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Bluetooth

[#card](#)

- Bluetooth is a **collection of protocols** that are a **cable replacement technology** (pc, headphones, printers) that implement a personal area network
 - Lower cost and lower power consumption than [IEEE 802.11](#)
- It was more successful with smartphones
- Limited coverage (one room) up to 10 meters
- Slow versions because it's not a replacement of [Wi-Fi](#), nowadays high speed versions use [Wi-Fi](#) inside

Versions

#card

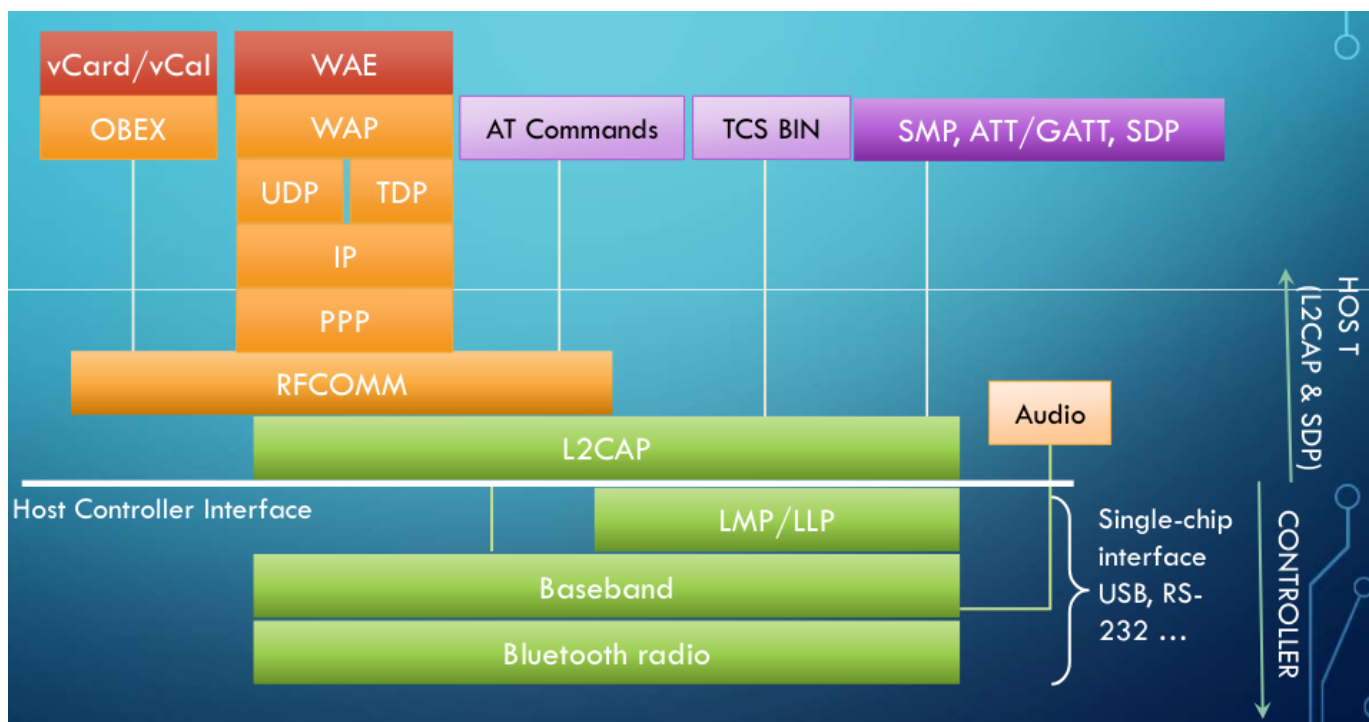
- 3.0, uses a parallel [IEEE 802.11](#) channel to increase up to 24 Mbps, that is negotiated with Bluetooth
- 4.0 in 2010, defines: classic Bluetooth, high speed Bluetooth and low energy Bluetooth (i.e. BLE ~1 Mbps)
- 5.0 in 2016, BLE with burst up to 2Mbps (important for IoT) and increase capacity for connectionless services (location relevant navigation)

Applications

#card #question

- cable replacement (original idea)
- sync devices (e.g. smartbands)
- access to the internet
- mobile social networking (e.g. Immuni or crowd sensing in general)

Architecture



- Host controller interface between hw/sw
- One host (logical layer), while one or more controllers for the physical layer for the different bluetooth versions
 - A bluetooth card contains the controller + L2CAP (logical link control and adaption protocol)
- Protocols (core in **bold**, others are adopted)
 - **Physical layer** defines

- **Radio**, frequencies
- **Baseband**, low level procedures
- **Data Link layer** defines the **setup and controller**
 - Lower part
 - **LMP** (link management protocol for BR/EDR)
 - **LLP** (link layer protocol for BLE)
 - Upper part
 - **L2CAP** (Logical Link Control and Adaptation): higher-level protocol multiplexing (package segmentation)
- **Application layer**
 - Management/discovery
 - **SDP** for service discovery
 - SMP, ATT/GATT (kind of a small [ZigBee](#) cluster library)
 - RFCOMM emulates serial port for cable replacement
 - Telephony AT, TCS

Controllers

- Basic rate (headphones for smartphone)
- Low Energy
- Alternate MAC, for high speed transport link [IEEE 802.11](#) (2 Mbps → 24 Mbps)

Basic rate or Enhanced data rate

- Operates at 2.4Ghz like [IEEE 802.15.4](#) and [IEEE 802.11](#)
- 1Mbps for BR, 3Mbps for EDR
- Forms a **piconet**: group of devices synchronized to a common clock and **frequency hopping pattern** [#todo](#)
 - Bluetooth BR/EDR is **connection oriented**, so piconet must be formed before, in order to communicate
- Logical links transport **synchronous** (like [IEEE 802.15.4](#)), **asynchronous** and **isochronous** data (start async and then for a period sync)
 - Synchronization is used to ensure low energy for BLE, because it's required at mac level and using sniff mode
- BR uses at peak 25mA

Low Energy (LE)

- Compared to [Basic rate Enhanced data rate](#)
 - smaller packets to reduce TX/RX power consumption
 - less channels for discovery and connection (searching over a smaller n)
 - simpler state machine

- used to **expose the state** rather than transferring
- Frequency division multiple access (FDMA) over 40 physical channels + Time division multiple access (TDMA).
- Physical channel divided with **advertising** and **connection** events, namely frame and its response
- other
 - latency 3ms
 - topology star
 - connections > 2billion
 - range 150m

Powe consumption

- less than 20mA at peak with an average of less than 5μA
 - even devices with coin cell battery!

Speed

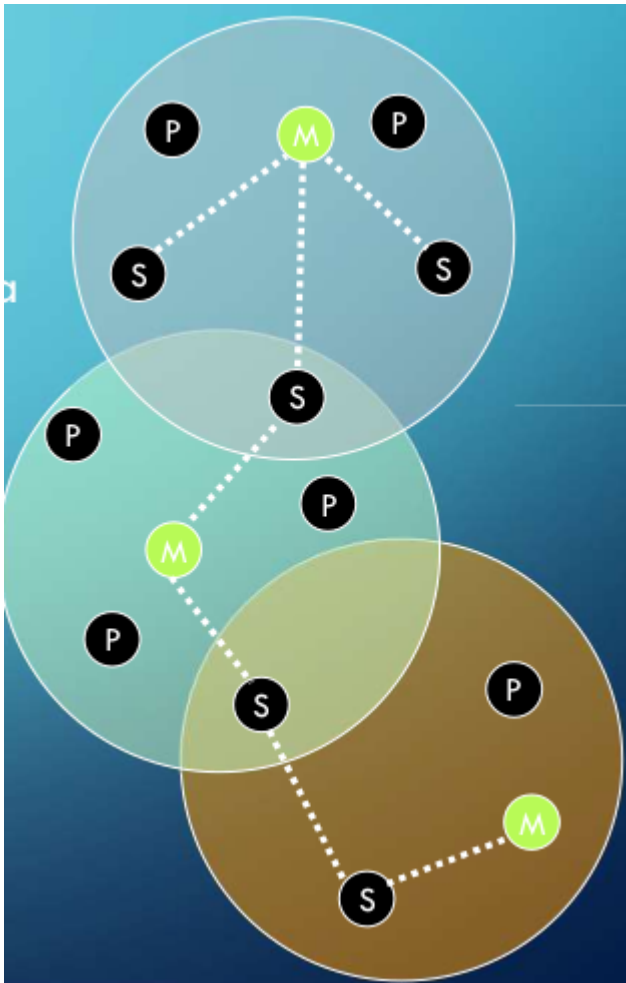
- up to 1Mbps nominal, but in reality for the overhead it's smaller

Topology

It's the piconet, formed by master and slaves

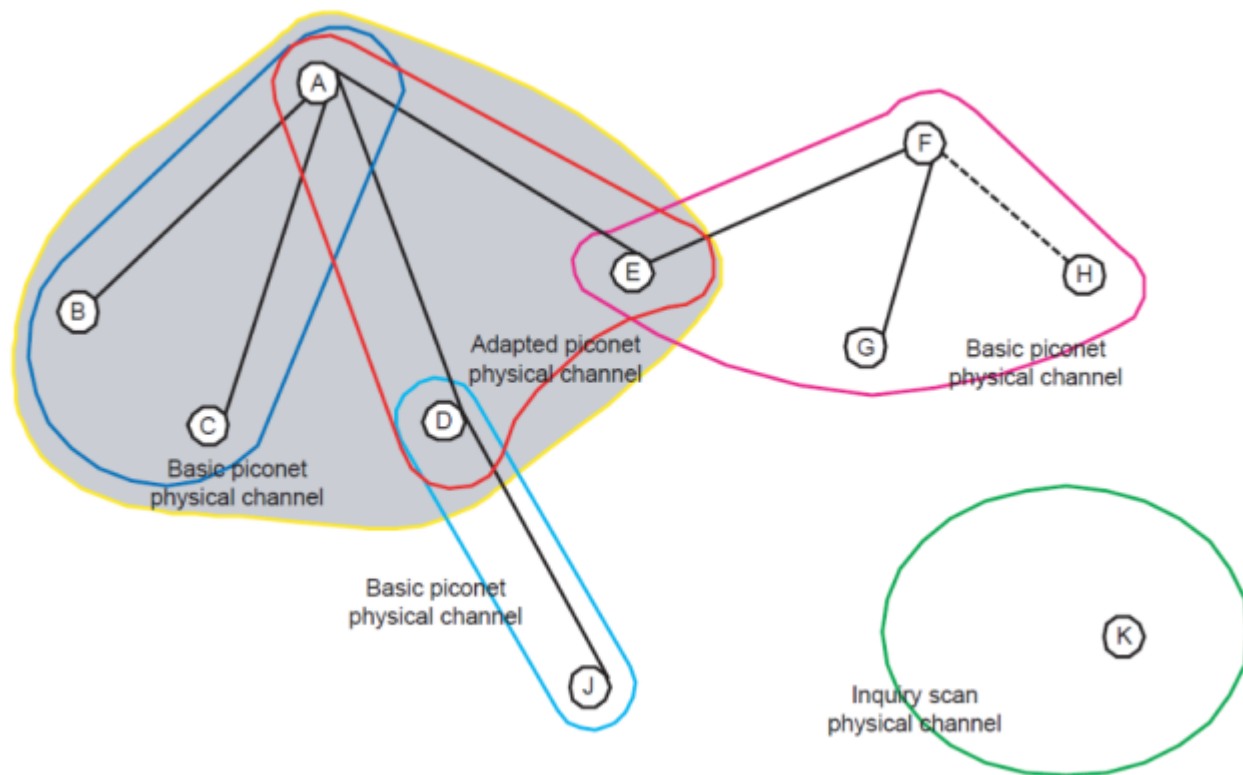
- **1 Master** than enforces the **synchronization** to enable the communication of the slaves, by **controlling the access** to the channels of the **slaves**
 - roles are not fixed
 - hence slaves can only communicate when the master says so
- Types
 - Point to point
 - Point to multipoint
- BR/EDR
 - Up to 7 slaves in a piconet, but other can be in **parked mode** to keep in sync with the master.
- LE
 - No limit to active slaves in a piconet
 - Just in one piconet

Scatternet



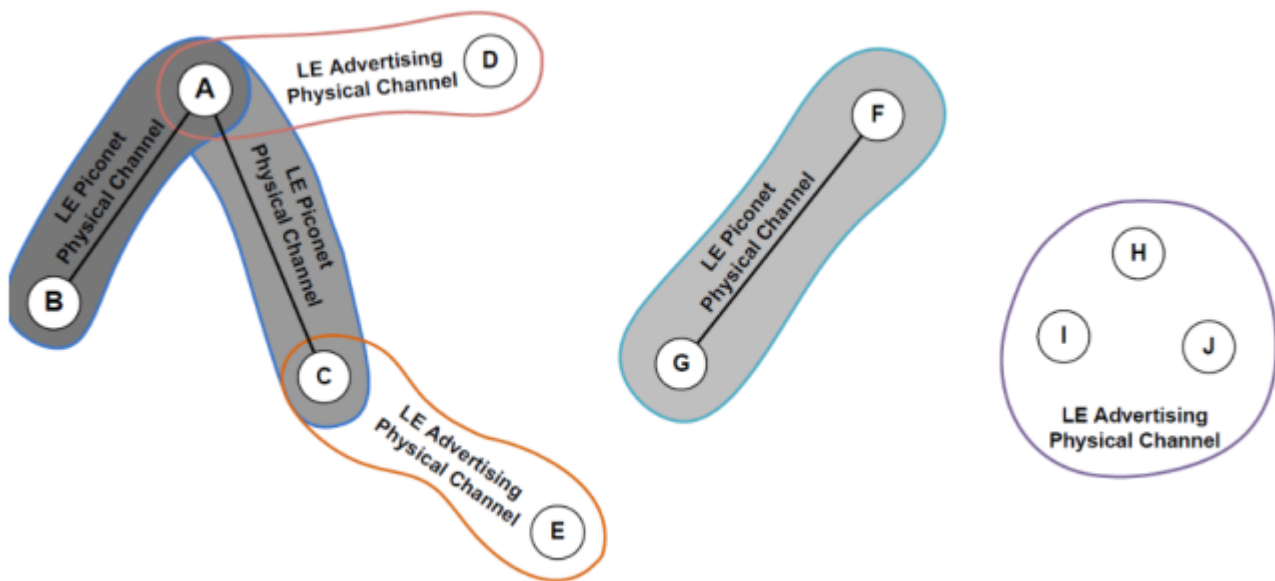
- to extend the range by doing multi-hop communication
- there is no routing protocol defined by the standard
- no usefull applications

BR/EDR example



- Several piconets in an area
- A is the master, the other slaves
 - They can use different low level mechanism
- F is master, the other slaves
 - H is temporarily **deep low power mode** maybe using the sniff state
- E is a slave both in the piconet of A and F, so it need to keep in sync with both in different time
- D is a slave in A but a master in his piconet with J
- K is not connected to any piconet but scanning for it in order to communicate
- Slaves cannot communicate point to point, but need to pass through the master

LE example



- communication
 - connection-oriented channels (grey one)
 - acts like the master in BR/EDR, so the master A will enforce the sync of the slaves B and C by telling them when to communicate
 - connection-less advertising channels, transparent
 - D is an **advertiser**, that is not being connected to a piconet but emitting periodically beacons to expose the state to any device in range that is scanning, in this case A is a **scanner**.
 - Be aware that D is not a slave, because there is no connection
 - I, H, J are not in a piconet, but they are advertising/scanners or just one of it.

Physical

Bluetooth radio layer

BR/EDR

random sequence of 79 channels is generated by the master

How it works in [ZigBee](#)?

bands in [ZigBee](#) are just 16 and it's always the same

- even if there will be overlap with bluetooth, there is the chance of inactive mode of one of the network
- frequencies are bigger

- different encoding

LE

- 40 channels
 - connection oriented only the first 37 channels used for **connection oriented** (master/slave)
 - 37, 38, 39 for connection, discovery and broadcast (search $O(3)$ rather than $O(40)$), used by **advertisers** to emit beacon and by **scanners** for listening

Transmisison power

[#low-priority](#)

- class 1: Tx power < 20 dBm (100 mW)
 - Long range (100 m);
- class 2: Tx power < 4 dBm (2.5 mW)
 - Normal range (10 m);
- class 3: Tx power < 0 dBm (1 mW)
 - Short range (10 cm).

Baseband layer

[#low-priority](#)

It creates the abstraction of physical channel that is a sequence of 79 frequencies, each piconet with a different sequence

- the slave connects and receive the sequence from the master
- Frequency hopping management (FH).
- management of the channel and of the link (to LMP/LLP)
 - Power control, Channel access, Link control (packets retransmission, sync/async link)
- Error correction

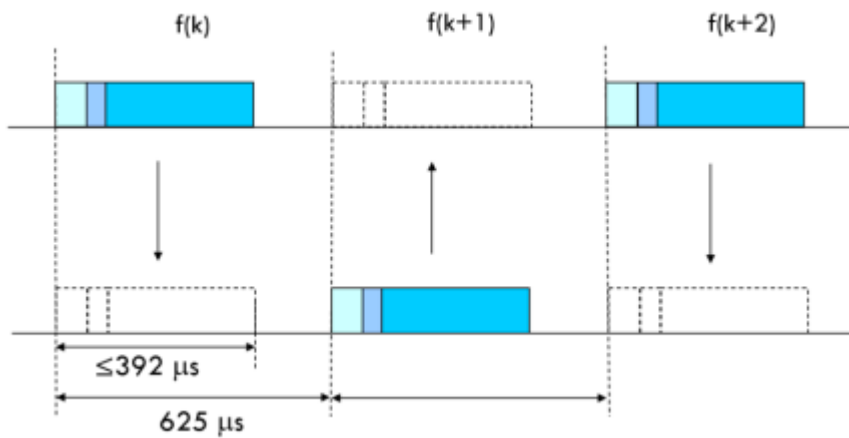
Logical transport types

[#low-priority](#)

- broadcast can be used to sync the slaves

Channel access BR/EDR

#exam



STATES

- standby
- connection
- park
 - only keep in sync
 - extreme low-power mode

Comparisons

#card

	Voice	Data	Audio	Video	State
Bluetooth ACL/HS	x	Y	Y	x	x
Bluetooth SCO/eSCO	Y	x	x	x	x
Bluetooth low energy	x	x	x	x	Y
Wi-Fi	(VoIP)	Y	Y	Y	x
Wi-Fi Direct	Y	Y	Y	x	x
ZigBee	x	x	x	x	Y
ANT	x	x	x	x	Y

State = low bandwidth, low latency data

Low Power

Zigbee

#card #question

- Bluetooth is widely available in different kind of devices, [ZigBee](#) is constrained over IoT devices
- Beginning of 2000 there was the need in the E-health sector and [IEEE 802.15.4](#) was not even there
- Only start topology
- Technically multi-hop is doable, but not known use-cases

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