

6.2 Core Specifications and Evolution

Bluetooth technology is not static; it has evolved through numerous versions, each adding new capabilities, increasing speed, and reducing power consumption.

Bluetooth 1.0 (1999):

- The initial release. It laid the groundwork but had significant issues with interoperability between devices from different manufacturers.
- Data Rate: ~1 Mbps.

Bluetooth 1.2 (2003):

- **Key Feature: Adaptive Frequency Hopping (AFH).** This was a major step in improving reliability. AFH allows a Bluetooth device to detect which frequencies in the 2.4 GHz band are noisy (e.g., from Wi-Fi or microwave ovens) and avoid them, reducing interference.

Bluetooth 2.0 + EDR (2004):

- **Key Feature: Enhanced Data Rate (EDR).** This introduced a new modulation scheme that tripled the theoretical data rate to 3 Mbps (with a realistic throughput of about 2.1 Mbps).

Bluetooth 2.1 + EDR (2007):

- **Key Feature: Secure Simple Pairing (SSP).** This dramatically improved the user experience of connecting devices. It introduced methods like Numeric Comparison, removing the need for users to enter a "0000" or "1234" PIN for most use cases, while also strengthening security against eavesdropping.

Bluetooth 3.0 + HS (2009):

- **Key Feature: High Speed (HS).** This version introduced a method to transfer large files by using a co-located 802.11 (Wi-Fi) radio for the actual data transfer, while Bluetooth was used for negotiation. It offered theoretical speeds of up to 24 Mbps but saw limited adoption due to its power requirements.

Bluetooth 4.0 (2010): The Birth of BLE

- **Key Feature: Bluetooth Low Energy (BLE).** This was a revolutionary update. BLE is a completely different protocol stack designed from the ground up for ultra-low-power applications. It allows devices like sensors and wearables to run for months or even years on a small coin-cell battery. Devices with both protocols are called "Dual-Mode."

Bluetooth 4.1 (2013):

- Focused on the Internet of Things (IoT). It allowed devices to act as both a central and a peripheral simultaneously and improved coexistence with 4G/LTE signals.

Bluetooth 4.2 (2014):

- Introduced key IoT features, including support for IPv6 (allowing devices to connect directly to the internet) and significant privacy and security upgrades.

Bluetooth 5.0 (2016): A Major Leap for BLE

- **2x Speed:** Increased the BLE data rate from 1 Mbps to 2 Mbps, enabling faster firmware updates and data transfers.
- **4x Range:** Introduced new physical layer (PHY) options to quadruple the range of BLE connections, enabling whole-home or building-wide coverage.
- **8x Advertising Data:** Increased the size of advertising packets, allowing for richer beacon applications and connectionless data transfer.

Bluetooth 5.1 (2019):

- **Key Feature: Direction Finding.** Introduced **Angle of Arrival (AoA)** and **Angle of Departure (AoD)** methods, enabling high-accuracy, real-time location systems (RTLS) with sub-meter precision.

Bluetooth 5.2 (2020):

- **Key Feature: LE Audio.** The next generation of wireless audio. It introduced the highly efficient LC3 Codec and Isochronous Channels, which are the foundation for new capabilities like Multi-Stream Audio and Auracast™ broadcast audio.

Bluetooth 5.3 (2021):

- Focused on efficiency and reliability with features like **Connection Subrating** for improved responsiveness at low power, and **Channel Classification Enhancement** to avoid noisy channels.

Bluetooth 5.4 (2023):

- **Key Feature: Periodic Advertising with Responses (PAWR)**. Enables secure, large-scale, bidirectional communication for thousands of low-power IoT devices, such as Electronic **Shelf Labels (ESL)**. Also introduced **Encrypted Advertising Data** for secure broadcasts.

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