Introduction to Bluetooth Technology Versions

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1. Bluetooth Overview

Bluetooth is a radio technology supporting short-range communication between devices. It enables short-range data exchange among fixed devices, mobile devices, and building personal area networks (PANs) using UHF radio waves in the 2.402–2.485 GHz ISM band. Today, Bluetooth is managed by the Bluetooth Special Interest Group (SIG). The Bluetooth SIG has over 25,000 member companies worldwide, spanning telecommunications, computing, networking, consumer electronics, and other fields. IEEE standardized Bluetooth as IEEE 802.15.1, but no longer maintains this standard. The Bluetooth SIG oversees the development of the Bluetooth specifications, manages the qualification program, and safeguards trademark rights. Manufacturers' devices must comply with Bluetooth SIG standards to enter the market as "Bluetooth devices." Bluetooth technology is protected by a patent network licensed to compliant devices.

2. Origins of Bluetooth

As its overview suggests, Bluetooth's core is short-range radio communication. Tracing back further, the foundation for short-range radio communication lies in Frequency-Hopping Spread Spectrum (FHSS) technology. FHSS technology was proposed in a patent filed in August 1942 by Hollywood actress Hedy Lamarr and pianist George Antheil. Inspired by the number of keys on a piano, they suggested controlling torpedoes via radio using 88 different carrier frequencies. Because the transmission frequency constantly hopped, it offered a degree of secrecy and interference resistance. However, this technology was largely overlooked until the military began using it on the battlefield in the 1980s.

The Bluetooth technology we use today began with a project initiated by Ericsson in 1994. The goal of this project was to research methods for low-power, low-cost wireless communication connections between mobile phones and other accessories. During this project, Ericsson realized that compatibility issues could be solved by connecting various communication

devices to the cellular network via the mobile phone, with the final link being a short-range wireless connection. To address this, Ericsson joined forces with IBM, Intel, Nokia, and Toshiba to form a "Special Interest Group" (SIG) – the precursor to the Bluetooth SIG.

Since then, the Bluetooth technical standard has undergone continuous innovation.

3. Evolution of Bluetooth Technology

3.1 Bluetooth Versions 1.0 Era

Bluetooth 0.7: Released by the SIG in 1998, supporting Baseband and LMP (Link Manager Protocol) communication protocols.

Bluetooth 0.8, 0.9, 1.0: Released successively in 1999, establishing the use of the 2.4 GHz band. Bluetooth 1.0 saw limited adoption due to incompatibility between products from different vendors, lack of protocol-level anonymity, and potential data leakage issues.

Bluetooth 1.1: Officially adopted as the IEEE 802.15.1 standard in 2001. This protocol defined the scope of the Physical Layer and Media Access Control (MAC), with a transmission rate of 0.7 Mbps. Development was still exploratory, and devices were susceptible to interference.

Bluetooth 1.2: Released in 2003, it added hardware address masking to prevent data leakage. Key enhancements included: Adaptive Frequency Hopping (AFH): Reduced interference between Bluetooth and other wireless devices, Extended Synchronous Connection-Oriented (eSCO) links: Provided Quality of Service (QoS) for audio transmission, meeting the needs of higher-end voice/audio products, Faster Connection: Reduced the time for device rediscovery and reconnection, improving stability and speed, Supported stereo audio transmission requirements, but only in simplex (one-way) mode.

3.2 Bluetooth Versions 2.0 Era

Bluetooth 2.0: Introduced in 2004, it is an improved version of 1.2, with functional optimizations based on 1.2. By improving the ability to handle multiple users and run multiple Bluetooth devices simultaneously, the transmission rate of Bluetooth devices reaches 3Mbps; it

supports duplex mode, enabling voice communication while transmitting documents/pictures; it adopts EDR technology, reducing power consumption, and due to the increased bandwidth, the number of connectable devices is increased.

Bluetooth 2.1: Introduced in 2007, it added the Sniff Scheduling power-saving function, the SSP (Simple Secure Pairing) function, and support for NFC (Near Field Communication). The Sniff Scheduling power-saving function can extend the interval between signal transmission for mutual confirmation between devices from 0.1 seconds in the old version to about 0.5 seconds, significantly reducing the workload of the Bluetooth chip. The addition of the SSP function improves the pairing experience of Bluetooth devices and enhances usability and security. With NFC, when two Bluetooth devices with built-in NFC chips are brought close to each other, the pairing password can be transmitted via NFC without manual input.

3.3 Bluetooth Versions 3.0 Era

Bluetooth 3.0: Introduced in 2009, its core is AMP, with significantly reduced power consumption, and added optional High Speed technology. AMP is a new alternative radio frequency technology that allows the Bluetooth protocol stack to dynamically select the correct radio frequency for any task. Bluetooth 3.0 introduced EPC (Enhanced Power Control) technology, and combined with 802.11, the actual idle power consumption is significantly reduced. High Speed enables Bluetooth to switch to 802.11 WiFi for high-speed data transmission, with a transmission rate of up to 24Mbps, 8 times that of Bluetooth 2.0, enabling data transmission between video recorders and high-definition TVs, PCs and PMPs, UMPCs and printers.

3.4 Bluetooth Versions 4.0 Era

Bluetooth 4.0: The first comprehensive Bluetooth protocol specification, proposing three modes: Classic Bluetooth (BR), High Speed Bluetooth (EDR), and Bluetooth Low Energy (BLE). "Classic Bluetooth" focuses on information communication and device connection; "High Speed Bluetooth" specializes in data exchange and transmission; "Bluetooth Low Energy" mainly

focuses on device connection that does not require much bandwidth, with power consumption reduced by 90% compared to older versions. The chip modes of version 4.0 are divided into Single mode and Dual mode. Single mode can only transmit with Bluetooth 4.0 and is not backward compatible with versions 3.0/2.1/2.0, mainly used in sensor devices with button batteries, such as heart rate monitors and thermometers with high power consumption requirements. Dual mode is backward compatible with versions 3.0/2.1/2.0, used in traditional Bluetooth devices while meeting low power consumption needs. Version 4.0 improves the Bluetooth transmission distance, up to more than 100 meters (under low energy mode), and at the same time, increases the response speed, which can be as short as 3 milliseconds. In addition, it uses the AES-128 CCM encryption algorithm for data packet encryption and authentication, making data transmission more secure.

Bluetooth 4.1: There are little changes in transmission rate and range, but significant improvements in software. It supports seamless collaboration with LTE. When Bluetooth and LTE radio signals transmit data simultaneously, Bluetooth 4.1 can automatically coordinate the transmission information of both to ensure collaborative transmission and reduce mutual interference. It allows developers and manufacturers to customize the reconnection interval of Bluetooth 4.1 devices, providing developers with higher flexibility and control. It supports cloud synchronization; Bluetooth 4.1 adds a dedicated IPv6 channel, so Bluetooth devices can synchronize data with the cloud via IPv6 as long as they are connected to a networked device (such as a mobile phone), meeting the application needs of the Internet of Things. It supports role swapping between extended devices and central devices. Headphones, watches, keyboards, and mice that support the Bluetooth 4.1 standard can send and receive data independently without purchasing data hubs such as tablets, PCs, and mobile phones. For example, smart watches and pedometers can communicate directly without going through smartphones.

Bluetooth 4.2: Improves data transmission speed and privacy protection, and allows devices to transmit data to the network through IPv6/6LoWPAN or Bluetooth smart gateways. Bluetooth 4.2 only allows trusted users to track device location and pairing location, increasing the level of privacy protection. In addition, the transmission speed of Bluetooth 4.2 is about 2.5 times higher than that of 4.0.

3.5 Bluetooth Versions 5.0 Era

Bluetooth 5.0: Introduced in 2016, it has faster and longer transmission capabilities in low energy mode. Compared with Bluetooth 4.2, Bluetooth 5.0 has twice the transmission rate (from 1MB/s to 2MB/s), four times the transmission distance (theoretically up to 300 meters), and eight times the broadcast data transmission volume (expanded from 37 bytes to 257 bytes), with the maximum transmit power increased by 10db to 20db. Version 5.0 supports indoor positioning and navigation functions, and can achieve indoor positioning with an accuracy of less than 1 meter when combined with WiFi. Version 5.0 also optimizes the underlying layer for the Internet of Things, striving to provide smarter home services with lower power consumption and higher performance.

Bluetooth 5.1: Introduced in 2019, on the basis of 5.0, it adds lateral functions and centimeter-level positioning services, greatly improving positioning accuracy.

Bluetooth 5.2: Introduced in 2020, it enhances the ATT protocol, LE power consumption control, and signal synchronization, resulting in faster and more stable connections and better anti-interference performance.