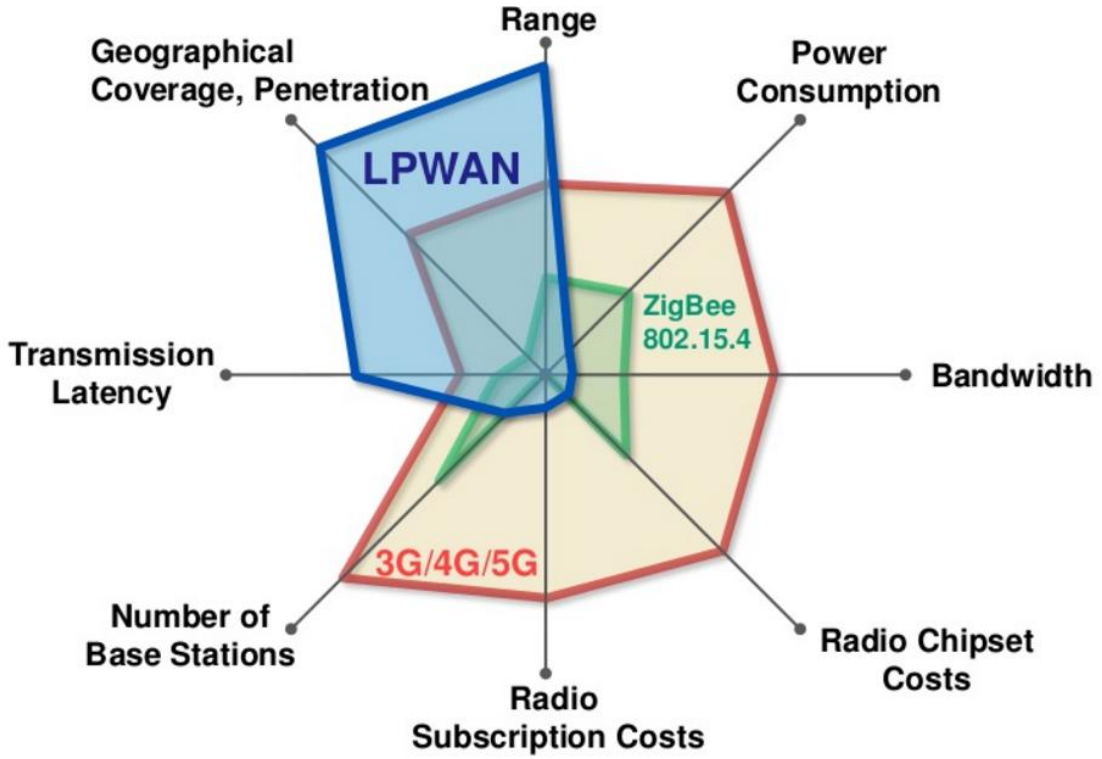
- **HTTP/HTTPS**: hypertext transfer protocol — the backbone of web communication. HTTPS adds a security layer (SSL/TLS)



- **WebSocket**: provides full-duplex communication over a single TCP connection, enabling real-time interaction between sensors/actuators and end users.

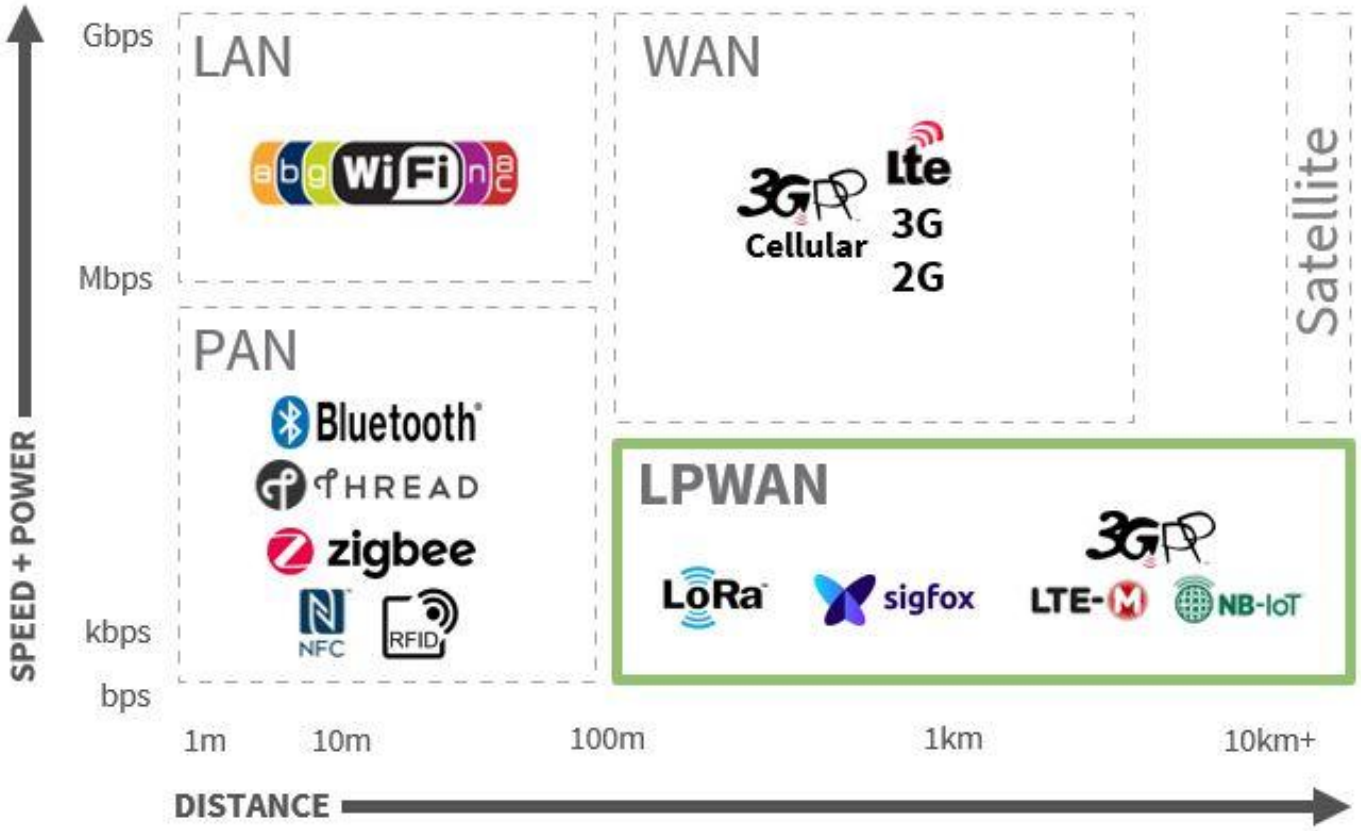
LPWAN

- IoT devices need to do more with fewer computational resources.
- Battery consumption becomes critical in many applications
- LPWAN technologies arise in this context.



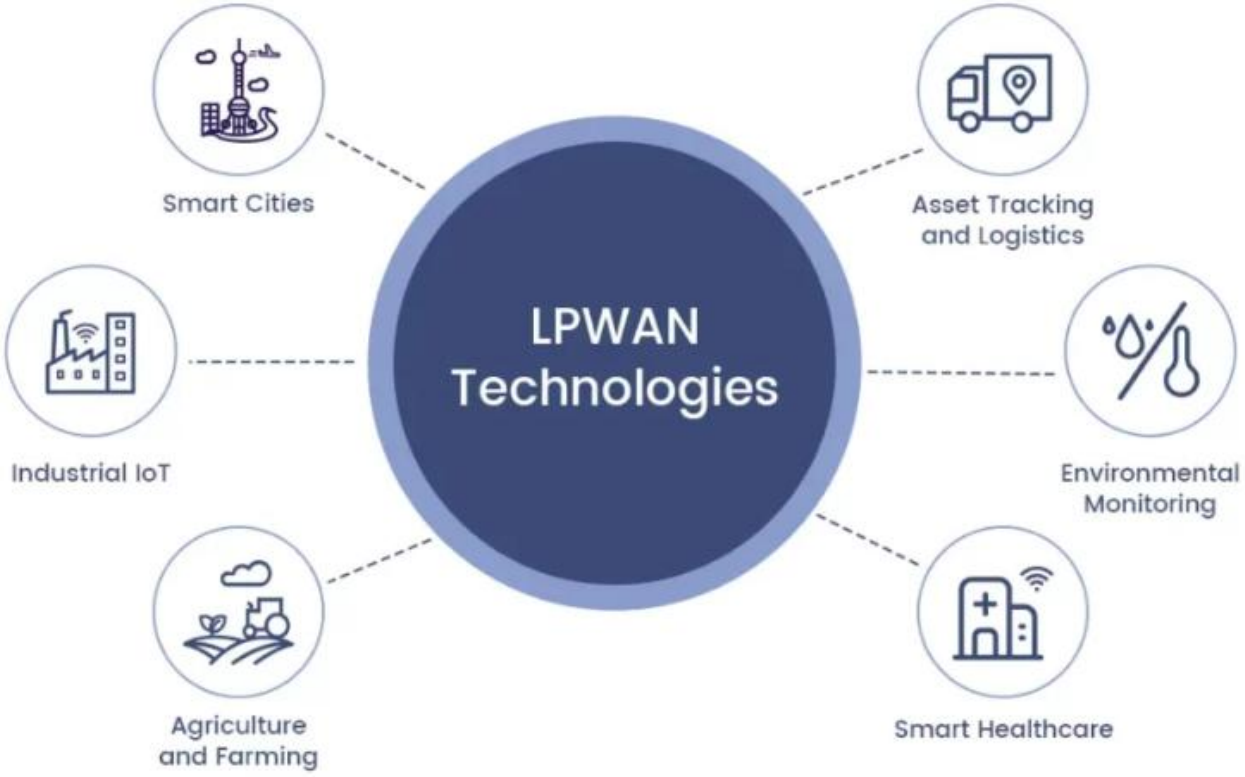
LPWAN technologies are characterized by:

- Coverage reaching several kilometers
- Low power consumption
- Low-cost devices and infrastructure
- Operation in licensed and unlicensed bands
- Low data rates (0.3 to 200 kbps)



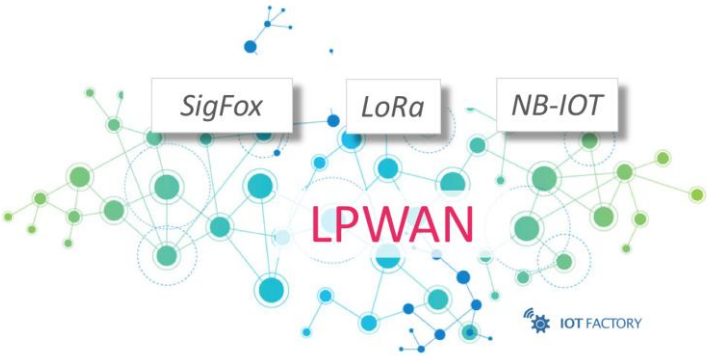
LPWAN – Applications

- LPWAN is the ideal solution for monitoring applications covering large areas and requiring low data rates.
  - Tracking and Logistics
  - Environmental Monitoring
  - Agriculture
  - Smart Healthcare
  - Industrial IoT
  - Smart Cities
  - Etc.



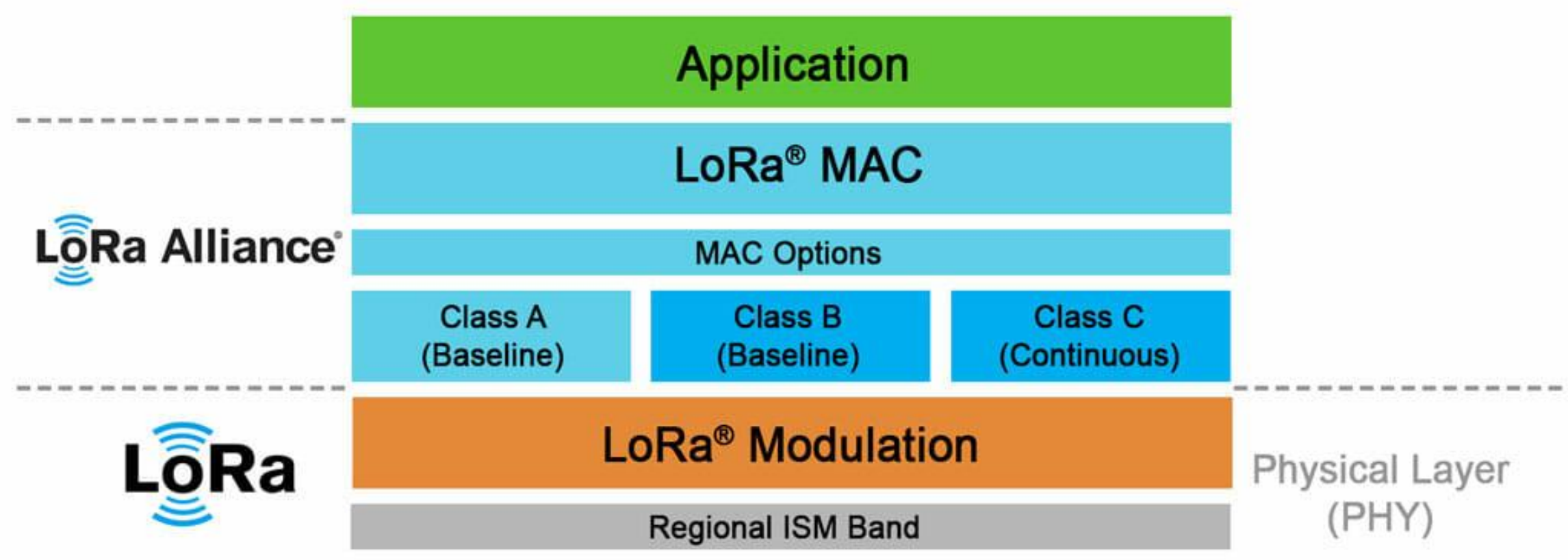
Main LPWAN Technologies

- NB-IoT (licensed band).
- SigFox (unlicensed band)
- LoRaWAN (unlicensed band)



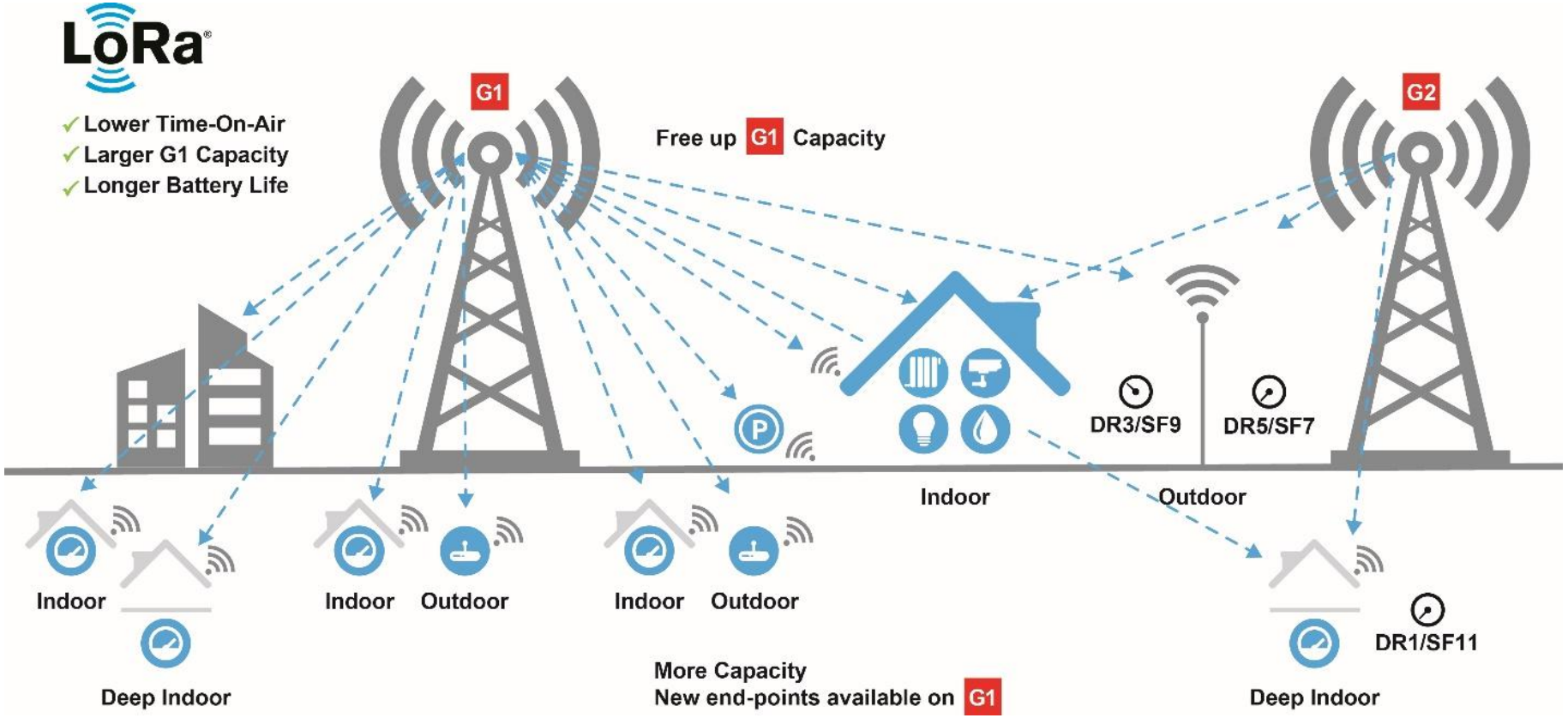
LoRa - Physical Layer

- LoRa is the physical layer of LoRaWAN: It is a spread spectrum modulation technique based on Chirp Spread Spectrum (CSS), developed by Semtech → proprietary technology.



LoRa - Network Coverage

- Adaptive Data Rate (ADR) is supported through variation of the Spreading Factor (SF)
  - Resistant to Doppler effect, multipath fading, and weak signal interference

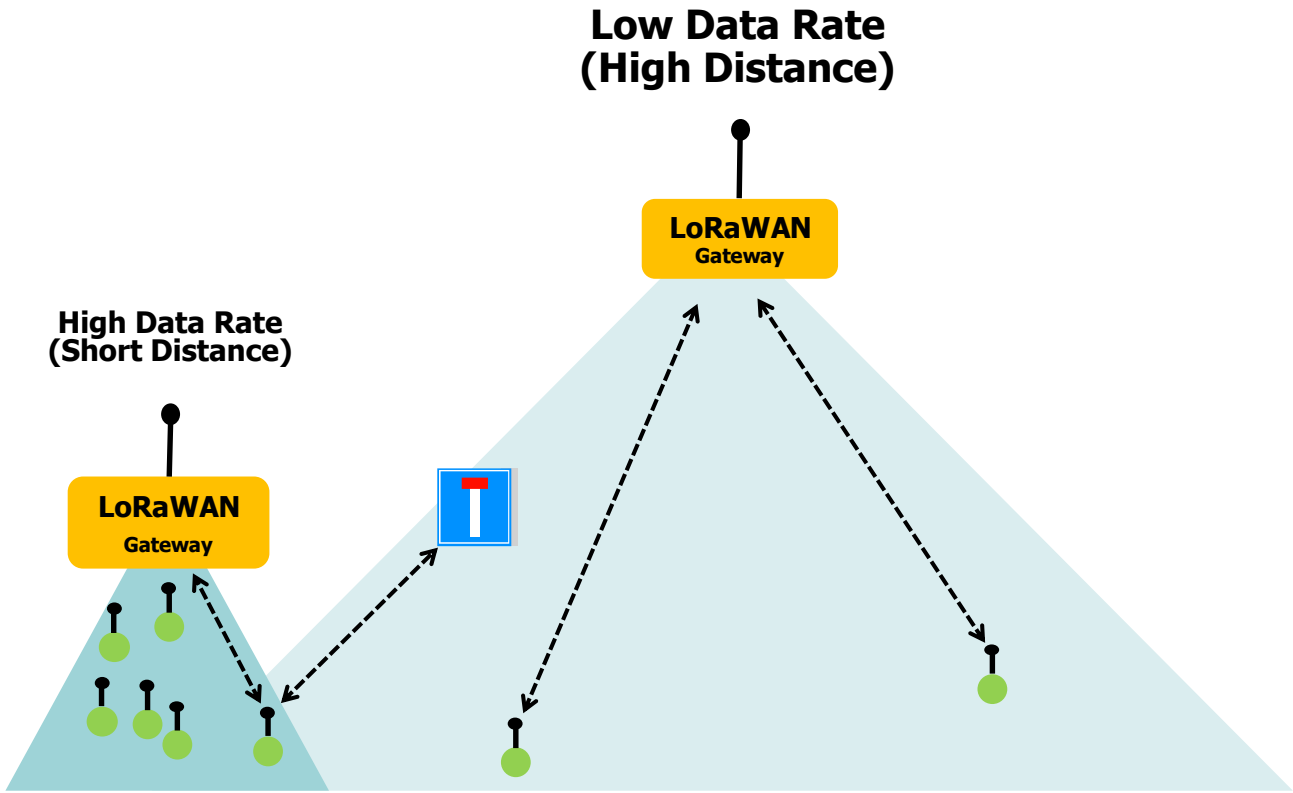


LoRa - Adaptative Date Rate (ADR)

- ADR adjusts depending on the distance from the device to the LoRaWAN router.
- High data rate (short distance) / Low data rate (long distance)

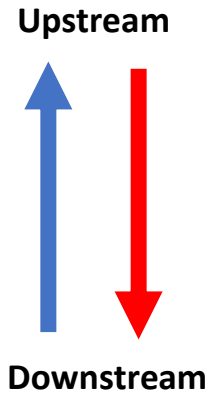
Dispositivo Final LoRaWAN

Gateway LoRaWAN



LoRa - Regional Parameters and Specifications

- Each country or region has their own frequency bands and specifications.



DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..14	RFU	
15	Defined in LoRaWAN[1]	

Table 5: EU863-870 TX Data rate table

União Europeia
863 – 870 MHz

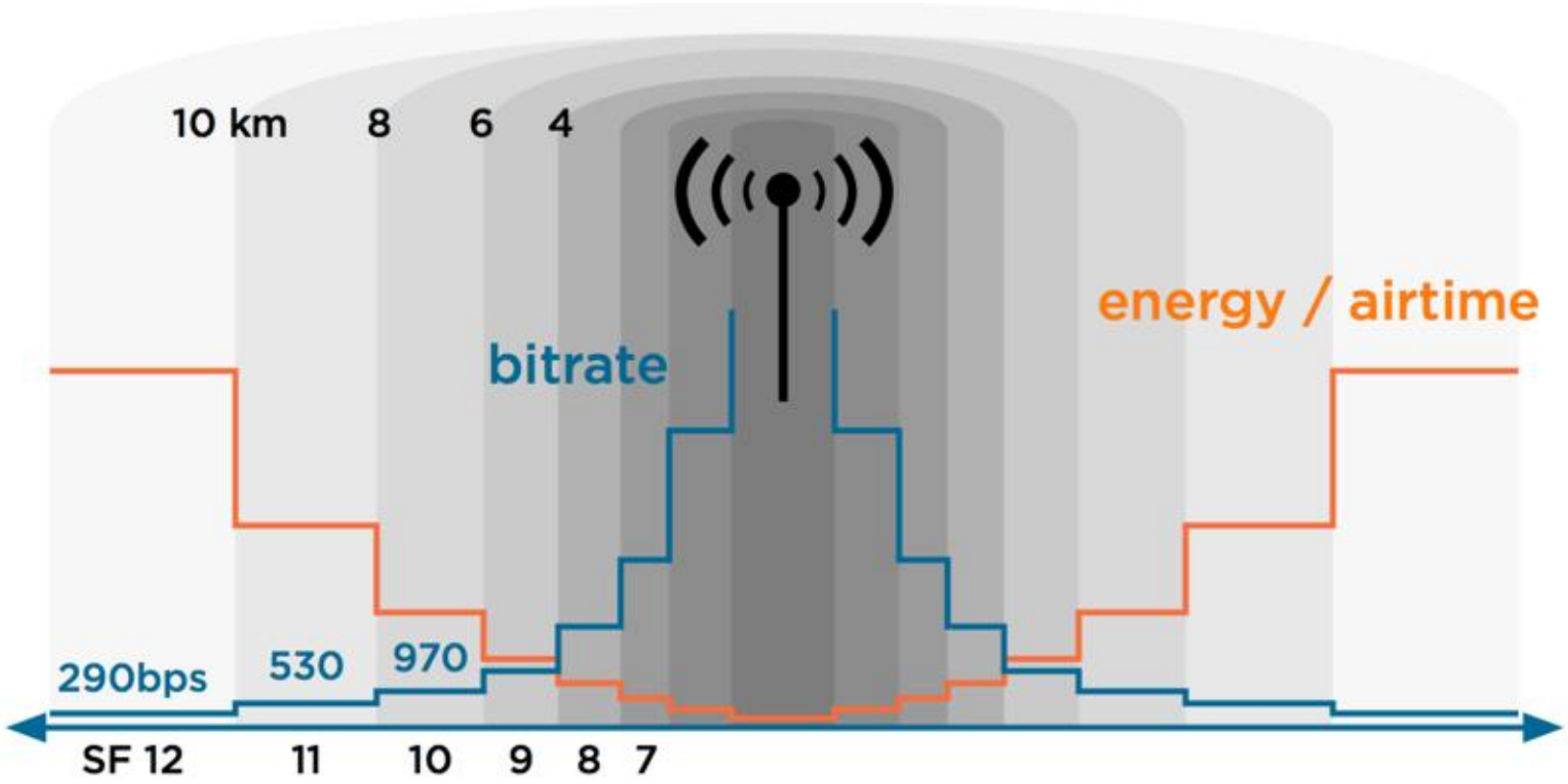
European frequency bands impose a duty cycle limit of less than 1%

LoRa - Spread Factor

- The higher the SF, the greater the energy consumption and airtime, but lower the data rate

$$Tc = \frac{2^{SF}}{B}$$

Tc is the chirp duration
B é bandwidth.
SF is the spreading factor



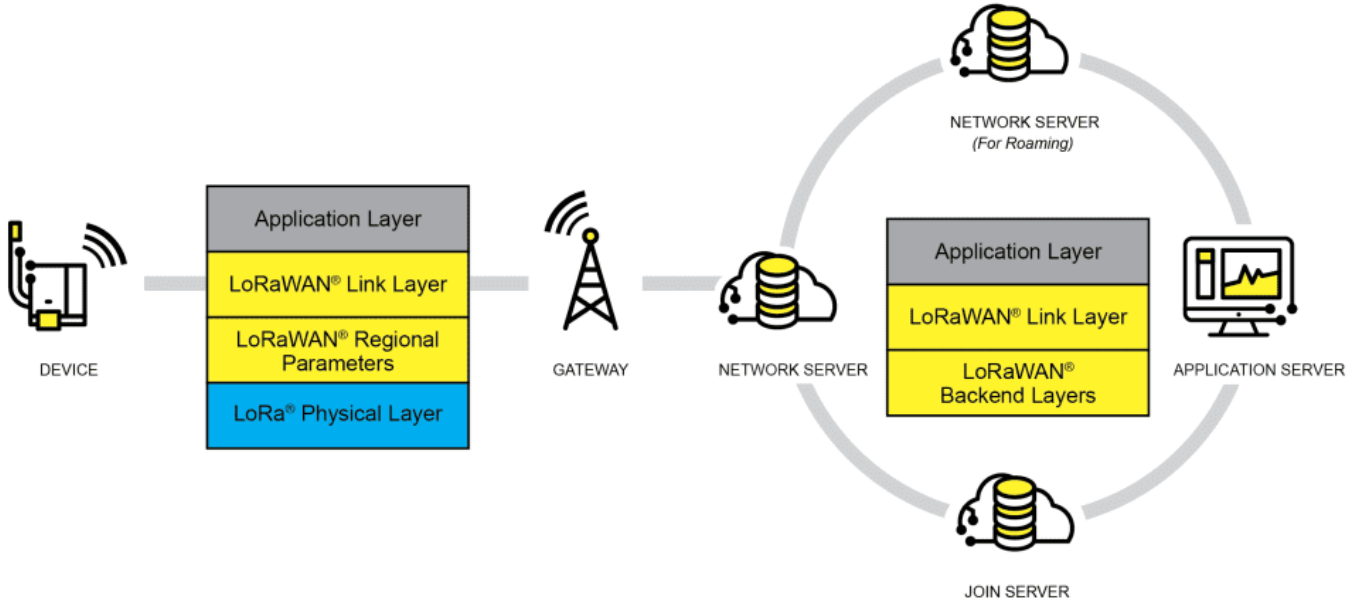
LoRa - Time on Air (ToA)

*Time on Air*em transmissões *upstream.* BW = 125 KHz e 20 Bytes de payload, 12 bytes de Overhead

DR5	DR4	DR3	DR2	DR1	DR0
SF7 BW 125	SF8 BW 125	SF9 BW 125	SF10 BW 125	SF11 BW 125	SF12 BW 125
71.9 ms	133.6 ms	246.8 ms	452.6 ms	987.1 ms	1,810.4 ms

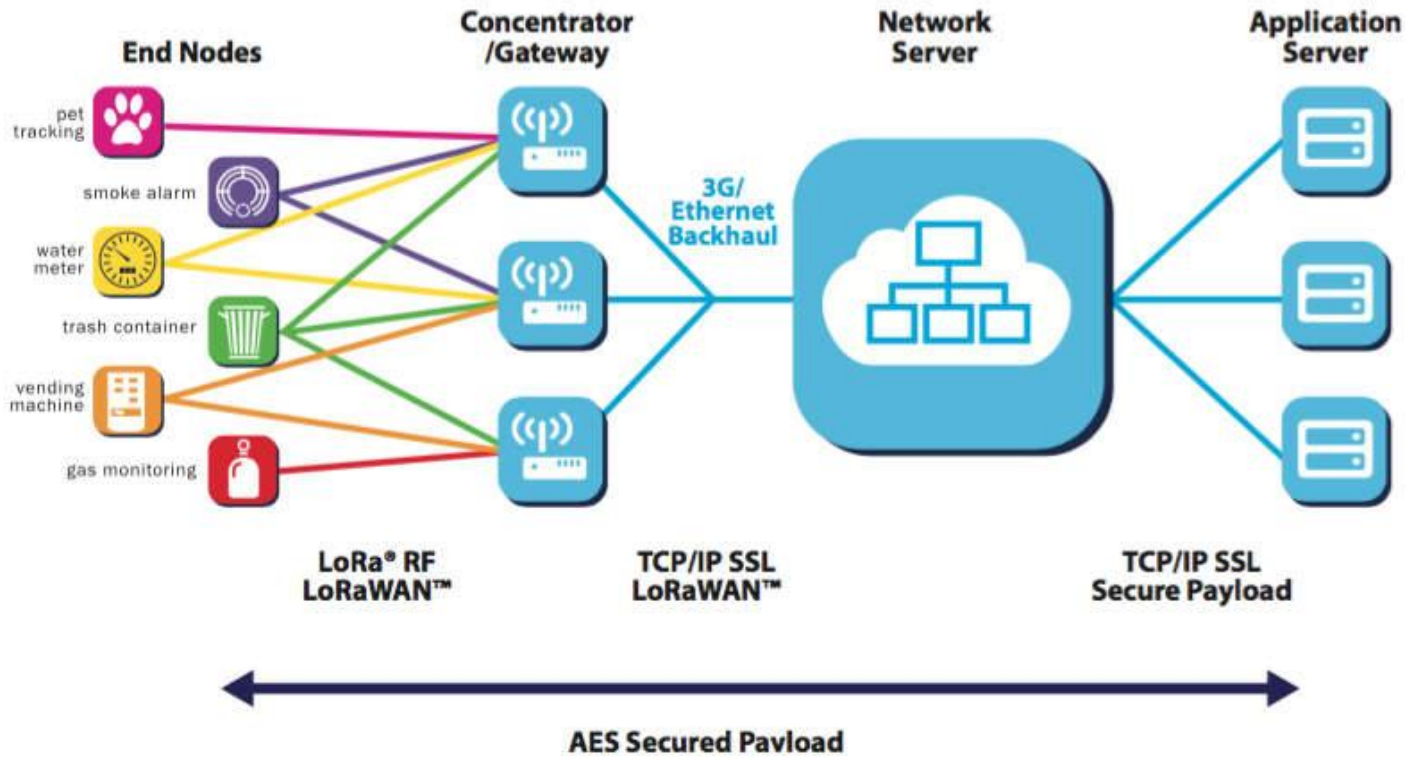
LoRaWAN

- LoRa refers to the physical medium, while LoRaWAN is the communication protocol operating at the data link layer.
- LoRaWAN networks are typically arranged in a star-of-stars topology.
- Gateways relay messages from known end devices to a network server, which then forwards them to an application server.



LoRaWAN Architecture

- Gateways connect to the network server via IP communication (Ethernet, WiFi, 3G/4G/5G), while end devices use LoRa modulation.
- LoRaWAN supports bidirectional communication: from the end device to the server (upstream) and from the server to the end device (downstream).

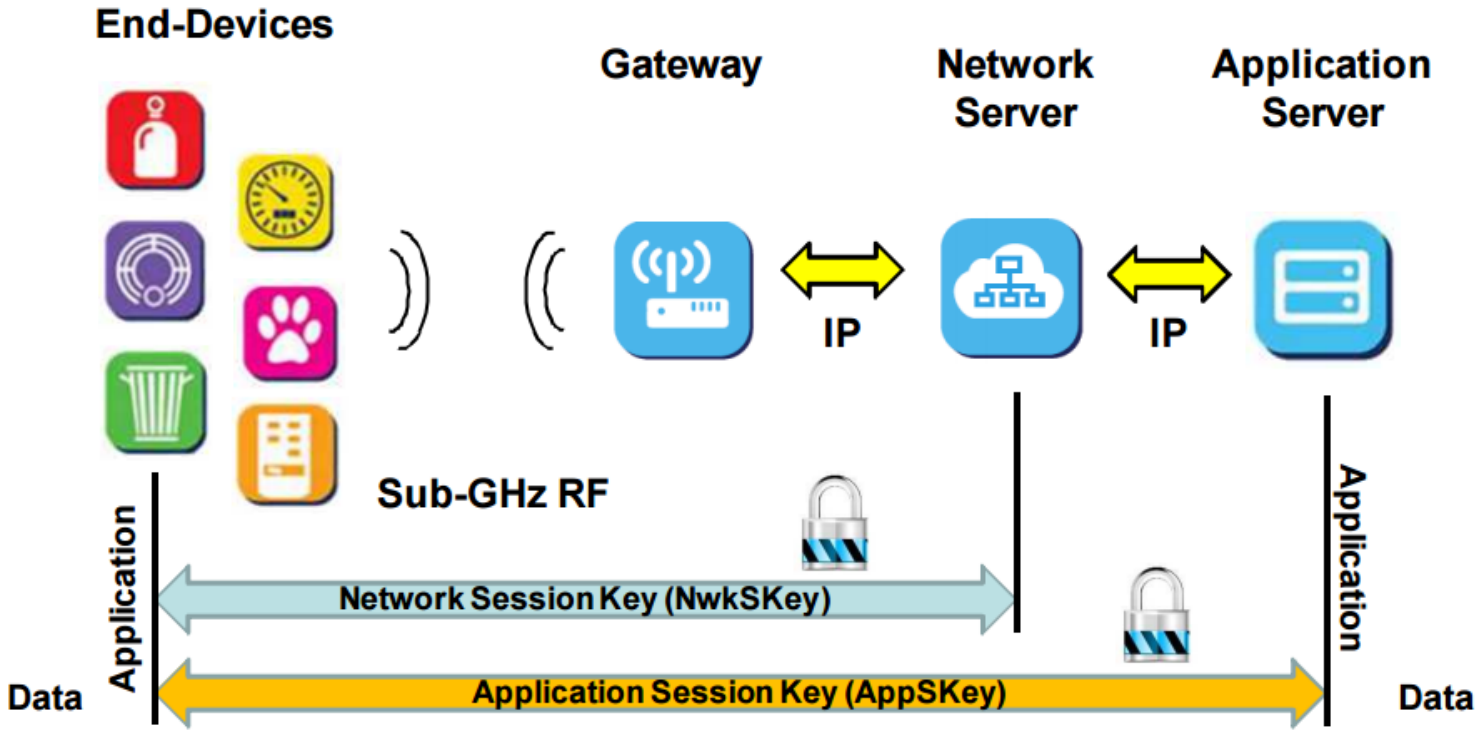


LoRaWAN Servers

- There are two main LoRaWAN servers used:
  - The Things Networks (TTN - Public).
  - ChirpStack Server (private).

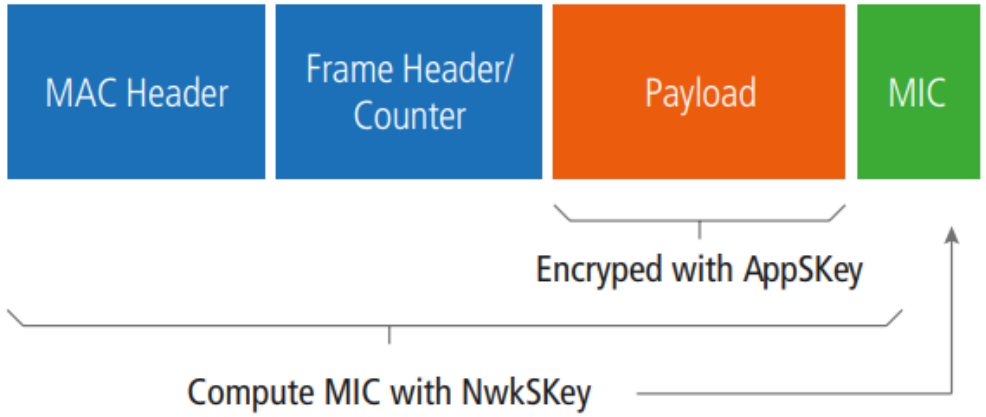
LoRaWAN security

- LoRaWAN provides two layers of encryption.
  - A 128-bit Network Session Key (**NwkSKey**) is shared between the end device and the Network Server.
  - A 128-bit Application Session Key (**AppSKey**) is shared between the end device and the Application Server.

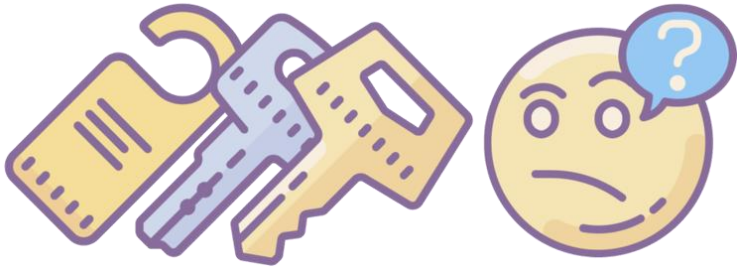


LoRaWAN Activation

- The encryption algorithm used is AES-128.
- The Network Session Key (NwkSKey) ensures the integrity of the entire LoRaWAN frame.
- The Application Session Key (AppSKey) encrypts and decrypts the payload of the LoRaWAN frame.

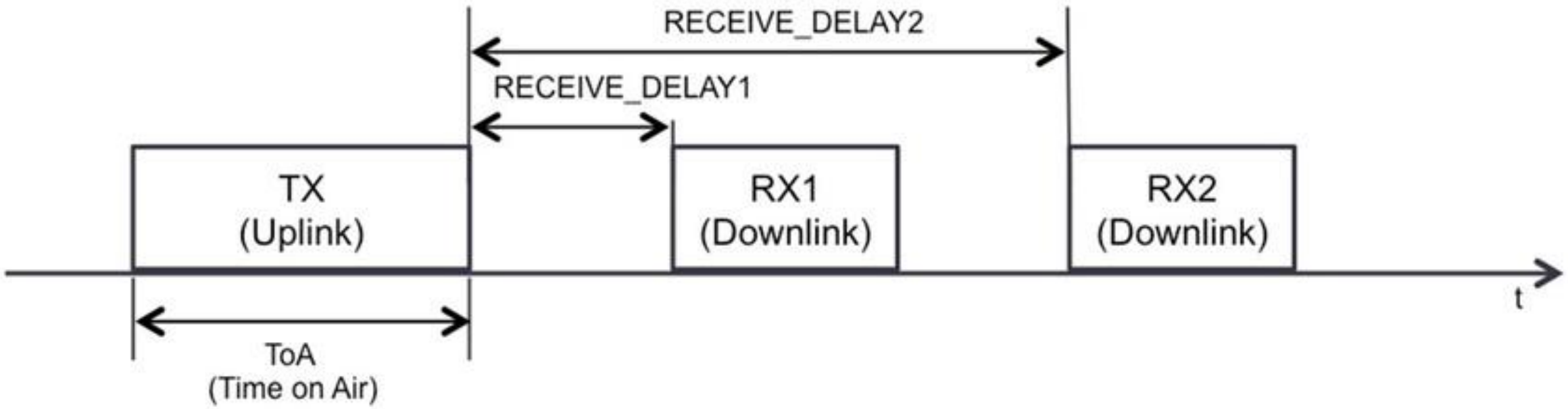


- There are two methods for session key activation:
  - Over-The-Air Activation (**OTAA**) and Activation By Personalization (**ABP**).



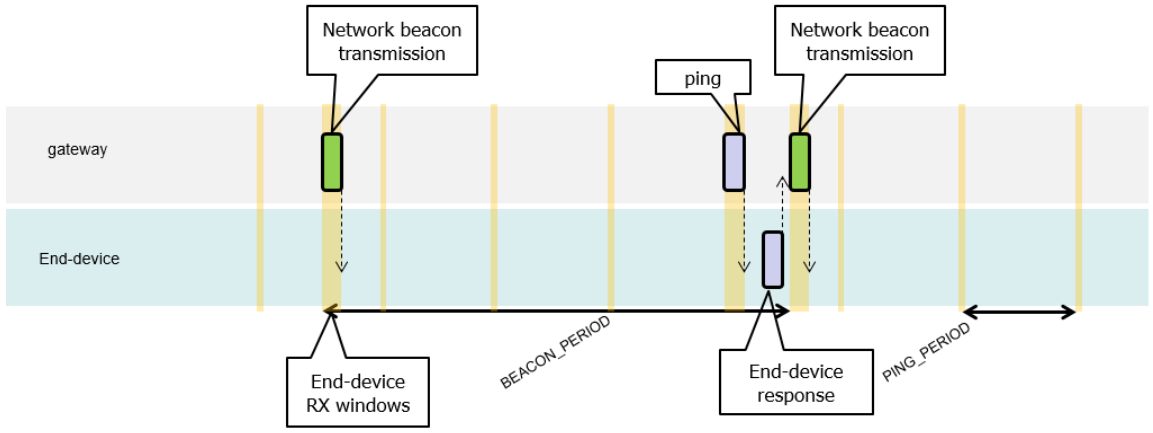
LoRaWAN – Device Classes

- **Class A**:
  - Uplink transmissions can be followed by two short receive windows for downlink.
  - It is the default class for all LoRaWAN devices and consumes the least energy.



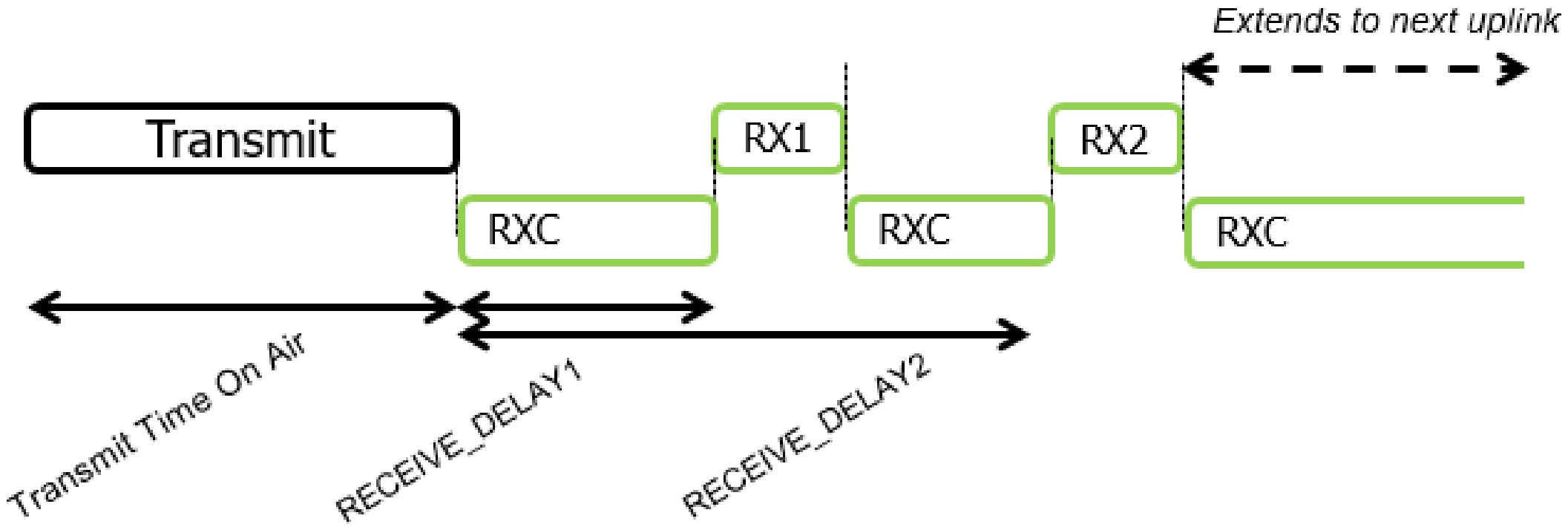
LoRaWAN – Device Classes

- **Classe B**
  - In addition to operating like Class A, Class B devices open additional scheduled receive windows.
  - These windows are scheduled via periodic beacons sent by the server.
  - Class B is intended for end devices that need to receive commands from a remote controller, such as switches or actuators.
  - Class B consumes more energy than Class A.

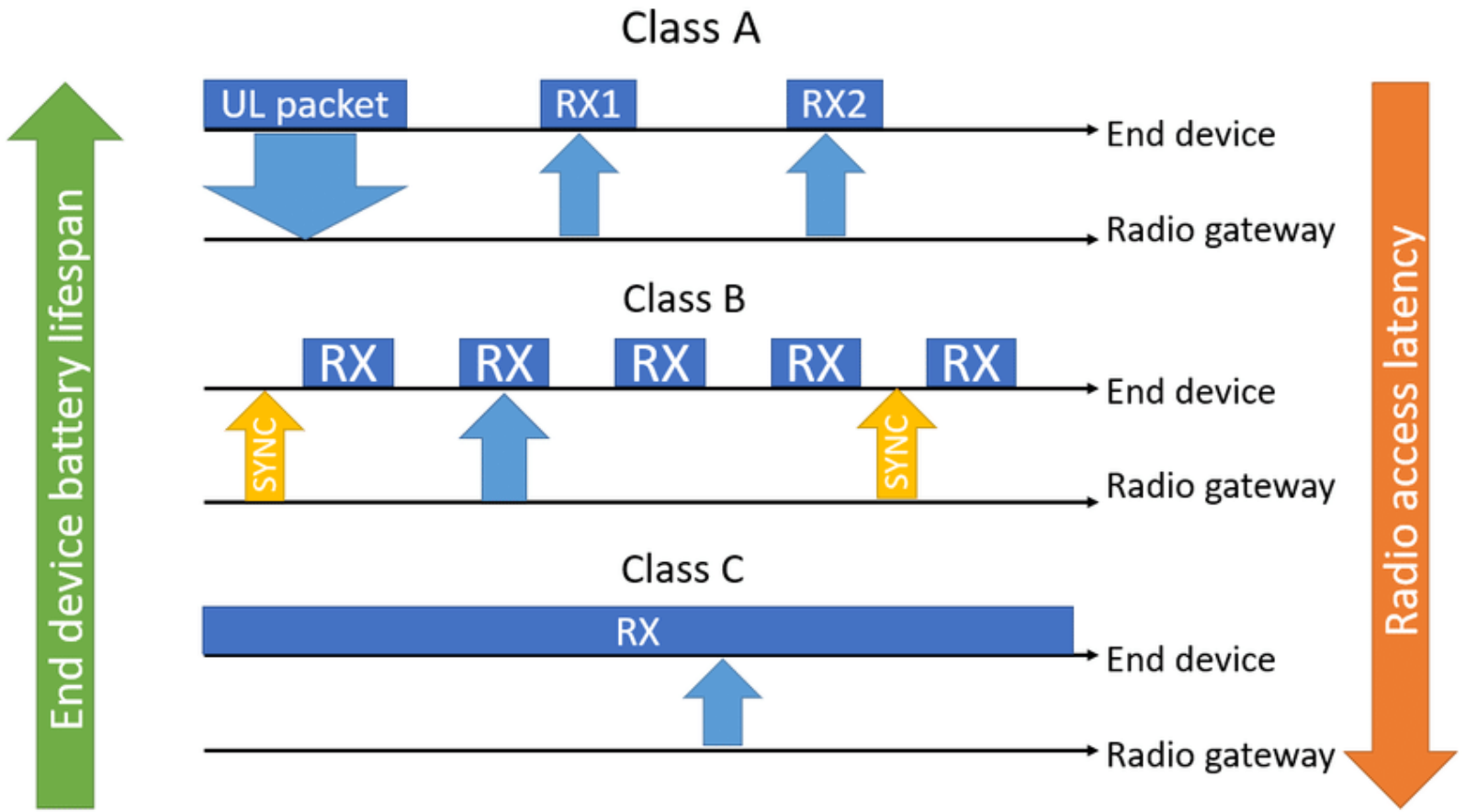


LoRaWAN – Device Classes

- **Classe C**
  - Receive windows are open nearly continuously and only closed during data transmission.
  - This is the most energy-consuming class.

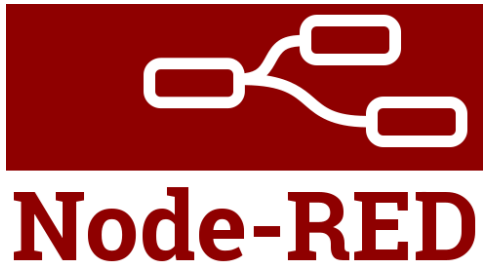


Comparison between LoRaWAN device classes



LoRaWAN Integration & Data Pipeline Tools

Node-Red: data collection and flow handling.

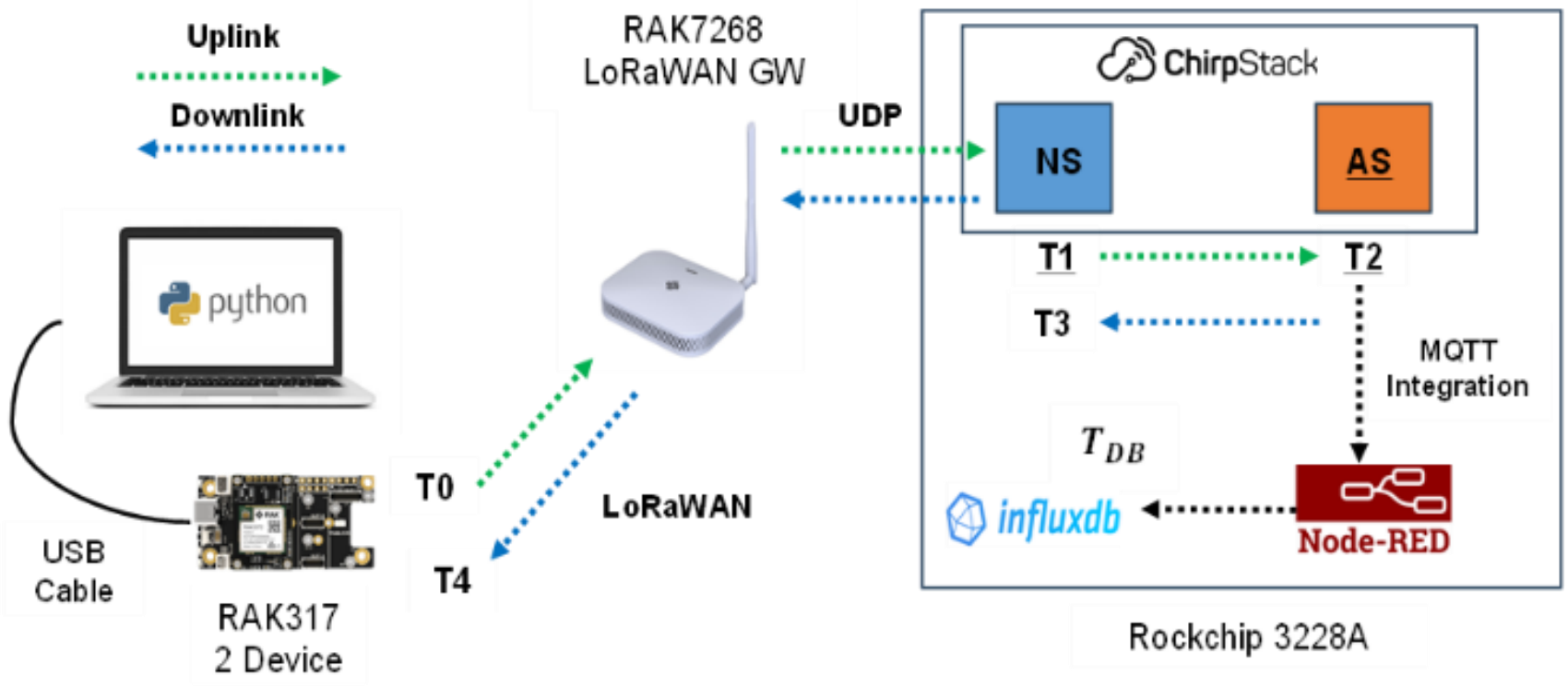


InfluxDB (time-series) , **MongoDB** (document) e **Redis** (cache): data storage.

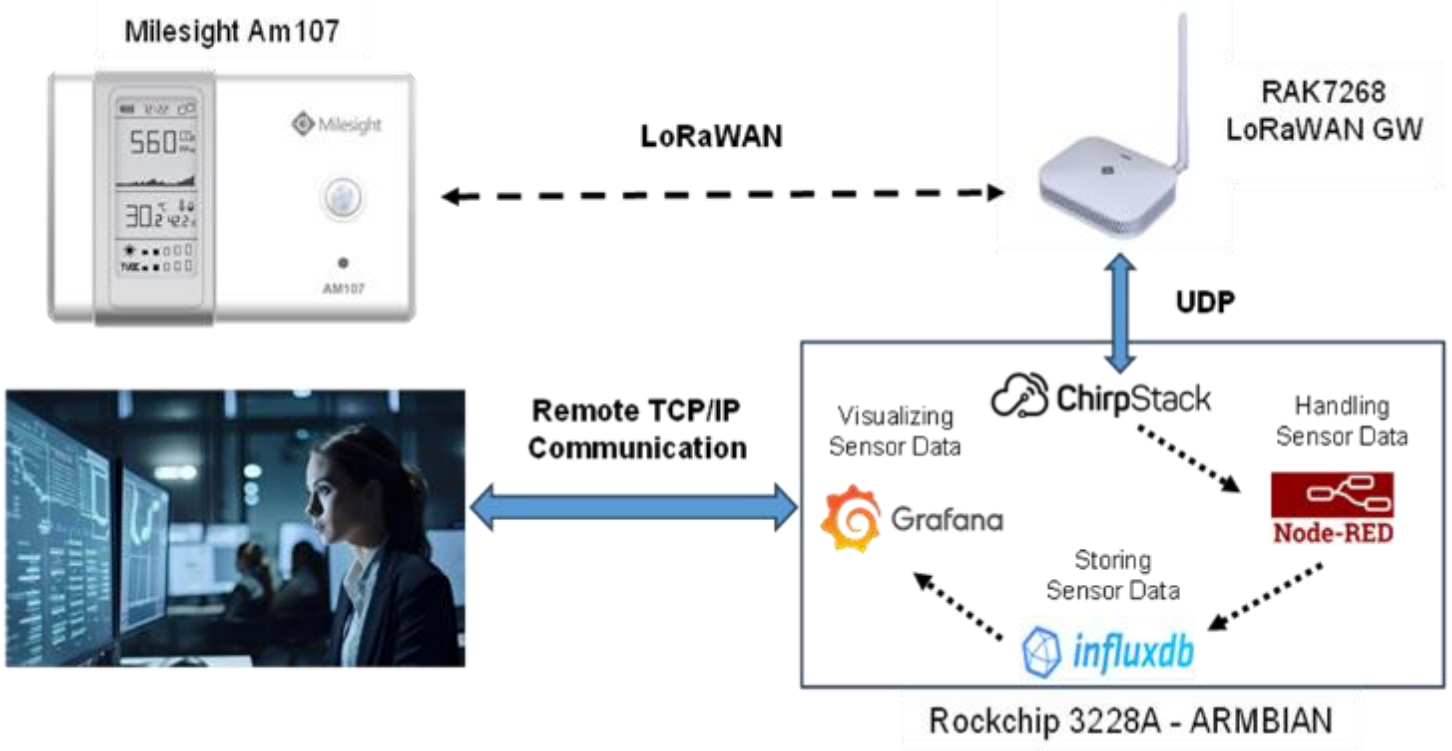
Mosquitto server and Webwooks: LoRaWAN Integration

Grafana: data visualization.

LoRaWAN Flow using integration and Data Pipeline Tools



LoRaWAN Flow using integration and Data Pipeline Tools



Conclusions and Takeaways

- LoRa + LoRaWAN fulfill IoT demands for **low power, long range, and secure links**.
- **OSI view:** LoRa = Layer 1, LoRaWAN MAC = Layer 2, MQTT/HTTP = Layer 7.
- Among LPWANs, **LoRaWAN is open, license-free, and integration-friendly**.
- Success hinges on balancing **Spreading Factor ⇆ data rate ⇆ battery life**.
- **MQTT → Node-RED → InfluxDB → Grafana** converts packets into real-time insights.
- Up next: **connect the MKR WAN 1310 to TTN** and witness your first uplink.

QUESTIONS?

Hands-On Exercise

www.github.com/dhiegofc/industrial_iot