# CS433: Internet of Things
# NCS463: Internet of Things

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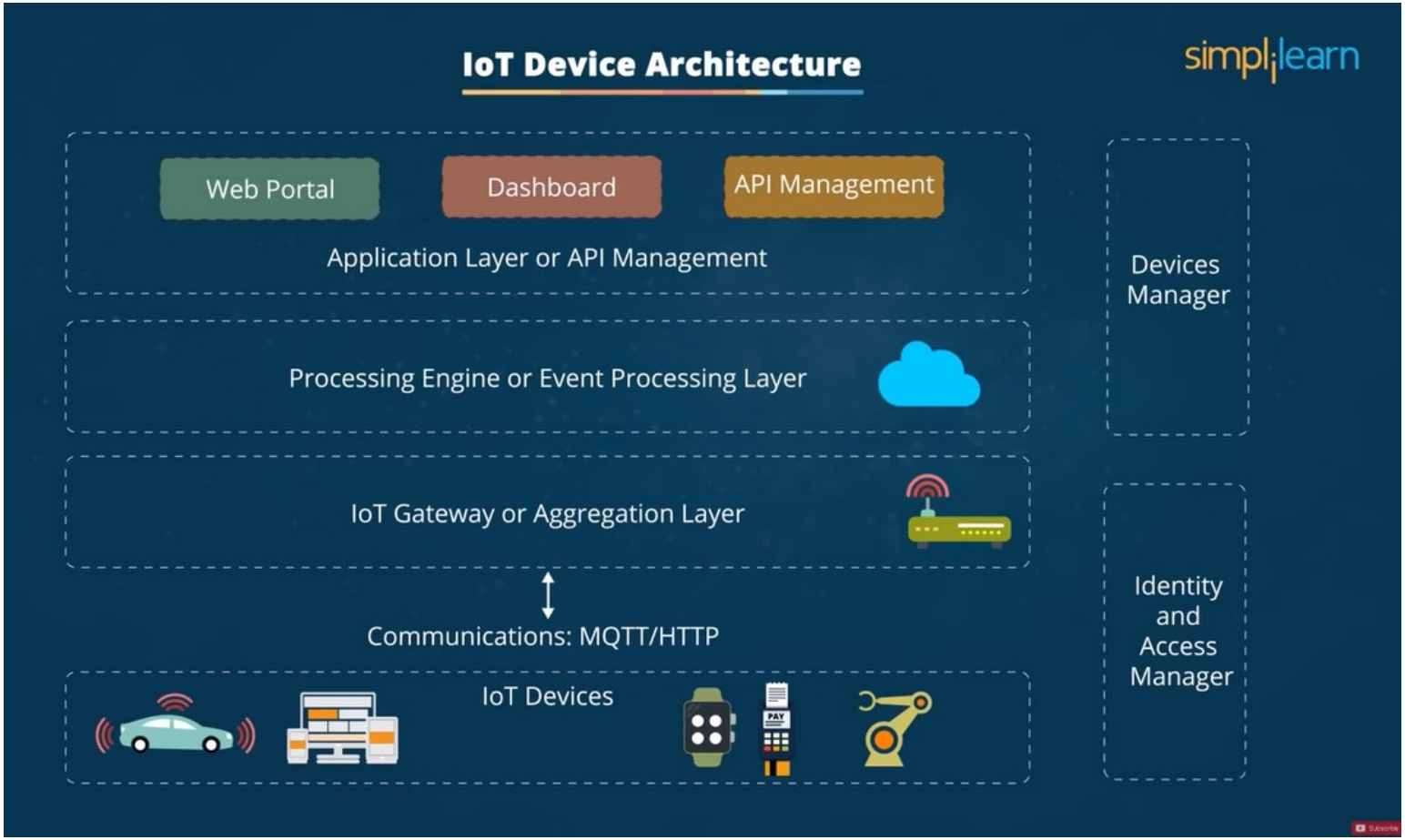
# Internet of Things – Architecture



# Communications

## ❑ Zigbee

- What are Zigbee?
- Zigbee Applications?
- Why Zigbee?
- Zigbee Architecture.
- Key Features of Zigbee.

Source: Zigbee

# Communications : Zigbee

## ❑ Zigbee

- Zigbee is a complete IoT solution — ZigBee is an open, global, packet-based protocol designed to provide an easy-to-use architecture for secure, reliable, low power wireless networks.
- ZigBee is a technological standard created for controlling and sensing the network. ZigBee is based on IEEE 802.15.4 and is created by Zigbee Alliance.
- ZigBee is a Personal Area Network standard that addresses the need for very low-cost implementation of Low power devices with Low data rates for short-range wireless communications.
- The ZigBee Alliance explains the origin of the name as: “The technique that honey bees use to communicate new-found food sources to other members of the colony is referred to as the ZigBee Principle. Using this silent, but powerful communication system, whereby the bee dances in a zig-zag pattern, he is able to share information, such as the location, distance and direction of a newly discovered food source to its fellow colony members.”

# Communications : Zigbee

## ❑ Zigbee Applications


ZigBee Remote Control


ZigBee Health Care


ZigBee Smart Energy


ZigBee Retail Services


ZigBee Home Automation


ZigBee Building Automation

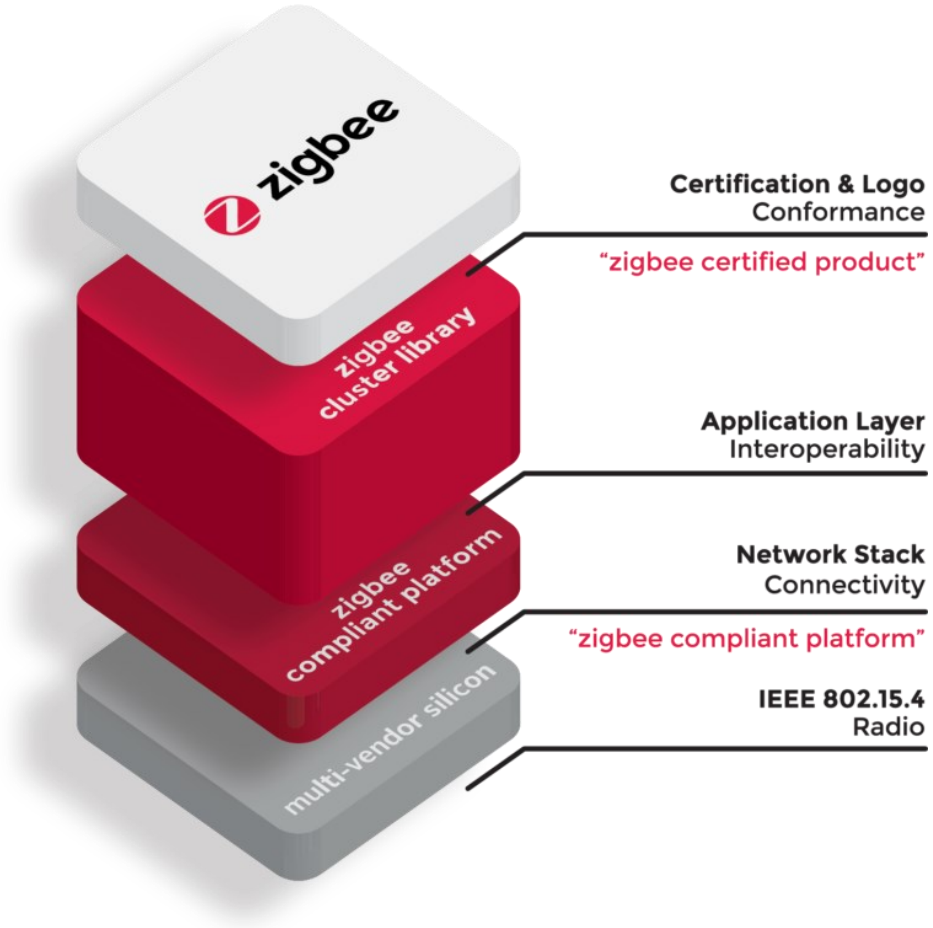

ZigBee Telecommunication Services

# Communications : Zigbee

- Zigbee (Why)

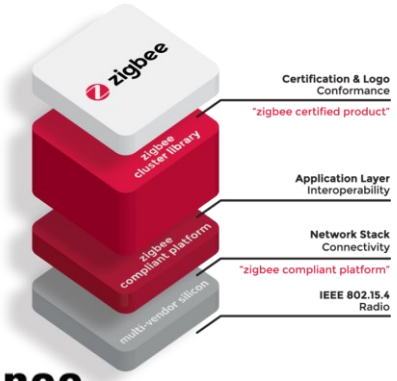
# Communications : Zigbee

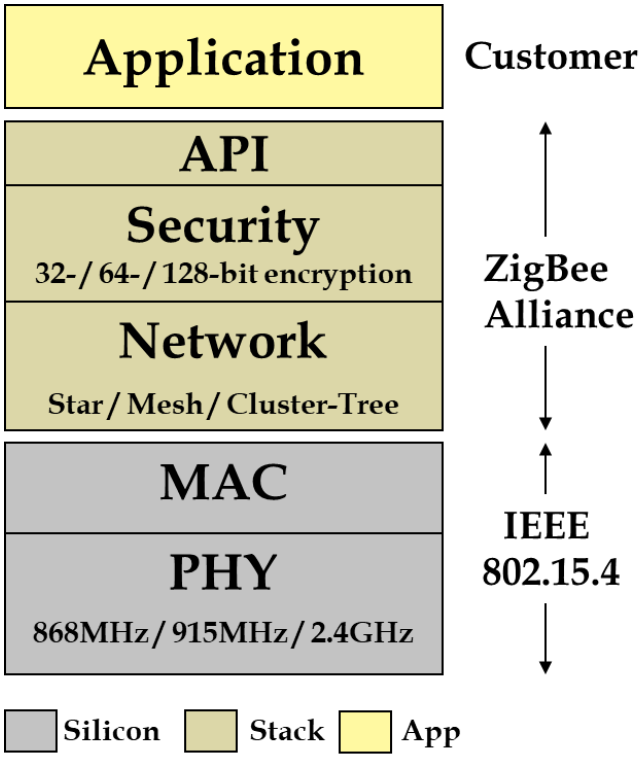
- Zigbee (Why)



# Communications : Zigbee

## ❑ Zigbee (Why)




### ZigBee Alliance

- "the software"
- Network, Security & Application layers
- Brand management

### IEEE 802.15.4

- "the hardware"
- Physical & Media Access Control layers

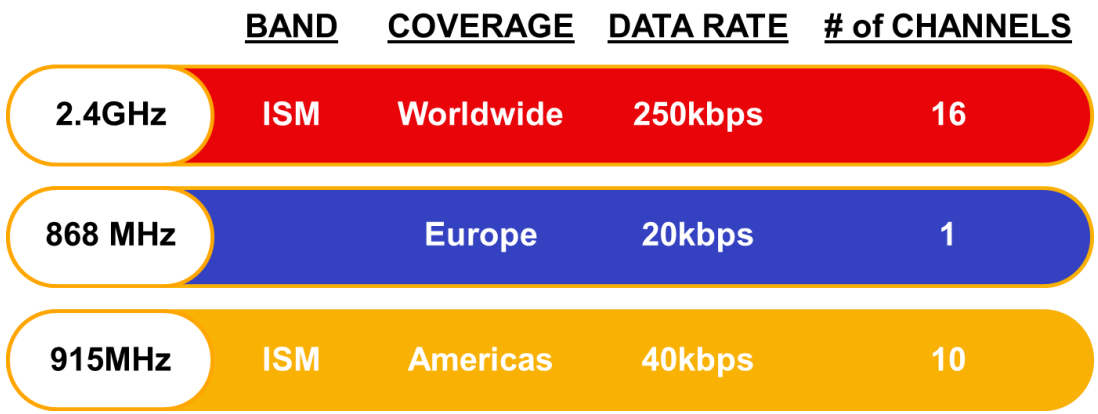
# Communications : Zigbee

- **Zigbee Characteristics:**
  - Low cost.
  - Easy to implement.
  - Low power consumption.
  - Supports up to 65,000 nodes.
  - Supports mesh, tree and start networks.
  - Low data rate. (20,40,250,1000) kbit per second.
  - Star or Peer-to-Peer operation.
  - low latency devices.
  - CSMA-CA channel access.
  - Dynamic device addressing.
  - Fully handshaked protocol for transfer reliability.

# Communications : Zigbee

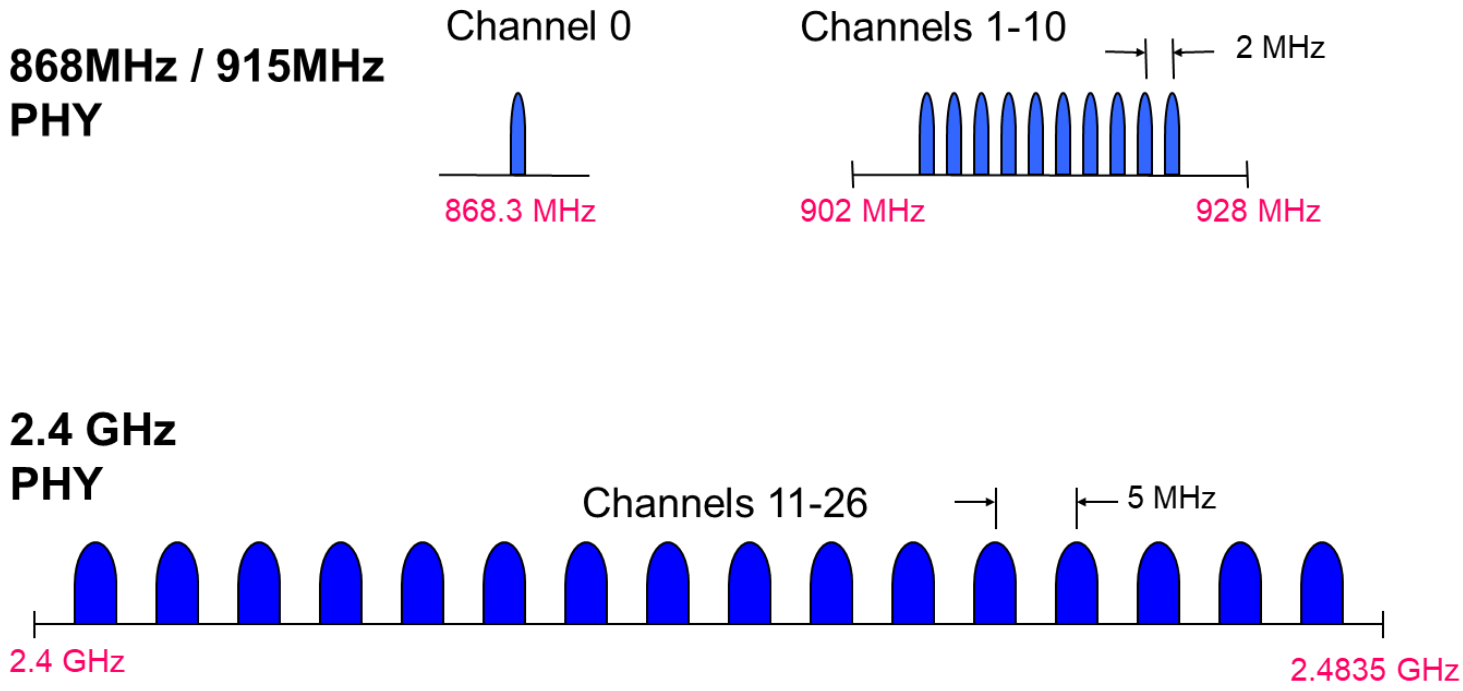
- **Zigbee Frequencies and Data Rates:**

| Frequency Band | Frequency Range | Region | Release Year |
|---|---|---|---|
| 868 MHz | 868–868.6 MHz | European countries | 2003- |
| 915 MHZ | 902–928 MHz | North America, Australia, and New Zealand | 2006- ( Modifications) |
| 2.4GHz | 2400–2483.5 MHz | World Wide | 2007 (CSS , UWB) |
| 780 MHz | 779–787 MHz | China | 2009 (PHYs) |
| 950 MHz | 950–956 MHz | Japan | |



# Communications : Zigbee

- **Zigbee Frequencies and Data Rates:**



# Communications : Zigbee

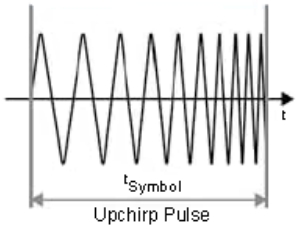
- **IEEE 802.15.4**
  - IEEE Std 802.15.4 is designed to be:
    - Short-range service without infrastructure.
    - Consume little power.
    - Low operating cost.
  - How ?
    - Low Duty cycle ( 99% inactive ,standby mode, consume≈ zero power)
    - Modulation (modulation scheme is chosen to be highly efficient, enabling a low-cost implementation (DSSS, QPSK , BPSK) ).
    - Quality of service (a simple full-handshake protocol to ensure reliable data transfer).

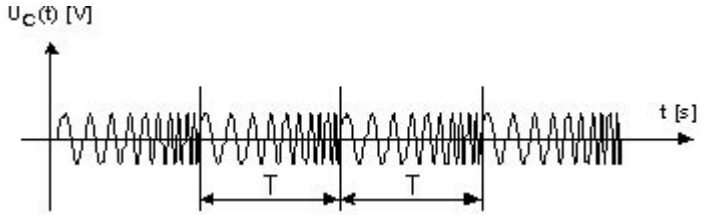
# Communications : Zigbee

- IEEE 802.15.4 PHY Layer provides the interface with the physical medium and is in charge of:
  - Activation and deactivation of the radio transceiver.
  - Energy Detection (ED) within the current channel.
  - Link Quality Indicator (LQI) for received packets.
  - Clear Channel Assessment (CCA) determines whether the wireless medium is ready or busy.
  - Channel frequency selection.
  - Data transmission and reception.

# Communications : Zigbee

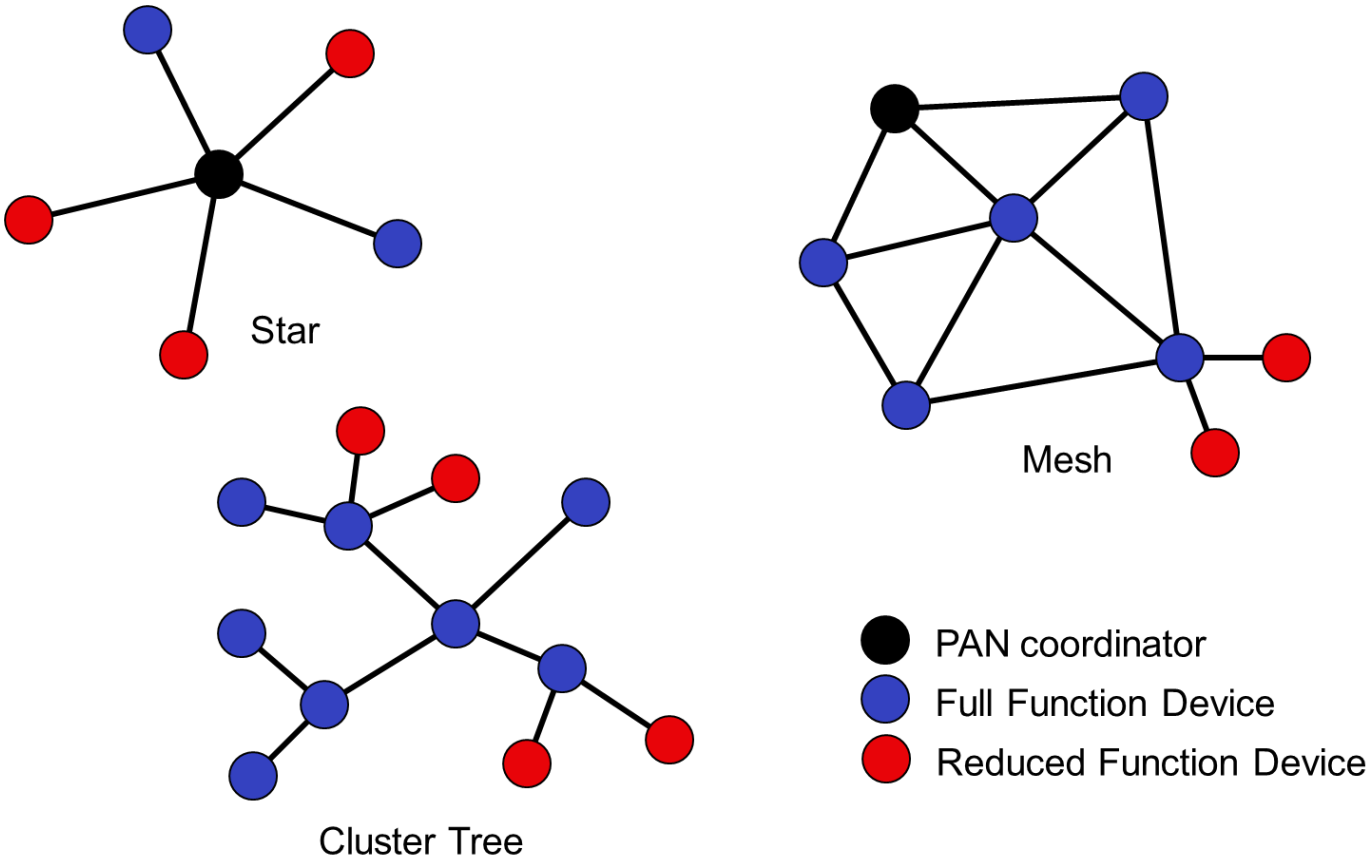
- IEEE 802.15.4 added Chirp Spread Spectrum (CSS)
  - Each symbol is transmitted with a chirp pulse and a fixed time duration.
  - Pros
    - Robust against Noise and Multipath Fading
    - Most effective Utilization of the given Bandwidth
    - Simple Synchronization due to chirp pattern repetition
    - Low power consumption
    - Quality on Demand support
  - Cons
    - Complexity
    - Hardware Implementation



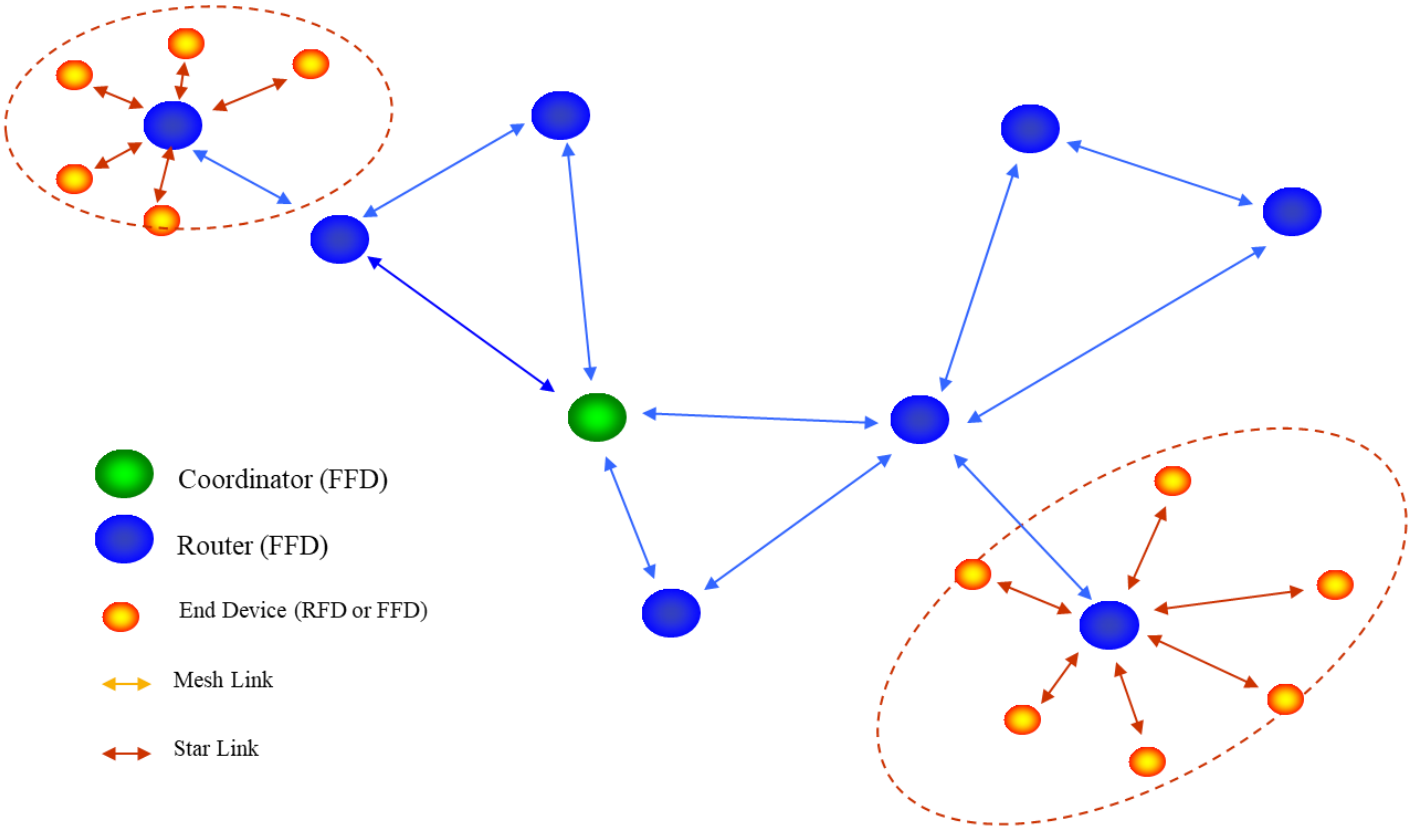
# Communications : Zigbee

## Zigbee Architecture



# Communications : Zigbee

## Zigbee Architecture



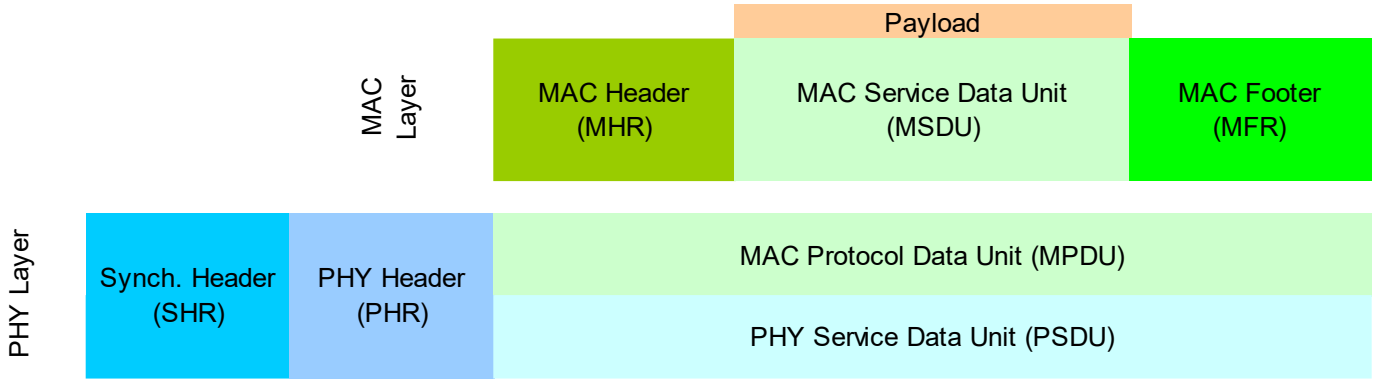
# Communications : Zigbee

## Zigbee Architecture

- Full function device (FFD)
  - Any topology
  - Network coordinator capable
  - Talks to any other device
- Reduced function device (RFD)
  - Limited to star topology
  - Cannot become a network coordinator
  - Talks only to a network coordinator
  - Very simple implementation

# Communications : Zigbee

## Zigbee Architecture – Frame Structure




## 4 Types of MAC Frames

- Data Frame
- Acknowledgment Frame
- MAC Command Frame
- Beacon Frame: Transmitted by network coordinator. Contains network information, frame structure and notification of pending node messages.

# Communications : Zigbee

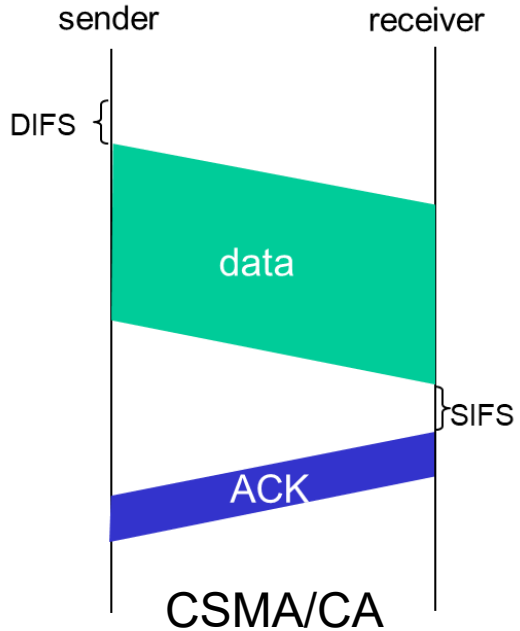
## Channel Access

- Contention Based Method (Carrier-Sense Multiple Access With Collision Avoidance Mechanism)
  - Carrier sense (CA): The initial idea is that participants may only send data over the network if the transmission medium is free. The carrier status detection checks the channel at any time, and data is not sent until it's available.
  - Multiple access (MA): Several stations share a transmission medium.
  - Collision avoidance (CA): A schedule tries to ensure that two or more participants do not start a transmission at the same time to avoid collisions. If overlapping does occur, this will be detected, and the transmission will be tried again.
- Contention Free Method (Coordinator dedicates a specific time slot to each device (Guaranteed Time Slot (GTS)))
  - TDMA is the channelization protocol in which the bandwidth of the channel is divided into various stations on a time basis.

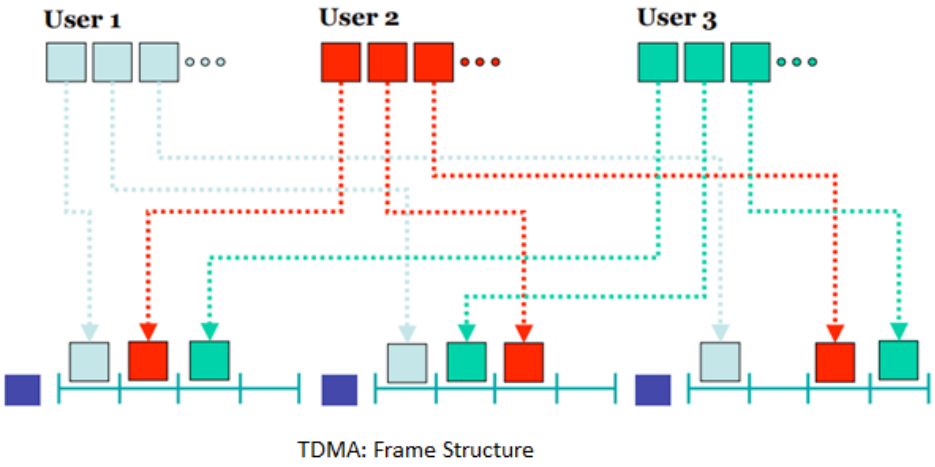
# Communications : Zigbee

## Channel Access

- if sense channel is idle for DIFS then transmit the entire frame (no CD).
- if sense channel busy then start a random backoff time timer counts down while channel idle, transmit when timer expires, if no ACK, increase random backoff interval, repeat.
- return ACK after **SIFS.**



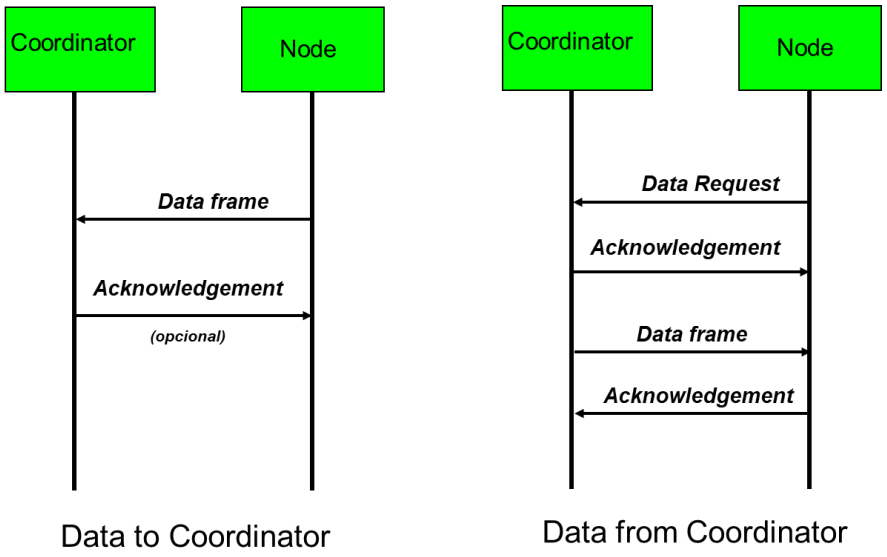

CSMA/CA




TDMA

# Communications : Zigbee

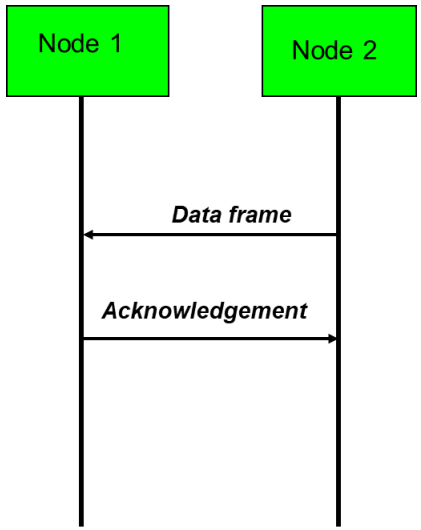
## Modes of Operation




Data to Coordinator

Data from Coordinator

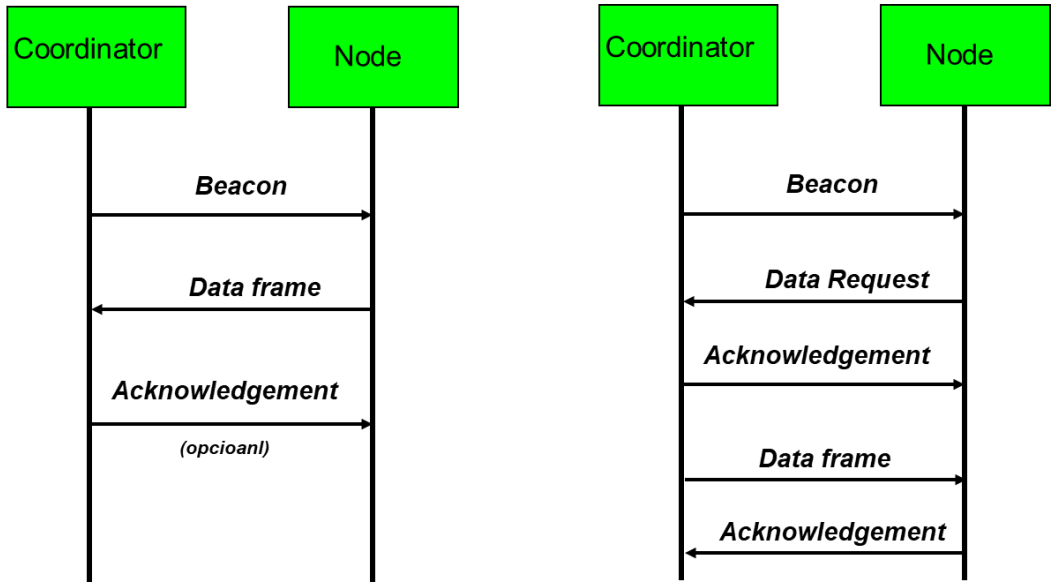
CSMA-CA
Nodes synchronized with Coordinator




Peer-Peer
Nodes synchronized with each other

# Communications : Zigbee

## Modes of Operation




Data to Coordinator

Data from Coordinator

Beacon Mode (Slotted CSMA-CA)

Nodes synchronized with Coordinator

# LoRa vs. Zigbee

| | LoRa | Zigbee |
|---|---|---|
| Specifications authority | LoRa Alliance | Zigbee Alliance |
| Year of development | 2009 | 1998 |
| Standard | IEEE 802.15.4 | IEEE 802.15.4 |
| Frequency band | 863 to 870 MHz, 902 to 928 MHz, 915 to 928 MHz, 2.4 GHz worldwide | 868MHz, 915 MHz, 2.4GHz |
| Transmission range | 3 miles (4.7 km) in urban areas, 10 miles (16 km) or more in rural areas | 10 to 100 meters |
| Power consumption | 300 bps to 37.5 kbps | low |
| Data rate | lower compare to Zigbee | 20 kbps (868 MHz), 40Kbps (915 MHz) , 250 kbps (2.4GHz) |
| Topology | star | star, tree, peer-to-peer and mesh |
| Cost | low | middle |
| Application | used as Wide Area Network | used as LR-WPAN i.e. low rate wireless personal area network |

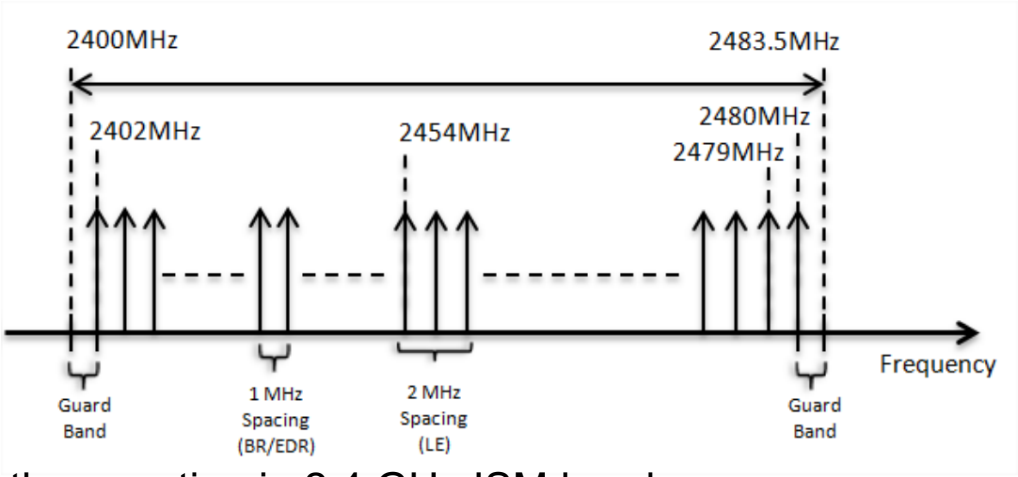
# Communications : Bluetooth

## ❑ Bluetooth

- Bluetooth wireless technology is an open specification for a low-cost, low-power, short-range radio technology for ad-hoc wireless communication of voice and data anywhere in the world.
- Bluetooth was invented by Ericsson in 1994. Originally conceived as a cable replacement technology.
- "King Harald Bluetooth (His dead tooth, which was a dark blue/grey color, and earned him the nickname Bluetooth.)…was famous for uniting Scandinavia just as we intended to unite the PC and cellular industries with a short-range wireless link."
- Bluetooth exchange works using short-wave radio, with radio bands ranging from 2.402 GHz to 2.480 GHz, and building a Personal Area Network (PAN). Typically, a master Bluetooth device can connect to a maximum of seven devices at a go.

# Communications : Bluetooth

## ❑ Bluetooth Frequency Bands




Bluetooth, operating in 2.4 GHz ISM band

- employs 79 RF channels with 1 MHz spacing for Basic and Enhanced Data Rates (BR/EDR) transmissions: f=2402+k MHz, k=0,…,78
- and 40 RF channels with 2 MHz spacing for Low Energy (LE) transmissions: f=2402+k*2 MHz, k=0, …,39 (LE).

https://download.ni.com/evaluation/rf/intro_to_bluetooth_test.pdf

# Communications : Bluetooth

## ❑ Bluetooth Modulations

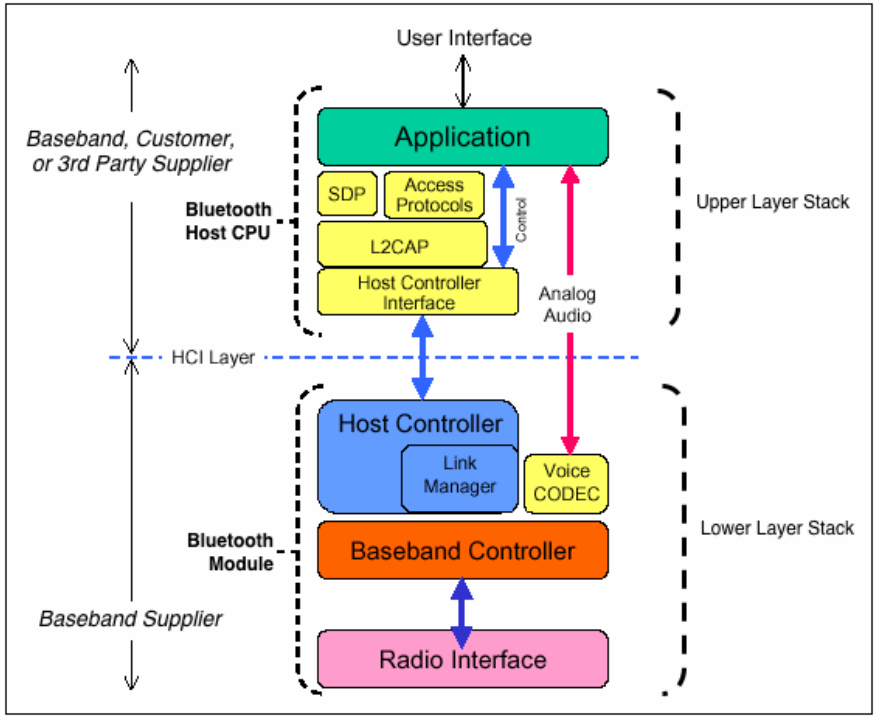
- Basic Rate:
  - Binary GFSK at 1 Msymbol/s
- Enhanced Date Rate:
  - p/4-DQPSK at 2 Msymbol/s
  - 8DPSK at 3 Msymbol/s
- Low Energy:
  - Binary GFSK with at 1 Msymbol/s

https://download.ni.com/evaluation/rf/intro_to_bluetooth_test.pdf

# Communications : Bluetooth

## ❑ Bluetooth Layers

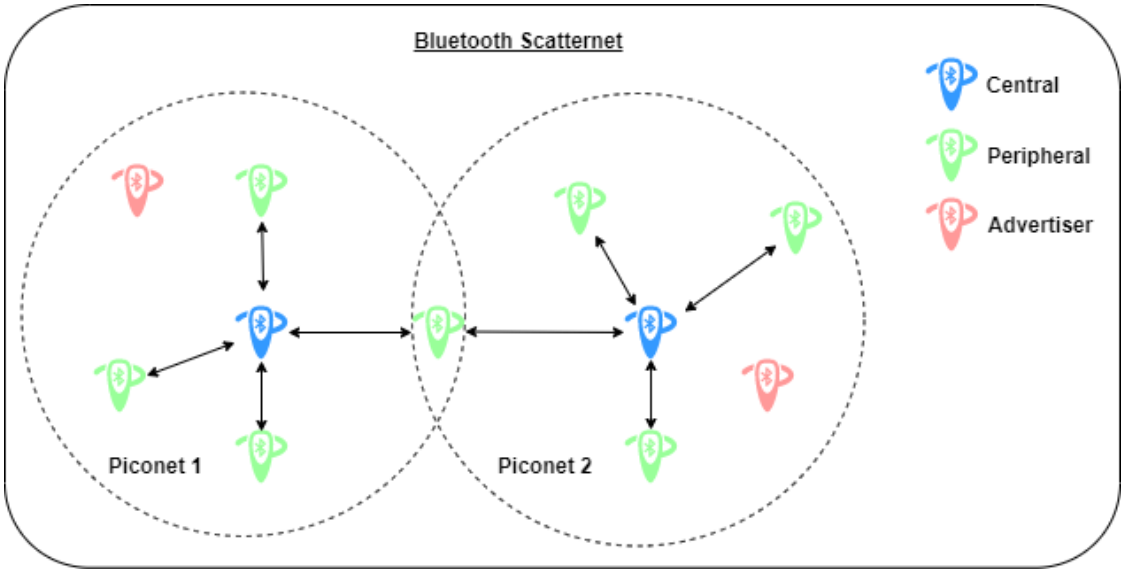
- The host controller interface (HCI) serves as the interface between the software part of the system and the hardware (i.e., the device driver).
- The L2CAP (logical link control and adaptation protocol) plays a central role in communication between the upper and lower layers of the Bluetooth stack. It keeps track of where data packets come from and where they should go.
- The service discovery protocol (SDP) is important to mention because it exists independently of other higher-level protocol layers. It provides the interface to the link controller and allows for interoperability between Bluetooth devices.



# Communications : Bluetooth

## ❑ Bluetooth Architecture

- The architecture of Bluetooth defines two types of networks:
  - Piconet
  - Scatternet

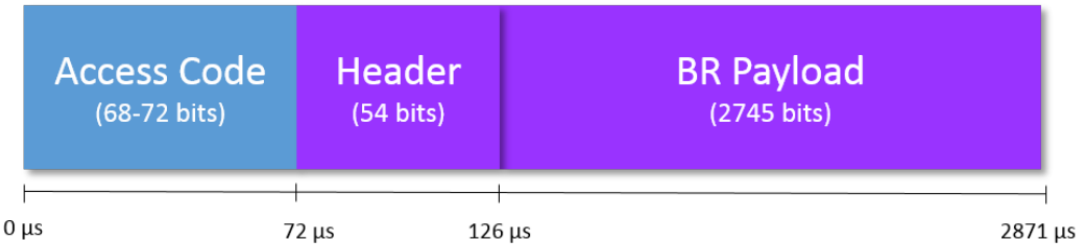



Before joining the piconet, each *Peripheral* node is in an advertiser role.

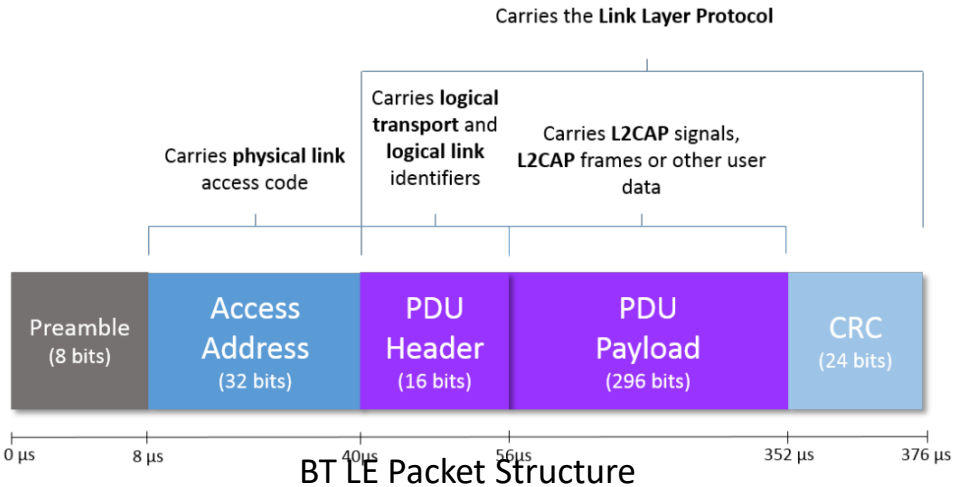
https://www.mathworks.com/help/bluetooth/gs/bluetooth-technology-overview.html

# Communications : Bluetooth

## ❑ Bluetooth Frame Structure




Basic Rate Packet Structure




BT LE Packet Structure

# Communications : Bluetooth

## ❑ Bluetooth Vs. Bluetooth LE.

| Feature | Bluetooth Classic | Bluetooth Low Energy (BLE) |
|---|---|---|
| Power consumption | High (approx 1W) | Low (approx 0.01W-0.5W) |
| Communication Range | 10m to 30m | 10m to 30m |
| Data Rate | 1Mbps for BR<br>2-3Mbps for EDR | 500kbps-1Mbps |
| Modulation Technique | GFSK for BR<br>8-DPSK or π/4-DQPSK for EDR | GFSK |
| RF Bandwidth | 2.4 GHz ISM band (2400-2483.5 MHz) | 2.4 GHz ISM band (2400-2483.5 MHz) |
| Number of Channels | 79 channels each of width 1Mhz | 40 channels each of width 2MHz |
| Spreading | Frequency Hopping Spread Spectrum (FHSS) | Frequency Hopping Spread Spectrum (FHSS) |
| Data link layer protocol | Time Division Multiple Access (TDMA) | Time Division Multiple Access (TDMA) |
| Error detection | 8 bit CRC or 16 bit CRC, and ACKs | 24 bit CRC, ACKs |
| Maximum number of active slaves | 7 | Unlimited |

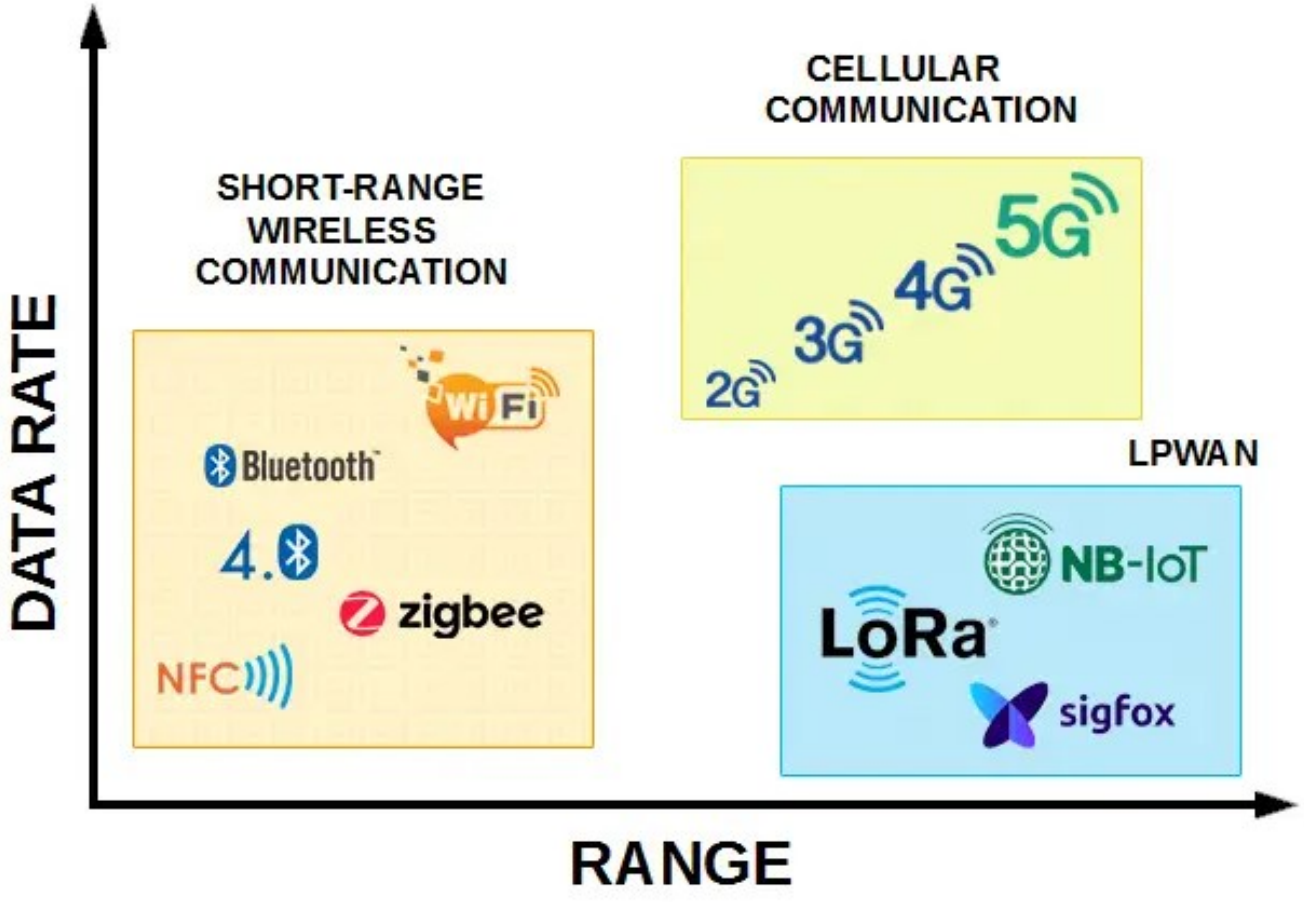
Bluetooth vs Bluetooth Low Energy - GeeksforGeeks

# A comparative study of LPWAN technologies

| Attribute | Bluetooth® Low Energy Technology | Wi-Fi | Z-Wave | IEEE 802.15.4 (Zigbee, Thread) | LTE-M | NB-IoT | Sigfox | LoRaWAN |
|---|---|---|---|---|---|---|---|---|
| Range | 10 m – 1.5 km | 15 m – 100 m | 30 m - 50 m | 30 m – 100 m | 1 km – 10 km | 1 km – 10 km | 3 km – 50 km | 2 km – 20 km |
| Throughput | 125 kbps – 2 Mbps | 54 Mbps – 1.3 Gbps | 10 kbps – 100 kbps | 20 kbps – 250 kbps | Up to 1 Mbps | Up to 200 kbps | Up to 100 bps | 10 kbps – 50 kbps |
| Power Consumption | Low | Medium | Low | Low | Medium | Low | Low | Low |
| Ongoing Cost | One-time | One-time | One-time | One-time | Recurring | Recurring | Recurring | One-time |
| Module Cost | Under $5 | Under $10 | Under $10 | $8-$15 | $8-$20 | $8-$20 | Under $5 | $8-$15 |
| Topology | P2P, Star, Mesh, Broadcast | Star, Mesh | Mesh | Mesh | Star | Star | Star | Star |

https://www.bluetooth.com/blog/wireless-connectivity-options-for-iot-applications-technology-comparison

# IoT wireless technologies




https://www.mokolora.com/lora-and-wireless-technologies