Bluetooth® 5

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Corso di Laurea in Ingegneria Elettronica

Released in December 2016

New features added in version 5:

- CSA 5 features (Higher Output Power)
- Slot Availability Mask (SAM)
- **2 Msym/s PHY for LE**
- **LE Long Range**
- High Duty Cycle Non-Connectable Advertising
- **LE Advertising Extensions**
- LE Channel Selection Algorithm #2

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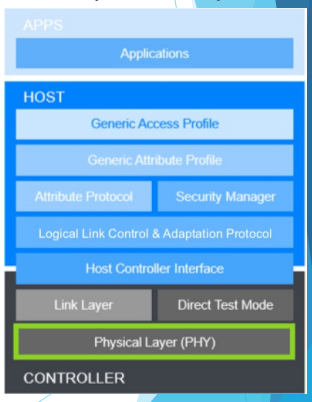
Twice the speed, four times the range

In previous specifications to those of the bluetooth 5 it was present only a single PHY that operated at 1 MSym/s

Bluetooth 5 introduces **2 new PHYs**:

- **2M PHY**: used for doubling the speed
- **Coded PHY**: used to increase the range of the previous version by 4 times.



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2M PHY

- **Reduced power consumption**, since the same amount of data is transmitted in less time, thus reducing radio- on time.
- **Improvement of wireless coexistence** because of the **decreased radio-on time** and therefore an improvement of the spectral efficiency.

- **Reducing the range**, as the higher speed results in **a decrease in radio sensitivity** on the receiving end.
- use of the 2M PHY is **restricted to the secondary advertisement and data channels**
- **older chipsets and modules may not support it**

There are two ways to utilize this mode:

- Secondary advertisements (extended advertising mode) are used and sent on the 2M PHY, which allow a connection on that PHY from the central device.
- Advertising on the primary or secondary channels using 1M or Coded PHY. After establishing the connection you can switch to 2M PHY

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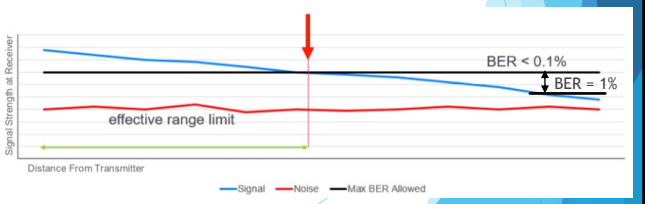
Coded PHY

- **Increase range**. Range up to ”800 meters”(?!?!) in line of sight.(useful in smart home sector)
- **Not increase the TX power.**
- **Higher power consumption**: we're transmitting multiple symbols to represent one bit of data, resulting in longer radio-on time to transmit the same amount of data.
- **Reduced data rate**: due to the fact that more bits are needed to transmit the same amount of data (125 kbps or 500 kbps)

Maximum range

…What is the maximum range at which data can be correctly extracted from the received signal, rather than how for can this electromagnetic energy travel and still be detected.



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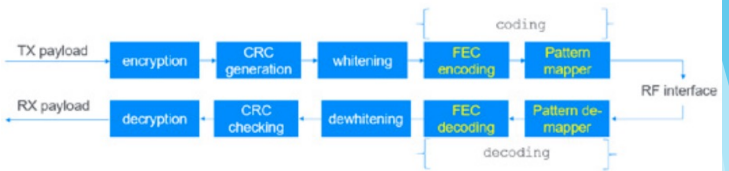
Coded PHY

- **Error Detection** : Bluetooth uses a type of checksum known as a Cyclic Redundancy Check (CRC) [Already present from BLE v.4]
- **Error Correction :** LE Coded PHY uses **Forward Error Correction**. It works by adding additional redundant bits to the transmitted packets, whose sole purpose is to support the application of the FEC algorithm and to determine the correct value that erroneous bits should have.



FEC Encoding : uses a convolutional encoder, which generates 2 bits for every input bit using two generator polynomials.

The **Pattern Mapper** converts each bit from the convolutional FEC encode into P symbols. Two different coding scheme S=2 and S=8.

Input (from FEC Encoder)	Output with S=2	Output with S=8
0	0	0011
1	1	1100

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PHY selection

The Host Controller Interface (HCI) supports a new command with which the *Change PHY Procedure* may be invoked by the host. This allows the host to select the PHY it wishes to use at any given time.

	LE 1M	LE Coded S=2	LE Coded S=8	LE 2M
Symbol Rate	1 Ms/s	1 Ms/s	1 Ms/s	2 Ms/s
Data Rate	1 Mbit/s	500 Kbit/s	125 Kbit/s	2 Mbit/s
Error Detection	CRC	CRC	CRC	CRC
Error Correction	NONE	FEC	FEC	NONE
Range Multiplier (approx.)	1	2	4	0.8
Bluetooth 5 Requirement	Mandatory	Optional	Optional	Optional

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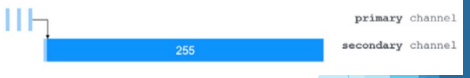
Extended advertising (1/3)

In **BLE 4** advertising packet are 37 byte (6 octet Header + up to 31 octet), and they are transmitted on up to 3 dedicated channel (37, 38, 39)

1) Larger Packet and Advertising Channel Offload

In **BLE 5** eight new PDUs related to advertising, scanning, and connecting were introduced, allowing the transmission of larger amounts of data.

- Packets can be up to **255 octet** long



This is possible :

- **offloading the payload** to one of the other channels in range 0-36.
- Transmitting only header data on channels 37,38,39
- Including a new field **AuxPtr** = the channel number on which the payload will be transmitted

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Extended advertising (2/3)

2) Advertising packet Chaining

It's possible to chain packets together and for each packet to contain a different subset of the whole data set.

Each chained packet can be transmitted on a different channel, with the AuxPtr header field referencing the next in the chain.

3) Periodic Advertising

Bluetooth 5 introduces the ability to perform periodic and deterministic advertising, which allows **scanners to synchronise their scanning** for packets with the schedule of the advertising device. → more power-efficient way to perform scanning.

Transmission of a packet on channel 37,38, 39 containing information to help locate the extended advertisement packet. That packet, in turn, contains fields that define the data needed to synchronize to the periodic advertisement packets

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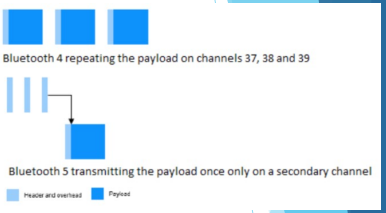
Extended advertising (3/3)

4) Reduce contection and Duty Cycle

Bluetooth 5 transmits data only once, with small headers referencing the primary channels.

The total amount of data transmitted is less and thus the duty cycle has been reduced.



This feature, combined with the new ways of using the primary advertisement channels(37,38,39) and secondary advertisement channels, allows to reduce the contention time of the channels themselves.

5) High Duty Cycle Non-Connectable Advertising

The minimum Advertising Interval has been reduced from 100ms to 20ms for non-connectable advertising. → allowing a rapid recognition of and response to advertising packets from devices like beacons.

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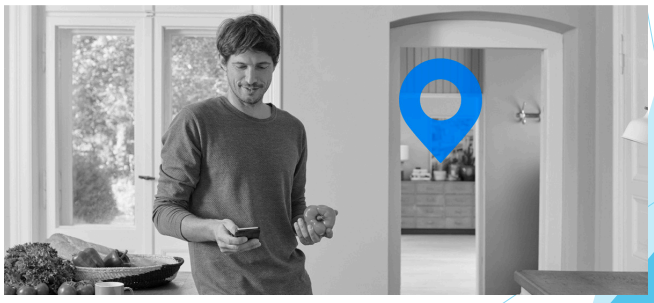
Bluetooth® 5.1



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Increased demand for location services

- Logistics companies try to increase the efficiency of the supply chain by monitoring resources in real time.
- Companies aim to monitor their staff and customers to improve productivity and sales.

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Bluetooth® 5.1

- Released January 2019
- Marketed as Bluetooth 5.1 Direction Finding.
- Introductions of direction finding functions:
  - Angle of Arrival (AoA)
  - Angle of Departure (AoD)

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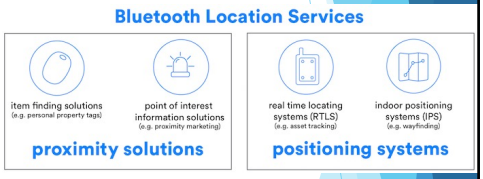
Location Services in Bluetooth

- **Proximity Solutions**: they allow you to determine when two devices are close and have an estimate of the distance. Useful in asset management, such as warehouses, or beacons for marketing campaigns.
- **Positioning Systems**:
  - Real-Time locating Systems (RTLS)
  - Indoor positioning System (IPS)

  Accuracy of the order of the meter.



With **5.1 Direction Finding** you will get two improvements:

- The accuracy in the localization that comes to be of the order of centimeters
- Know the direction from which a device is transmitting.

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RF direction finding techniques (1/2)

Def: Part of the radio technology that allows to establish the origin of any radio wave

1. **RSSI-based techninque**
   - provides the approximate distance based on the intensity of the signal.
   - More measurements from multiple different points increases accuracy.
   - Use of only one antenna per device.

2. **Time of Arrival (ToA) technique**
   - The time it takes for a radio signal to arrive from a single TX to a single RX is calculated
   - Use of only one antenna per device
   - Problem of having a very precise synchronized clock.
   - Accuracy can be up to 1 meter.

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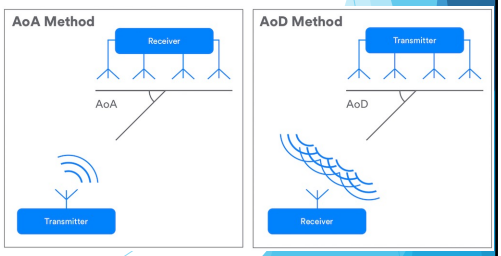
RF direction finding techniques (2/2)

With Bluetooth 5.1, the Bluetooth Special Interest (SIG) has chosen to support a third technique.

3. **Technique based on AoA e AoD**
   - **Arrival of angle**, a receiving device tracks the arrival angles for individual objects;
   - **Angle of Departure**, a device is able to calculate its position in space by exploiting the angles of multiple beacons and their positions.
   - Use of »**IQ**« signal data (in-phase or quadrature) information.
   - Accuracy of 5 °
   - One of the two devices must have **an array antenna**.



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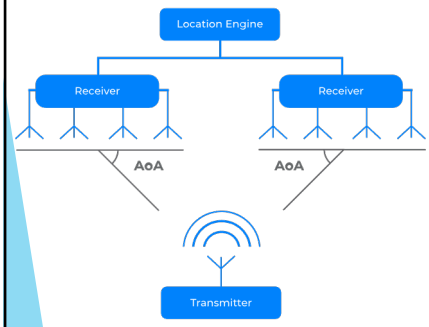
Angle of Arrival (AoA) Method

Enabling «buildings» to determine the location of people and things within

- The transmitter can also have a single antenna and send packets enabled for direction finding.
- The Receiver (locator) must have the array antenna.



Asset Tracking
Factories tracking material workflow and hospitals tracking the location of expensive mobile equipment
(FONTE:Bluetooth SIG)

Worker Safety
Manufacturing facilities ensuring workers do not wander into unsafe areas
(FONTE:Bluetooth SIG)

Player Performance
Sports teams tracking the real-time location and performance of athletes
(FONTE:Bluetooth SIG)

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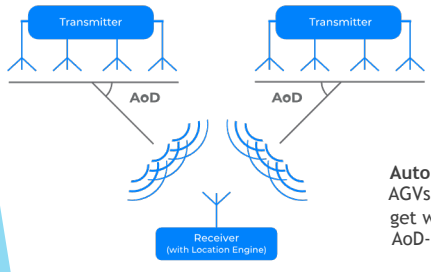
Angle of Departure (AoD) Method

Enabling people and things to determine their location within a building

- The transmitter has an array antenna
- The receiver has a single antenna
- Suitable for indoor navigation applications



Indoor Navigation
From airports to museums to convention centers, Bluetooth AoD-based indoor positioning systems can enhance the visitor experience.
(FONTE:Bluetooth SIG)

Autonomous Guided Vehicles (AGVs)
AGVs need to know where they are to get where they need to go. Bluetooth AoD-based indoor positioning systems let them know, precisely.
(FONTE:Bluetooth SIG)

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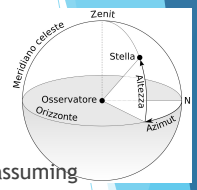
Array of Antennas



Generally divided into 3 types:

1. **ULA** - **Uniform Linear Array**

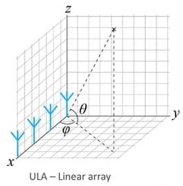
   Simple to design and build, but calculates the azimuth angle assuming that the object is constantly moving in the same plane.

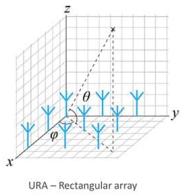
2. **URA** - **Uniform Rectangular Array**
3. **UCA** - **Uniform Circular Array**

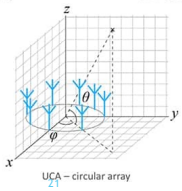
URA and UCA allow you to measure both azimuth and elevation (Zenith angle).

An Array of effective antennas will ensure the collection of accurate IQs.

Problems in the design: mutual interference between adjacent antennas.







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- Presented in January 2020 at CES 2020
- Introducing a new generation of Bluetooth Audio: LE Audio
- Isochronous Channels (ISOC)
- LE Power Control (LEPC)
- Enhanced Attribute Protocol (EATT)

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Bluetooth audio devices

From the very start, Bluetooth technology has proven itself to be the go-to solution for wireless audio.

- Using the BR / EDR (Basic Rate / Enanched Data Rate) or Bleutooth Classic
- High power consumption
- SBC codec «Low-complexity Subbad Codec, in use for 20 years with questionable quality and efficiency.
- Fixed Bit rate
- Broadcast to only one device at a time.

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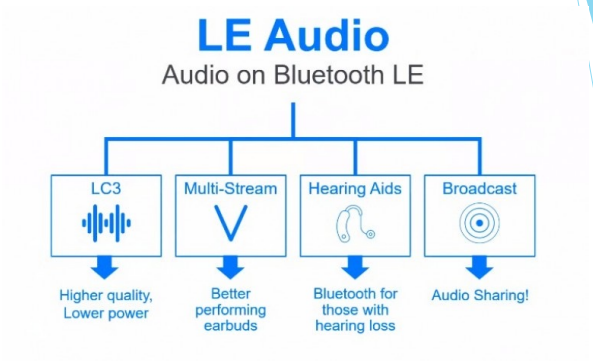

It has the same features and specifications as the Bluetooth Classic by improving them and adding new ones.

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LE Power Control (LEPC)

Wireless receivers have an optimal received signal strength range. A value outside this range can cause problems with decoding the received signal.

With **LEPC**, the change in power level can be:

- **Volunteer.** The tx changes the power and communicates it to the receiver.
- **Upon request by the receiver.** The modification works bidirectionally.

The use of LEPC and maintaining the RSSI within the optimal range leads to:

- Better control over signal quality
- Reduction of error rates at the receiving end
- Enhance coexistence with other signals in the 2.4 GHz band (WiFi, Zigbee)

If the two devices support this function (optional), they must use it for power management.

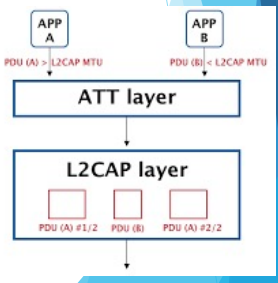
Enhanced Attribute Protocol (EATT)

- Updated version of ATT. It is optional.
- Simultaneous / parallel transactions between a BLE client and a server
- It reduces the latency of operations in some applications
- Requires encryption of the connection between two devices.

Es: useful when multiple apps on a smartphone need to interface with a BLE device.

Separation between the MTU (Maximum Transmission Unit) of the L2CAP layer from the MTU of the ATT.

If MTU_{L2CAP} is smaller than MTU_{ATT}, L2CAP will break the top-level PDUs into smaller chunks by interleaving them with chunks from other apps.



Bluetooth®

5.3

Released July 2021

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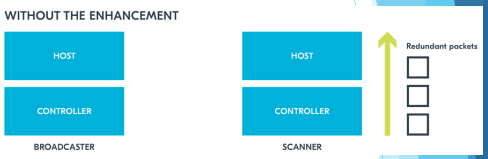
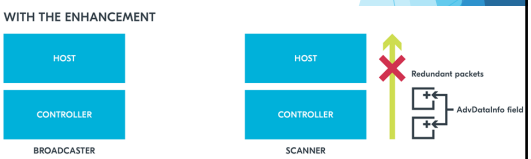
Periodic Advertising Enanchement

- Introduction of the **AdvDataInfo (ADI)** field that can be included in periodic advertising packets, enabling more efficient processing of redundant data.

All periodic advertising packets are reported by the controller to the host on the scanner side, including duplicated copies of already received packets. This can lead to wasted processing energy on the scanner side.



scanner(s) can now immediately detect when they receive a duplicate of a previously received packet and discard it in the controller rather than passing it to the host.



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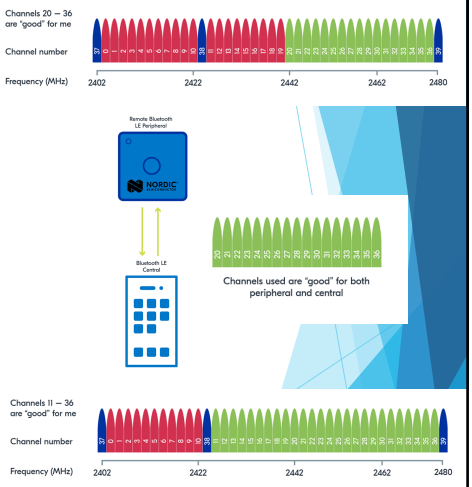
Channel Classification Enhancement

Bluetooth LE Peripheral devices are now able to provide a connected Central device with radio channel classification data which may be used by the Central device when performing channel selection during adaptive frequency hopping.

This improves throughput and reliability by reducing susceptibility to interference taking place at the Peripheral when the Peripheral and Central devices are not physically close to each other.



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Grazie per l'attenzione

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