CS433: Internet of Things
NCS463: Internet of Things

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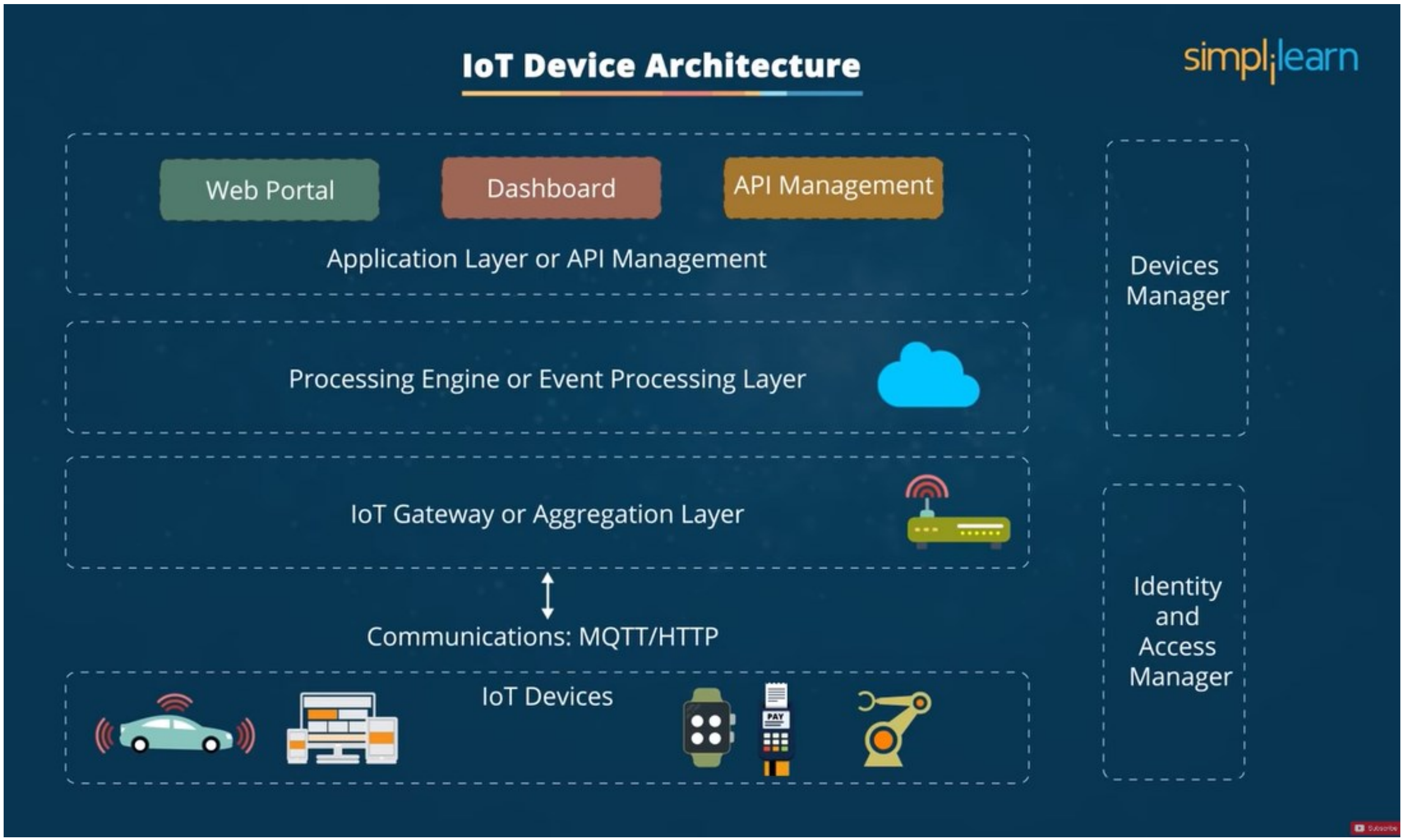
Internet of Things – Architecture

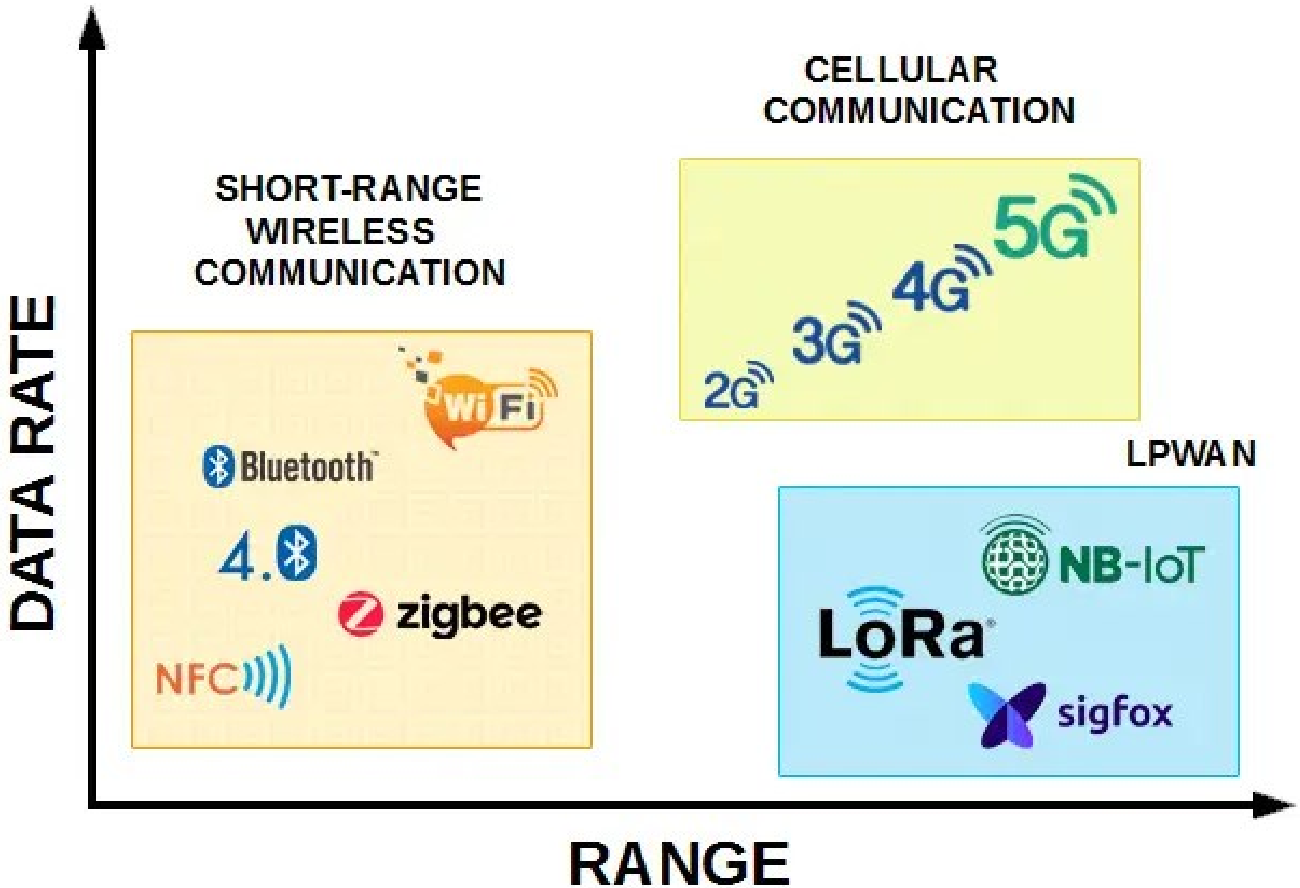


Communications

❑ Data Link Layer Communication Protocols in IoT

- LPWAN (LoRaWAN. / Sigfox. / NarrowBand–IoT)
- Bluetooth. / Zigbee. / Z-Wave
- Ethernet / WiFi.
- RFID / NFC.

LoRaWAN vs. other IoT wireless technologies



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Communications

❑ Data Link Layer Communication Protocols in IoT

- LPWAN

LPWAN (Low Power Wide Area Network) is a wireless wide area network technology whose range varies from 2 km to 1000 km. Sigfox and LoRa are examples that involve all major LPWAN technologies.

- **LoRaWAN**

LoRaWAN(**Lo**ng **Ra**nge Wide Area Network) is a wide area network protocol. It is a low-power consumption protocol that targets wide-area network (WAN) applications with better security and mobility. It is along with range bidirectional communication which has a range of more than 10 km.

- **Sigfox**

Sigfox is a form of wireless communication that provides low-power and long-range wireless connectivity for devices. The messages are transmitted over the Sigfox global network. Sigfox provides one of the largest IoT networks. It is like a Cellular network type that sets up antennas on towers.

- **NB-IoT**

NB-IoT comes under the category of LPWAN (Low Power Wide Area Networks), having the capability to connect devices that require small amounts of data, low bandwidth, and long battery life. NB-IoT is a narrow-band radio technology for IoT devices and applications that requires wireless connectivity over a long range at a low cost and using little power for long battery lives respectively.

Communications

❑ Data Link Layer Communication Protocols in IoT

- Bluetooth

  Bluetooth is a short-range wireless communication network for exchanging data between the connected devices. It is cheaper and more effective for short-range distances. It is a 2.4GHz network. It provides a data transfer rate of 3 Mbps in a range of 50m to 150m.

- Zigbee

  Zigbee is similar to Bluetooth technology with 2.4 GHz frequency. It is a low-power personal communication network. It is cheaper and is widely used for several applications. Its range varies from 10-100m. Zigbee supports star or mesh network topology.

- Z-Wave

  Z-wave is based on low-power RF(Radio Frequency) based technology. It operates in 900 MHz frequency bandsIt offers data transfer rates of 9.6Kbps, 40Kbps, or 100Kbps. Its range of 100m.

Communications

❑LoRa and LoRaWAN

- What are LoRa and LoRaWAN ?
- LoRaWAN Architecture.
- Key Features of LoRaWAN.

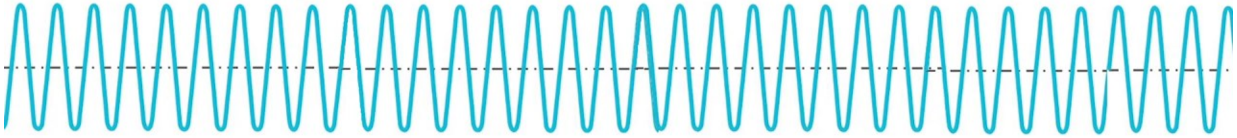
❑LoRaWAN vs. Zigbee

❑ LoRaWAN vs. Bluetooth

Source: What-is-lorawan

Communications: LoRa

- LoRa is a wireless modulation technique derived from Chirp Spread Spectrum (CSS) technology. It encodes information on radio waves using chirp pulses - similar to the way dolphins and bats communicate! LoRa-modulated transmission is robust against disturbances and can be received across great distances.

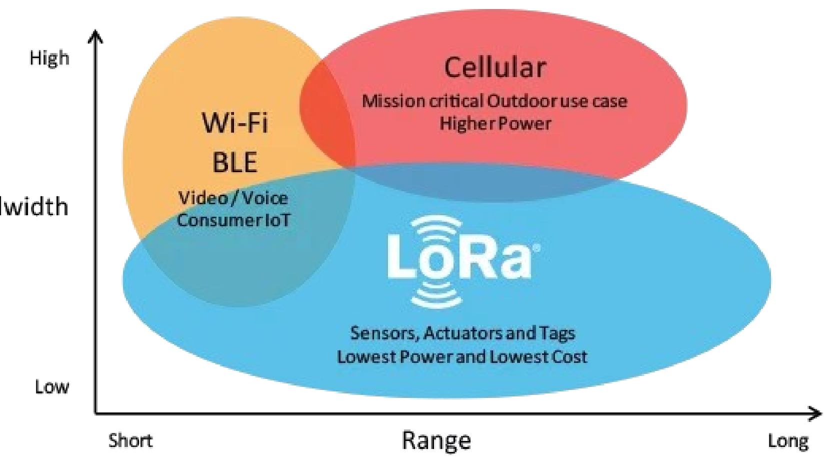


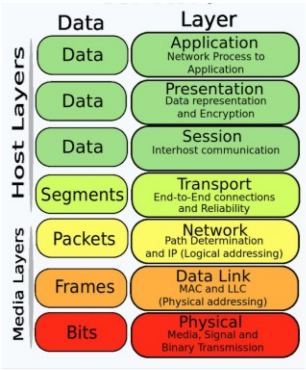
Communications: LoRa

- LoRa is a wireless modulation technique derived from Chirp Spread Spectrum (CSS) technology. It encodes information on radio waves using chirp pulses - similar to the way dolphins and bats communicate! LoRa-modulated transmission is robust against disturbances and can be received across great distances.
- LoRa is ideal for applications that transmit small chunks of data with low bit rates. Data can be transmitted at a longer range compared to technologies like WiFi, and Bluetooth. These features make LoRa well-suited for sensors and actuators that operate in low-power mode.
- LoRa can be operated on the license-free sub-gigahertz bands, for example, 915 MHz, 868 MHz, and 433 MHz. It also can be operated on 2.4 GHz to achieve higher data rates compared to sub-gigahertz bands, at the cost of range. These frequencies fall into ISM bands that are reserved internationally for industrial, scientific, and medical purposes.
- As announced by the LoRa Alliance® on December 7, 2021, LoRaWAN® is officially approved as a standard for Low Power Wide Area Networking (LPWAN) by the International Telecommunication Union (ITU).

Communications: LoRaWAN

- LoRaWAN is a Media Access Control (MAC) layer protocol built on top of LoRa modulation. It is a software layer that defines how devices use the LoRa hardware, for example when they transmit, and the format of messages.
- The LoRaWAN protocol is developed and maintained by the LoRa Alliance. The first LoRaWAN specification was released in January 2015.
- LoRaWAN is suitable for transmitting small size payloads (like sensor data) over long distances. LoRa modulation provides a significantly greater communication range with low bandwidths than other competing wireless data transmission technologies.



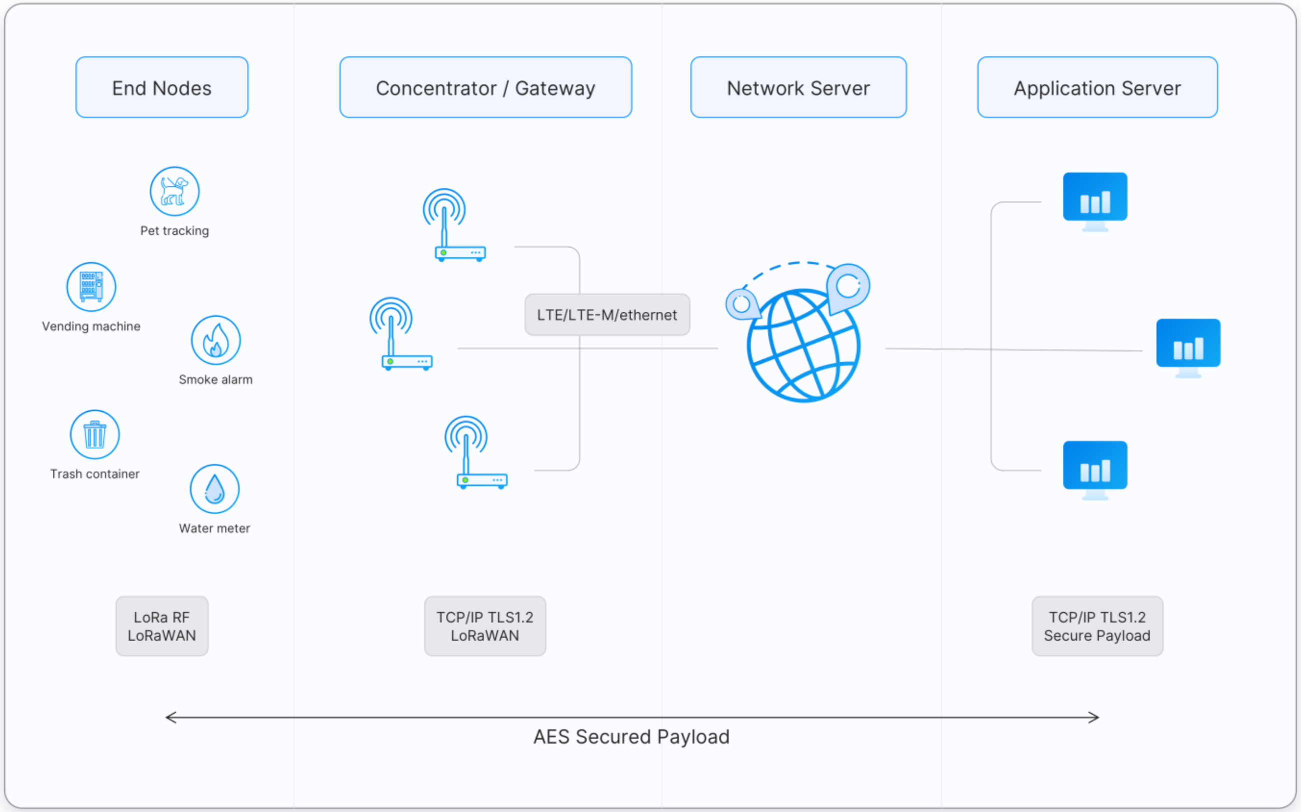


Communications: LoRaWAN

- LoRaWAN Advantages:
  - Ultra low power - operates in low power mode and can last up to 10 years on a single coin cell battery.
  - Long range - a distance of over 10 kilometers in rural areas and up to 3 kilometers in dense urban areas.
  - Deep indoor penetration - LoRaWAN networks can provide deep indoor coverage, and easily cover multi-floor buildings.
  - License free spectrum
  - End-to-end security- LoRaWAN ensures secure communication using AES-128 encryption.
  - Low cost - Minimal infrastructure, low-cost end nodes, and open-source software.
- LoRaWAN use cases in IoT
  - Smart farms
  - Water conservation- Identification and faster repair of leaks in a city’s water network.
  - Food safety- Temperature monitoring ensures food quality maintenance.
  - Smart waste bins - Waste bin level alerts sent to staff to optimize the pickup schedule.
  - Airport tracking - monitors vehicles, personnel, and luggage.
  - Cattle health

Communications: LoRaWAN

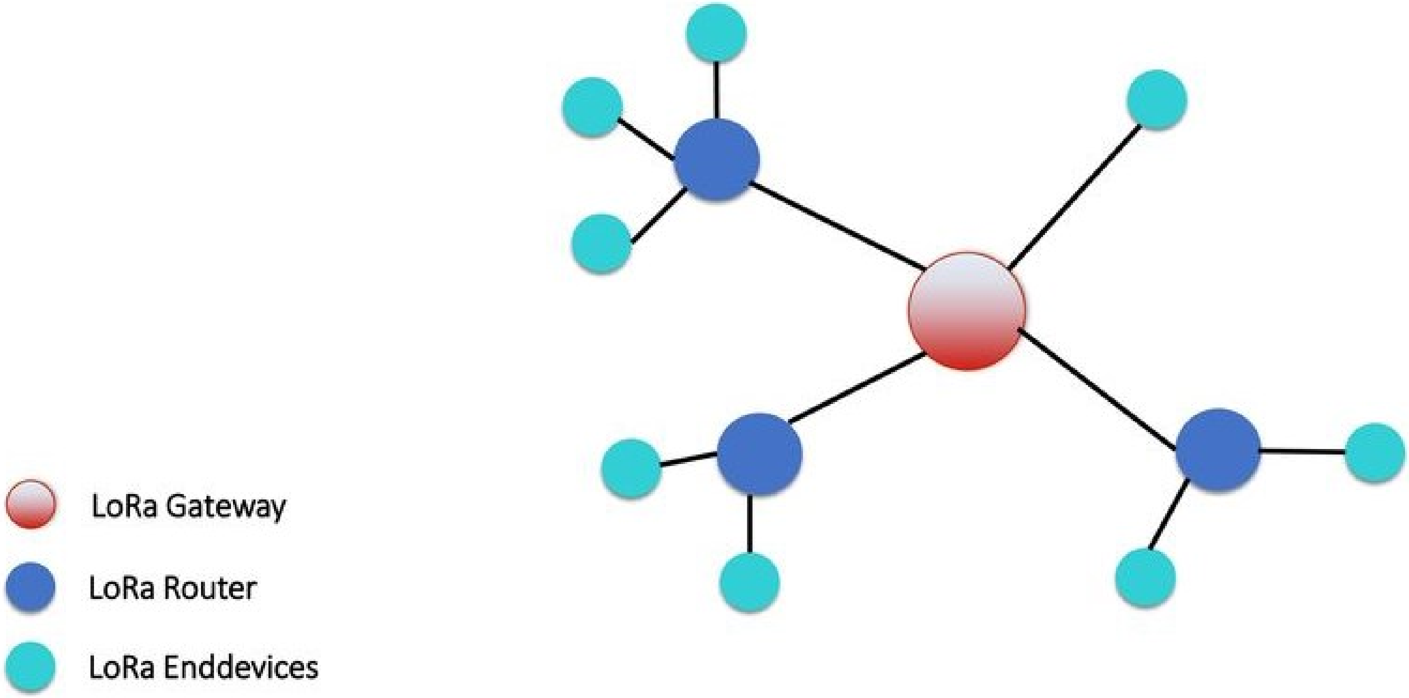
LoRaWAN Architecture



Communications: LoRaWAN

LoRaWAN Architecture

- LoRaWAN networks are deployed in a star-of-stars topology.



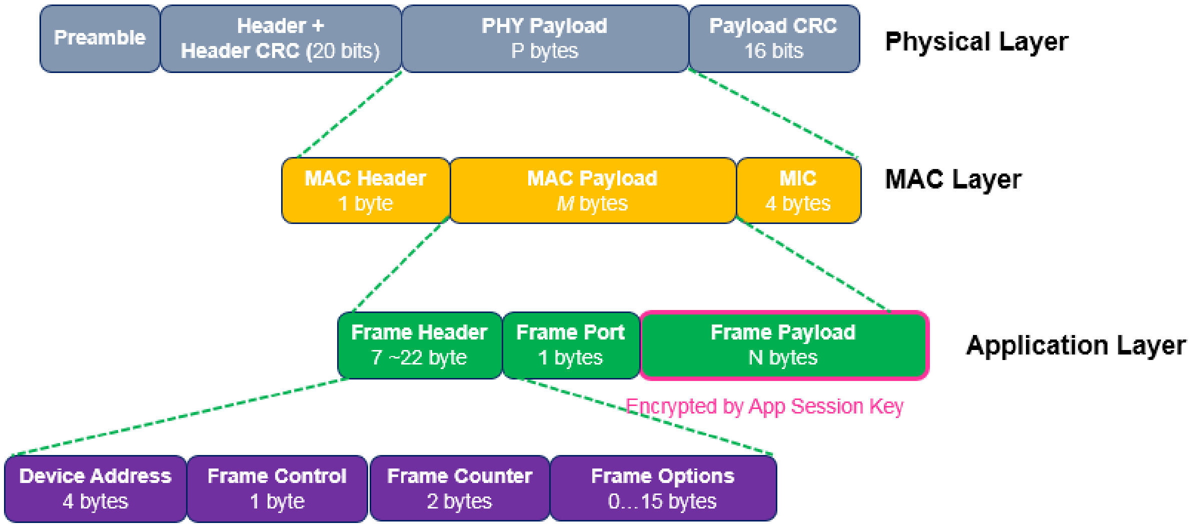
Communications: LoRaWAN

LoRaWAN Architecture

- LoRaWAN networks are deployed in a star-of-stars topology.
- LoRaWAN networks use an ALOHA-based protocol.
  - End devices don’t need to peer with specific gateways. Messages sent from end devices travel through all gateways within range.
  - These messages are received by the Network Server. If the Network Server has received multiple copies of the same message, it keeps a single copy of the message and discards others. This is known as message deduplication.
  - In ALOHA, each node or station transmits a frame without trying to detect whether the transmission channel is idle or busy. If the channel is idle, then the frames will be successfully transmitted. If two frames attempt to occupy the channel simultaneously, a collision of frames will occur and the frames will be discarded. These stations may choose to retransmit the corrupted frames repeatedly until successful transmission occurs.

Communications: LoRaWAN

LoRaWAN Architecture – Frame Structure



Communications: LoRaWAN

Message Types

- Uplink and Downlink Messages
  - Uplink: sent by end devices to the Network Server
  - Downlink: sent by the Network Server to only one end device
- MAC Message
  - Join-request
  - Join-accept
  - Confirmed Data Up
  - Confirmed Data Down
- Data Messages
  - There are 4 data messages. These data message types are used to transport both MAC commands and application data which can be combined together in a single message.
  - Data messages can be confirmed or unconfirmed. Confirmed data messages must be acknowledged by the receiver whereas unconfirmed data messages do not need to be acknowledged by the receiver.

Communications: LoRaWAN

LoRaWAN Security

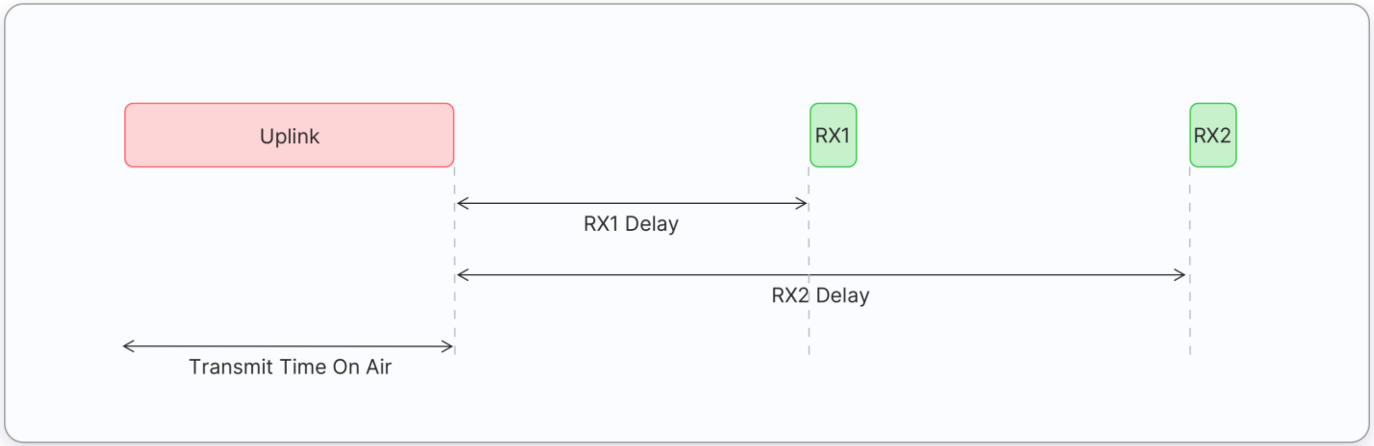
Security Keys

- Session Keys
  - When a device joins the network (this is called a join or activation), an application session key AppSKey and a network session key NwkSKey are generated. The NwkSKey is shared with the network, while the AppSKey is kept private. These session keys will be used for the duration of the session.
  - The Network Session Key (NwkSKey) is used for interaction between the Node and the Network Server. This key is used to validate the integrity of each message by its Message Integrity Code (MIC check).
  - The Application Session Key (AppSKey) is used for encryption and decryption of the payload.
- Application Key
  - The application key (AppKey) is only known by the device and by the application. Dynamically activated devices (OTAA) use the Application Key (AppKey) to derive the two session keys during activation.

Communications: LoRaWAN

Device Classes

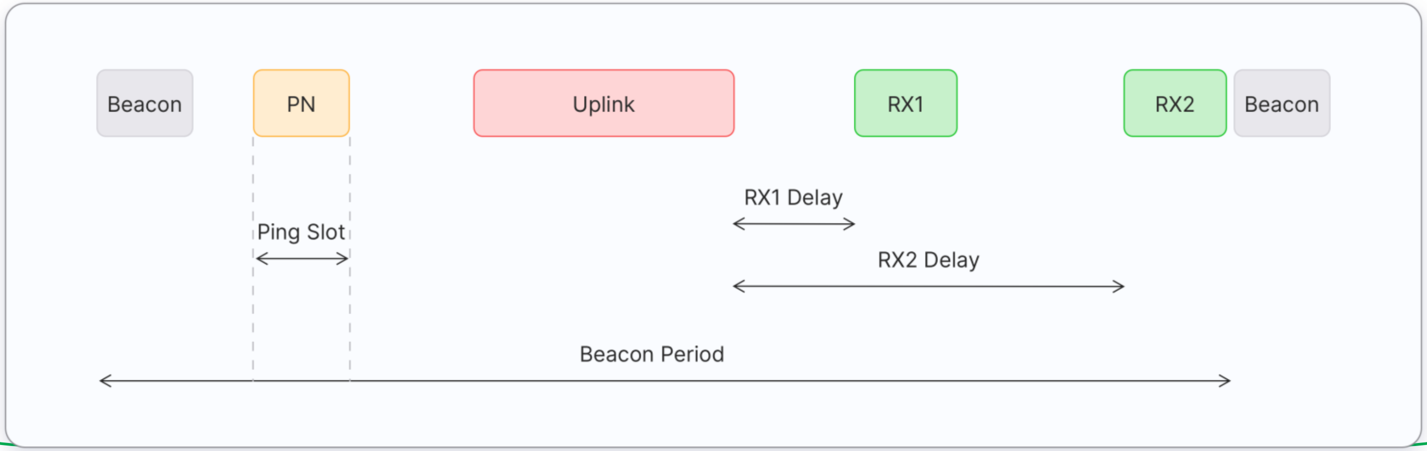
- Class A.
  - All LoRaWAN end-devices must support Class A implementation. A Class A device can send an uplink message at any time. Once the uplink transmission is completed, the device opens two short receive windows for receiving downlink messages from the network.



Communications: LoRaWAN

Device Classes

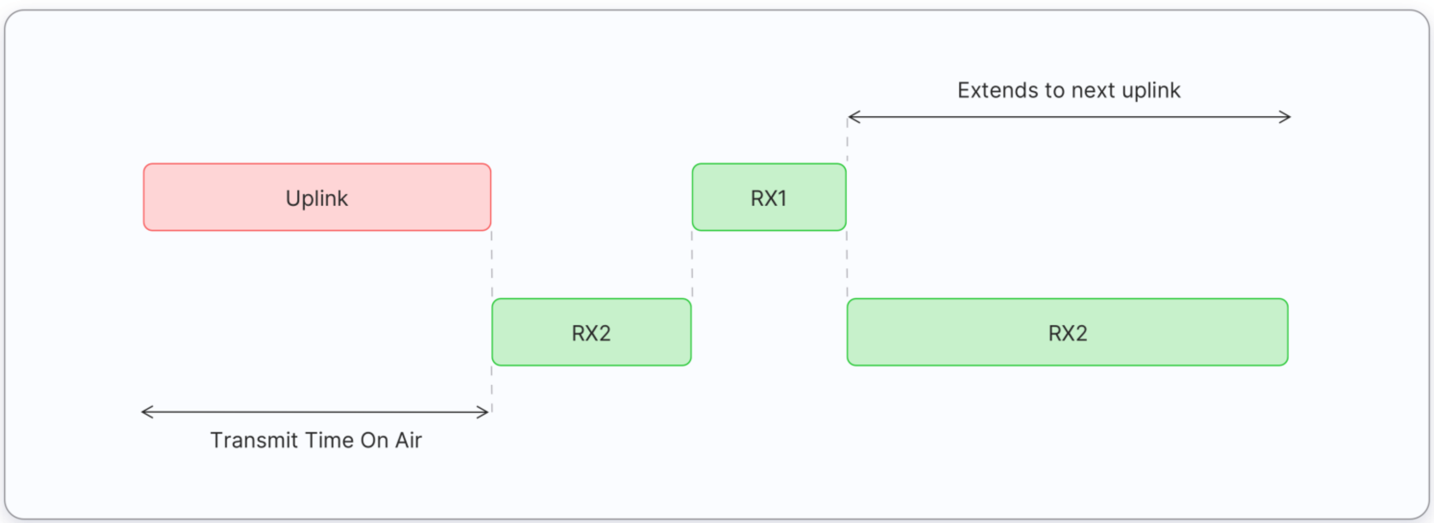
- Class B.
  - Class B devices extend Class A capabilities by periodically opening receive windows called ping slots to receive downlink messages.
  - The network broadcasts a time-synchronized beacon (unicast and multicast) periodically through the gateways, which is received by the end devices.
  - These beacons provide a timing reference for the end devices, allowing them to align their internal clocks with the network. This allows the network server to know when to send a downlink to a specific device or a group of devices. The time between two beacons is known as the beacon period.



Communications: LoRaWAN

Device Classes

- Class C.
  - Class C devices extend Class A capabilities by keeping the receive windows open unless transmitting an uplink, as shown in the figure below. Therefore, Class C devices can receive downlink messages at almost any time, thus having very low latency for downlinks.

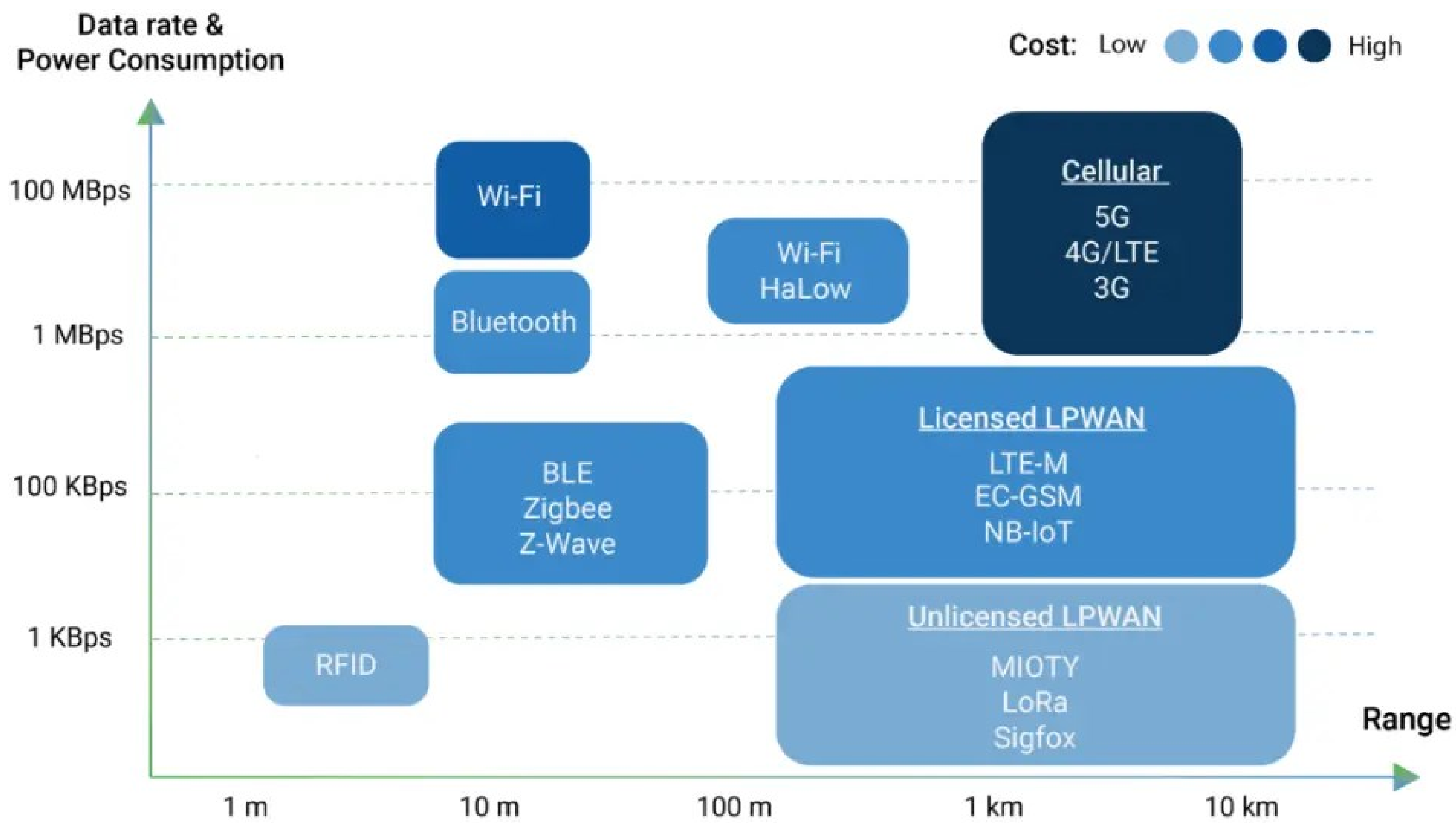


Communications: LoRaWAN

Adaptive Data Rate

- LoRa is based on Chirp Spread Spectrum (CSS) technology, where chirps (also known as symbols) are the carrier of data.
- The spreading factor controls the chirp rate, and thus controls the speed of data transmission. Lower spreading factors mean faster chirps and therefore a higher data transmission rate.
- ADR can optimize device power consumption while ensuring that messages are still received at gateways.
- When ADR is in use, the network server will indicate to the end device that it should reduce transmission power or increase data rate.
- End devices that are close to gateways should use a lower spreading factor and higher data rate, while devices further away should use a high spreading factor because they need a higher link budget.

LoRaWAN vs. other IoT wireless technologies



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A comparative study of LPWAN technologies

Characteristics \ Type of LPWAN	**SigFox**	**LoRa (LoRaWAN)**	**NB-IoT**
Modulation	BPSK	CSS	QPSK
Frequency	Unlicensed ISM bands	Unlicensed ISM bands	Licensed LTE bands
Bandwidth	100 Hz	250 kHz and 125 kHz	200 kHz
Maximum data rate	100 bps	50 kbps	200 kbps
Bidirectional	Limited / Half-duplex	Yes / Half-duplex	Yes / Half-duplex
Maximum messages/day	140 (UL), 4 (DL)	Unlimited	Unlimited
Maximum payload length	12 bytes (UL), 8 bytes (DL)	243 bytes	1600 bytes
Coverage Range	10 km (urban), 40 km (rural)	5 km (urban), 20 km (rural)	1 km (urban), 10 km (rural)
Interference immunity	Very high	Very high	Low
Authentication & encryption	Not supported	Yes (AES 128b)	Yes (LTE encryption)
Adaptive data rate	No	Yes	No
Handover	End devices do not join a single base station	End devices do not join a single base station	End devices join a single base station
Localization	Yes (RSSI)	Yes (TDOA)	No (under specification)
Allow private network	No	Yes	No
Standardization	Sigfox company is collaborating with ETSI on the standardization of Sigfox-based network	LoRa-Alliance	3GPP

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LoRa vs. NB-IoT

	LoRa	NB-IoT
Year of development	2015	2017
Frequency band	Unlicensed spectrum	Licensed frequency bands
Transmission coverage	12 – 15 km	18 – 20 km
Number of supported nodes	60,000	200,000
Data transfer rate	Lower data transfer rate	Higher data transfer rate (10x LoRa's rates)
Battery performance	Longer battery life	Shorter battery life
Cost	Lower cost per device (but gateway required)	Higher cost per device (but no gateway required)
Private network capability	Yes	No