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Master's degree ICT Internet Multimedia Engineering

Department of Information Engineering (DEI)
Master degree on ICT for Internet and Multimedia Engineering (MIME)

Internet of Things and Smart Cities
05 – Bluetooth Low Energy (BLE)

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Bluetooth

Overview

- **Bluetooth** is a wireless technology designed to connect devices of different functions such as telephones, notebooks, computers (desktop and laptop), cameras, printers, when they are at a **short distance** from each other.
  - Initially proposed by Ericsson.
  - Standardized as **IEEE 802.15.1**.
  - Originally thought as a solution to replace wired connections within computers.
- 3 classes of Bluetooth:
  - **Bluetooth Classic** (Basic Rate / Enhanced Data Rate – BR/EDR).
  - Bluetooth High Speed.
  - **Bluetooth Low Energy.**

Bluetooth

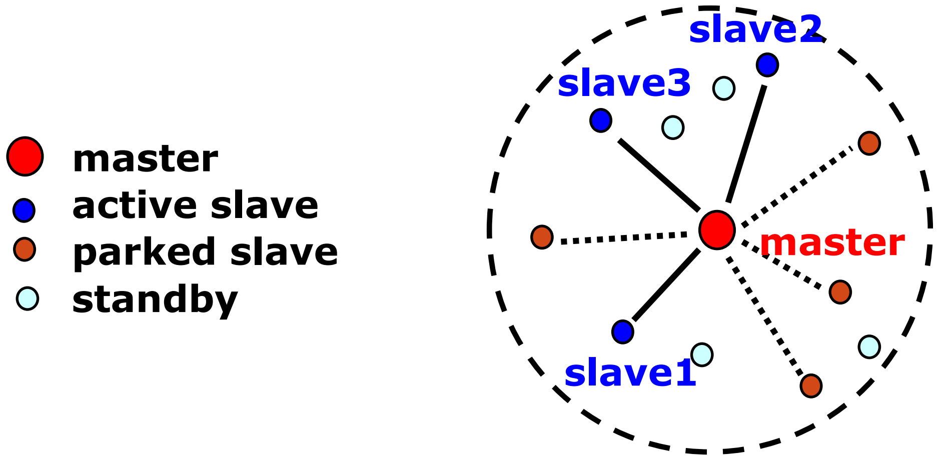
Applications

- **Bluetooth Classic (Basic Rate / Enhanced Data Rate – BR/EDR)**
  - Audio streaming (headphones, speakers, car audio systems, …).
  - Peripheral devices (keyboards, mice, printers, …).
  - File transfers (sending files between phones, computers, and other devices).
- **Bluetooth High Speed**
  - (High-resolution) video streaming.
  - Tethering (for sharing internet connections between devices).
- **Bluetooth Low Energy**
  - Wearables
  - Beacons (utilized in proximity marketing and location-based service)
  - Smart Home devices

BR/EDR

Topology

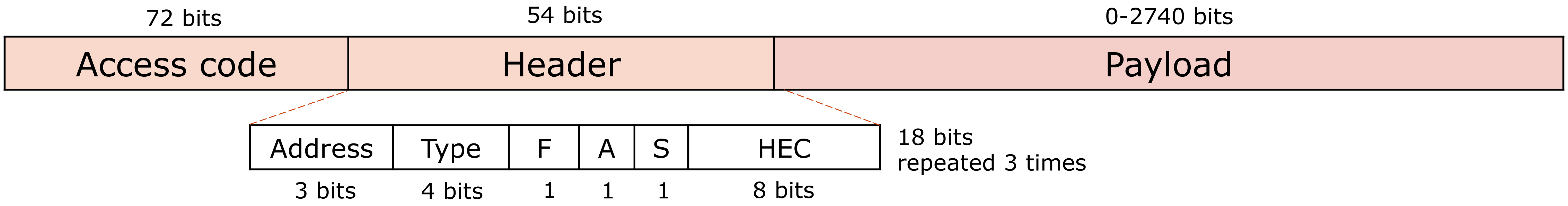
- Units connect in small networks called **piconets** (that can be combined to form what is called a **scatternet**).
  - Each piconet can host from 2 to 8 **active** devices.
  - Up to 255 in sleep (**parked**) state: synchronized but cannot take part in communication until it is moved to the active state.
  - One unit acts as **Master**, the others as **Slaves.**
  - Master manages the channel access by using a **polling** algorithm.



BR/EDR

Frame

- **Access code**: Synchronization bits and piconet ID.
- **Header**: 18-bit pattern repeated 3 times.
  - Address (3 bits for 2^3-1=7 possible destinations in the piconet).
  - Type of message.
  - F: Flow (=1 is receiver cannot accept packets).
  - A: Acknowledgment (Stop and Wait, 1 bit is enough).
  - S: Sequence number (Stop and Wait, 1 bit is enough).
  - HEC: header error correction.



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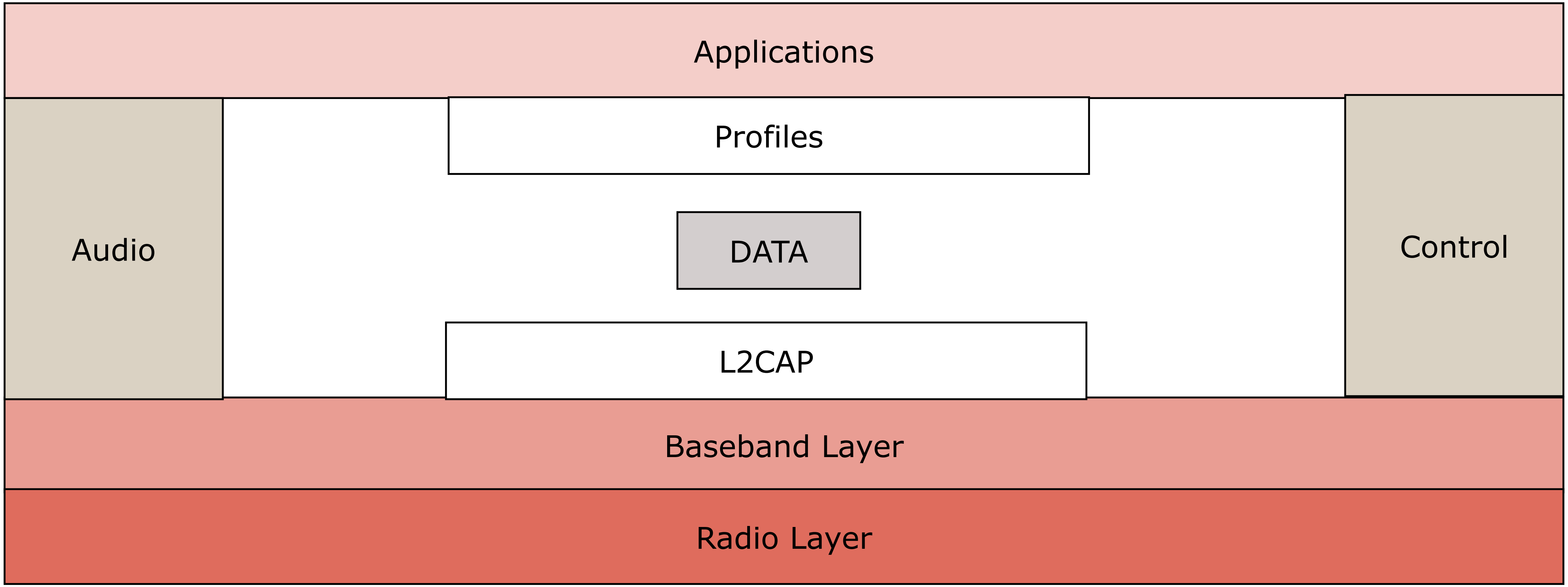
Layers



BR/EDR

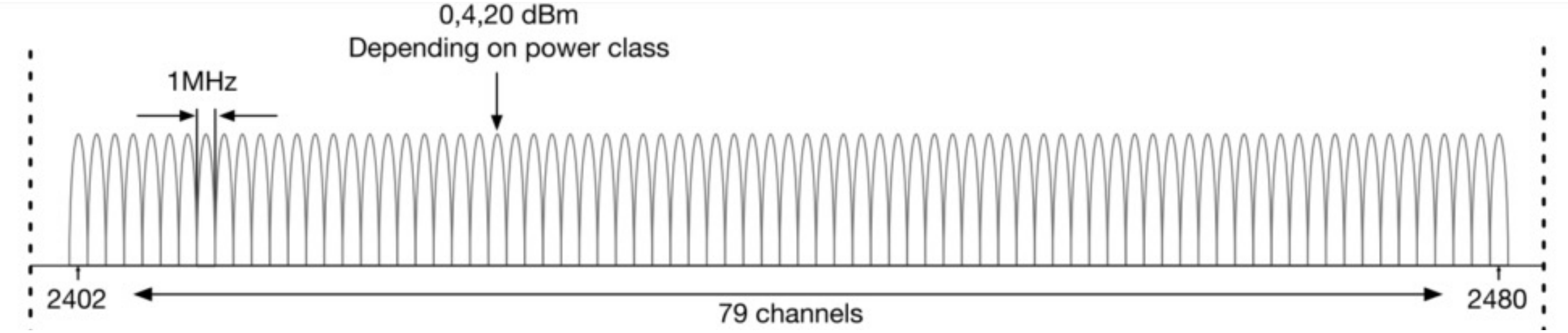
Radio Layer

- Roughly equivalent to the **PHY** layer in LANs.
- Three different **modulation** schemes:
  - Gaussian Frequency Shift Keying (**GFSK**) with Gaussian Filtering: 1 Mbit/s.
  - **π/4-DQPSK**: 2 Mbit/s.
  - **8-DQPSK**: 3 Mbit/s.

BR/EDR

Radio Layer

- Operate in the **2.4 GHz ISM band**, divided into 79 channels of 1 MHz each.
- The range depends on the transmission power (up to ~100 m).
- **Frequency-Hopping Spread Spectrum (FHSS)**: Bluetooth hops 1600 times/s→ frequency used for only 625 μs (**dwell time**) before it hops to another frequency.
  - This is also to reduce interference, since ISM bands are very crowded.

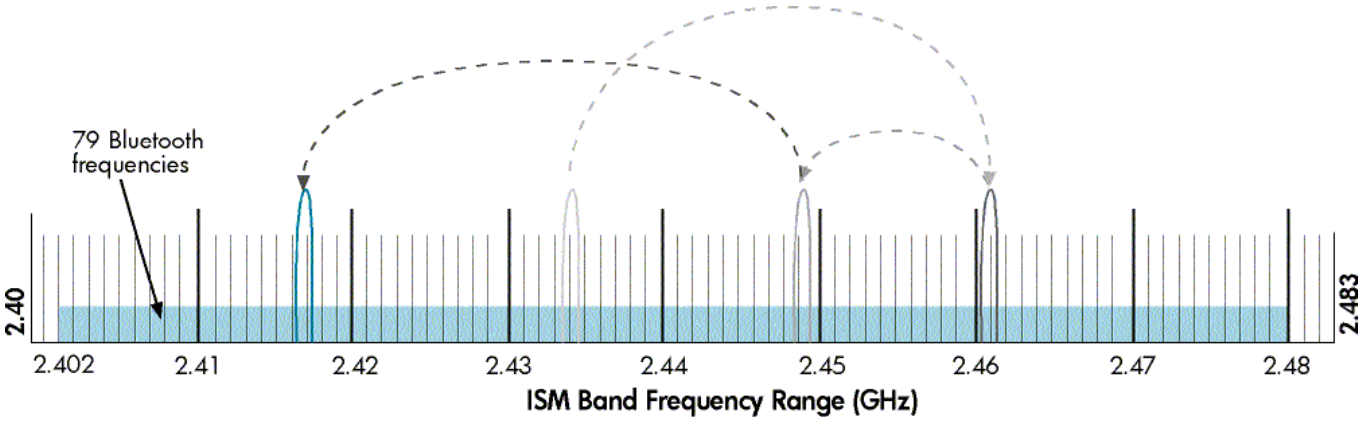


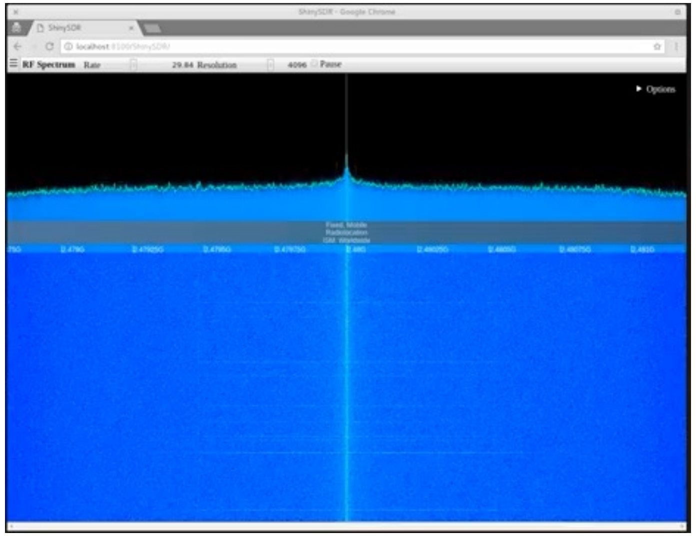
BR/EDR

Radio Layer – FHSS

Problem: where/how to hop? How can two devices know what is the next frequency to hop to? → Bluetooth needs **coordination** and **link establishment** (we'll see.....).

https://www.youtube.com/watch?v=6qNWQxRKoss



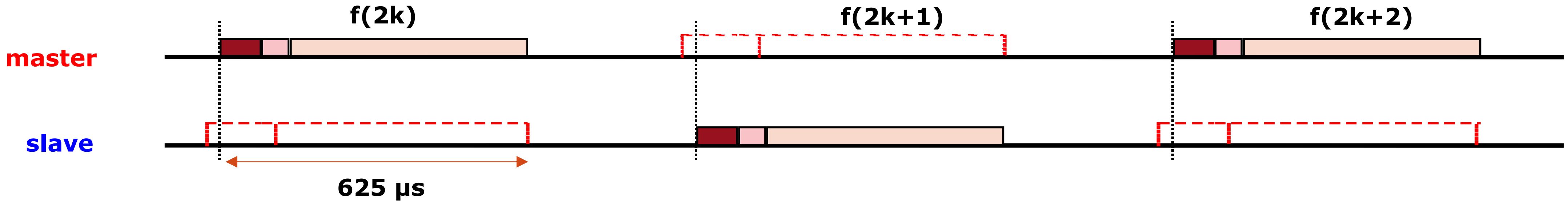


RF Spectrum Rate 29.84 Resolution 4096 □ Pause

BR/EDR

Baseband Layer

- Roughly equivalent to the **MAC** layer in LANs.
- **Time Division Duplex (TDD)**, with slots of 625 µs.
  - Bi-directional data transmission is realized by alternating slots in the two directions.
  - Master to a slave (**EVEN** slots) or slave to the master (**ODD** slots).
- Each transmission occurs on a different 1-MHz RF channel, according to a frequency-hopping pattern that is different for each piconet (this is similar to walkie-talkies using different carrier frequencies) → WHERE and HOW?



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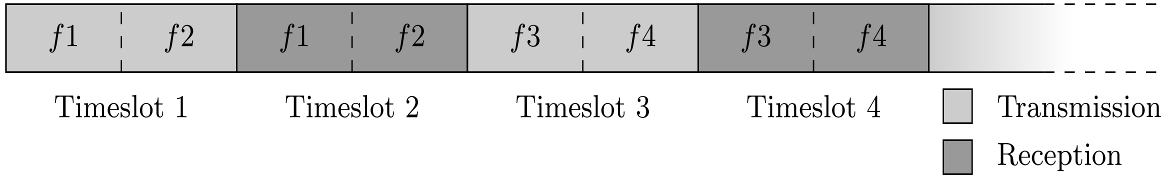
Baseband Layer: Connection procedure

- **PHASE 1: Inquiry**
  - Master initializes the communication link.
  - Master establishes the pseudo-random hopping sequence for the piconet.
  - Terminals go in sleep mode.
- **PHASE 2: Paging (it may take a lot of time)**
  - The Master pages another Slave.
  - The Slave sends a reply to the source (Device Access Code (DAC)).
  - The Master sends the list of future planned hops of frequency.
  - The Slave sends a second DAC to the source.



BR/EDR

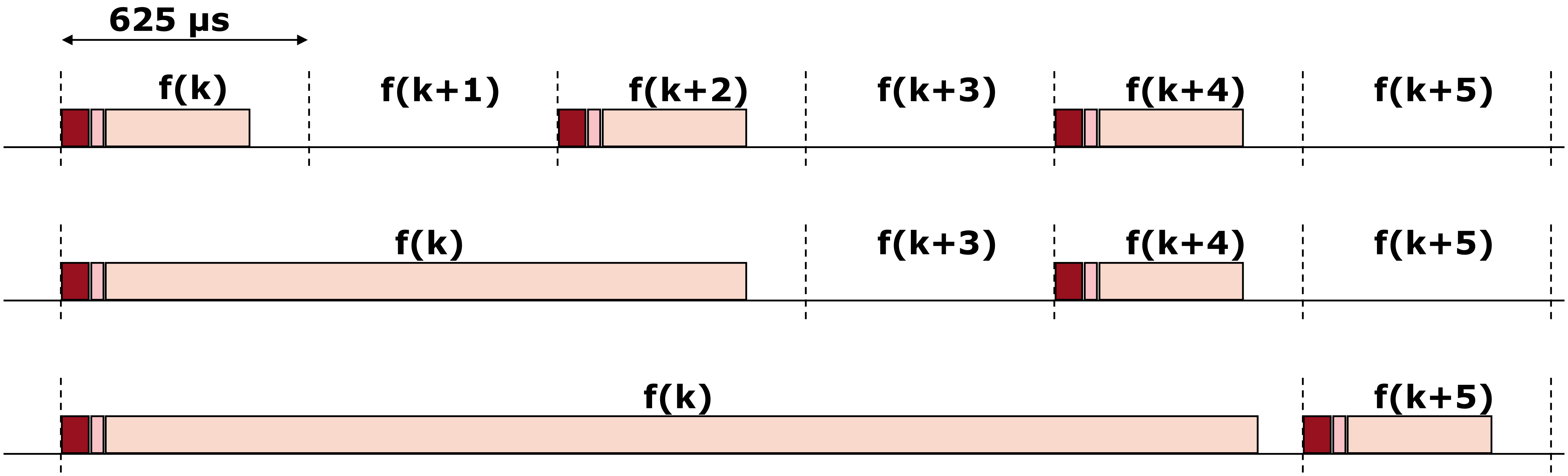
L2CAP

- **Logical Link Control and Adaptation Protocol (L2CAP)** is used for multiplexing, segmentation, reassembly, QoS and group management.
- Supports two types of communication:
  - **Synchronous Connection Oriented (SCO)** (latency more important than integrity).
    - Synchronous, symmetric, connection-oriented service.
    - MAC is deterministic: slots reserved to voice traffic at regular time intervals.
  - **Asynchronous Connection-Less (ACL)** (integrity is more important than latency).
    - Packet oriented, asymmetric, asynchronous.
    - If a payload encapsulated in the frame is corrupted, it is retransmitted.
    - Packets can be 1, 3 or 5 slot long.
    - Carrier frequency does not change during the transmission in a multislot.
    - Multislot packets reduce overhead due to header and guard time (~259 μs).

BR/EDR

L2CAP ACL

- Packets can be 1, 3 or 5 slot long.



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BR/EDR

Profiles

- **Profiles**: different application-specific protocol stacks.
- Nearly 40 profiles.
- Some profiles have a quite narrow application score (e.g., headset profile).
- Some profiles support more flexible and general applications (e.g., PAN).
- The networking capability of BR/EDR depends on the profile.

List of Bluetooth profiles
https://en.wikipedia.org/wiki/List_of_Bluetooth_profiles

BLE

Overview

- **Bluetooth Low Energy (BLE)** is a more recent extension meant specifically for sensors or low-power IoT devices.
- Some differences wrt BR/EDR:
  - Fewer channels: 40 (2 MHz) instead of 79 (1 MHz).
    - 3 (out of 40) **advertisement channels** for special use.
  - **GPSK** modulation only.
  - Data rate up to 2 Mbit/s (vs. 1 Mbit/s in GPSK-BR/EDR).
    - Higher data rate results in shorter transmission times → **less energy consumption**.
  - Lower power consumption.
  - Different codes for error protection.
  - Dwell time for frequency hopping is only determined during connection establishment.

BLE

Communication modes

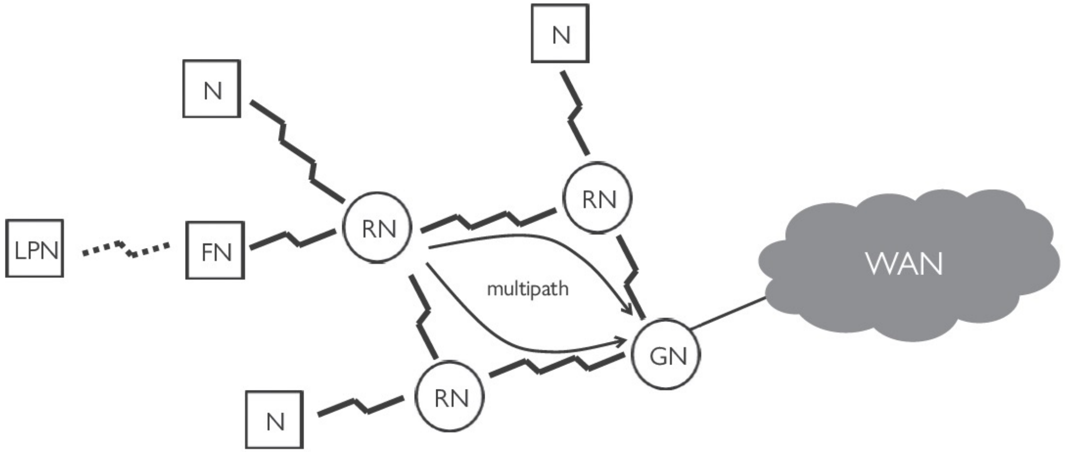
- In BLE the nodes can assume 4 roles (vs. 2 in BR/EDR):
  - **Broadcaster**: a node which periodically transmits advertisements, but does not allow connections to be established (e.g., iBeacon).
  - **Observer**: a node that just listens for advertisements and does not attempt to open connections (e.g., smartphone with an active localization App).
  - **Peripheral**: a node which transmits advertisements and may accept connection requests, acting as a **Slave**.
  - **Central**: a node which may open connection towards a peripheral, acting as the **Master** once the information relative to a peripheral has been received through advertisements.

BLE

New profiles

- New profiles: Heart Rate, Internet Protocol Support Profile, **Mesh Profile**…
- **Mesh Profile**: it allows the creation and management of mesh networks.
  - Some nodes may act as relays.
  - **Low Power Nodes**: sleep for some time, and wake up periodically to talk with **Friend Nodes** nearby, which store the message that they could not receive while sleeping.
  - **Managed flooding mechanisms** to avoid loops.

RN: relay node
GN: gateway node
LPN: low power node
FN: friend node



BR/EDR vs. BLE

Comparison

Feature	BR/EDR	BLE
Power consumption	Higher	Lower
Data rate	Up to 3 Mbps (8-DPSK)	Up to 2 Mbps (GFSK)
Latency	Lower	Higher
Connection Type	Point-to-point	Point-to-point, broadcast, mesh
Use case	Audio, peripherals, …	IoT, wearables, sensors. …
Compatibility	Classic Bluetooth devices	Bluetooth 4.0 and newer