BLE Communication

Understanding Bluetooth Low Energy Technology

Agenda

- What is BLE?
- How does BLE work?
- BLE Applications
- Advantages of BLE
- Summary

What is BLE?

Definition of BLE:

Bluetooth Low Energy (BLE), also known as Bluetooth Smart, is a wireless communication technology designed for short-range communication with low power consumption.

It operates on the same 2.4 GHz ISM (Industrial, Scientific, and Medical) band as Classic Bluetooth but uses a different modulation scheme.

Key Features of BLE:

Low power consumption: BLE is optimized for devices requiring long battery life, making it ideal for wearables, sensors, and other IoT devices.

Short-range communication: BLE typically operates within a range of 10 to 100 meters, depending on environmental factors.

Low data rate: BLE sacrifices data throughput for power efficiency, enabling it to transmit small bursts of data.

What is BLE?

Use Cases:

BLE is widely used in various applications, including:

Wearable devices (e.g., fitness trackers, smartwatches)

Healthcare (e.g., medical sensors, remote monitoring)

Home automation (e.g., smart locks, lighting control)

Asset tracking and proximity detection

Differentiation from Classic Bluetooth:

Unlike Classic Bluetooth, which is optimized for continuous data streaming and higher data rates, BLE is designed for intervaled communication with minimal energy consumption.

BLE devices typically operate in one of two modes: advertising mode (for peripheral devices to broadcast their presence) and connection mode (for data exchange with central devices).

BLE Architecture

Introduction to BLE Architecture:

Bluetooth Low Energy (BLE) follows a client-server architecture model.

Devices in BLE communication are categorized into two main roles: Central and Peripheral.

Central Devices:

Central devices, often smartphones or tablets, initiate and control the communication with peripheral devices.

They typically scan for nearby peripherals and establish connections with them.

Peripheral Devices:

Peripheral devices, such as sensors, wearables, or other small electronics, advertise their presence to nearby central devices.

They respond to connection requests from central devices and exchange data as needed.

BLE Physical Layer

Frequency Band: BLE operates in the 2.4 GHz ISM (Industrial, Scientific, and Medical) band, which is an unlicensed frequency band.

Modulation: It uses Gaussian Frequency Shift Keying (GFSK) modulation to encode data for transmission, allowing for efficient spectrum usage.

Channels: The 2.4 GHz band is divided into 40 channels, each with a bandwidth of 2 MHz. Three of these channels are used as advertising channels for device discovery and connection establishment.

BLE Modulation

Introduction to GFSK:

- GFSK is a modulation technique used in Bluetooth Low Energy (BLE) communication.

Principle:

- It modulates the frequency of a carrier wave to represent digital data, facilitating efficient transmission of binary signals.

Key Characteristics:

- Continuous Phase Modulation (CPM): Smooth transition between frequency shifts.
- Spectral and Bandwidth Efficiency: Concentrates signal energy, reducing interference.

Advantages in BLE:

- Interference Immunity: Robust performance in noisy environments.
- Compatibility: Widely supported by BLE transceivers.
- Power Efficiency: Contributes to low-power operation of BLE devices.

Implementation:

- Used for data transmission and reception between BLE devices.
- Enables reliable communication over short distances.

Applications:

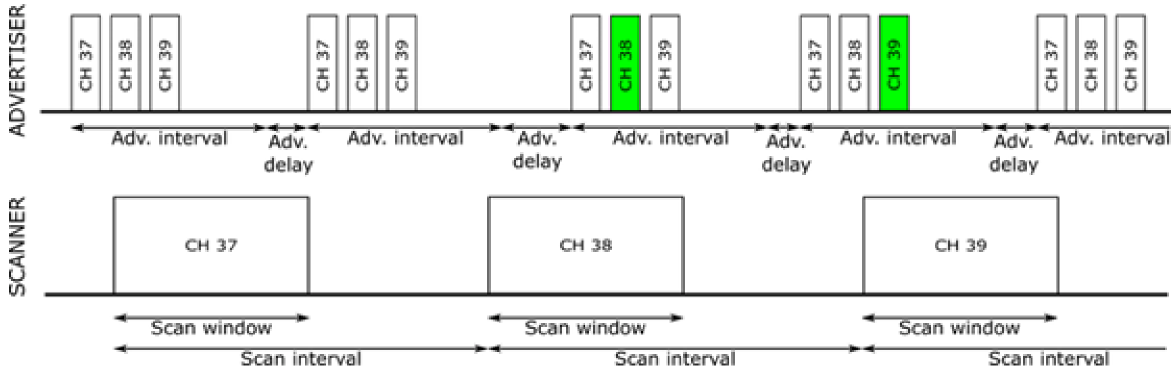
- IoT devices, wearables, healthcare monitors, and smart home appliances utilize GFSK in BLE communication.

BLE Advertising & Scanning

Advertising: Peripheral devices periodically broadcast advertising packets containing information about their identity, services, and capabilities.

Scanning: Central devices scan for nearby advertising packets to discover available peripherals. They listen on the advertising channels and collect information from advertising packets to identify and connect to peripherals of interest.

Here is what this might look like:

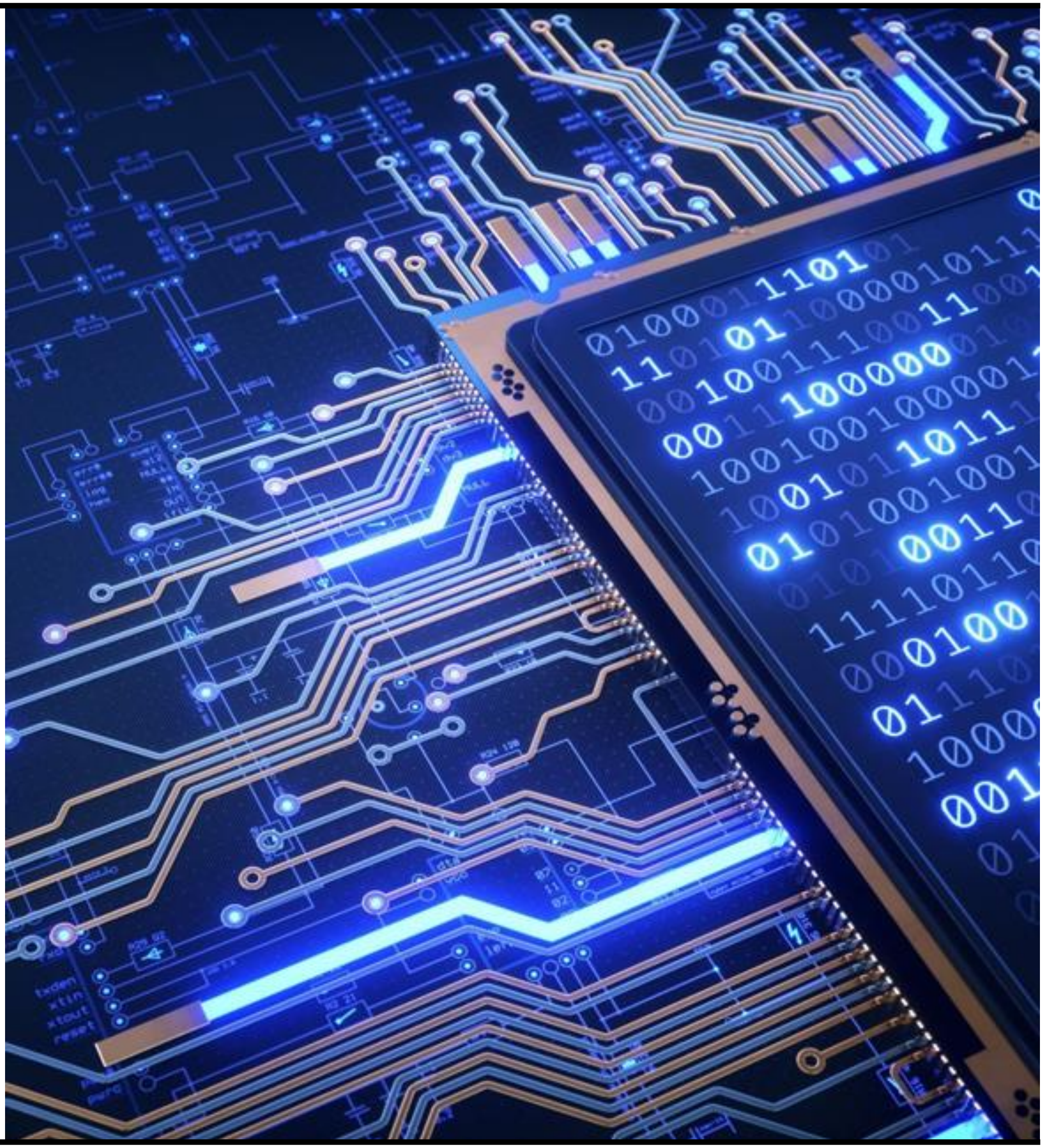


BLE Connection

Connection Parameters: When a central device finds a peripheral it wants to connect to, it sends a connection request specifying connection parameters such as connection interval, slave latency, and connection timeout.

Connection Acceptance: The peripheral responds with a connection acceptance packet, acknowledging the connection request and agreeing on the connection parameters.

Connection Interval: Determines how often devices exchange data during the connection, impacting both data throughput and power consumption.



BLE Data Exchange

GATT (Generic Attribute Profile) and GAP (Generic Access Profile):

GATT: defines a hierarchical data structure that organizes data into Services, Characteristics, and Descriptors.

Services represent a collection of related characteristics.

Characteristics contain actual data or provide configuration information.

Descriptors describe the characteristics' attributes.

GAP: manages the device's connection and defines roles and procedures for device discovery, connection establishment, and security.

These are essential for learning how a BLE system works.

BLE Connection Management

Slave Role: The peripheral device typically operates in the slave role, responding to requests from the central device.

Master Role: The central device acts as the master, controlling the communication and managing multiple connections if necessary.

Connection Events: Data exchanges between devices occur during connection events, which are scheduled based on the connection parameters agreed upon during connection establishment.

BLE Low Power

Low-Duty Cycle: BLE devices typically operate in low-duty cycle modes to conserve energy, waking up periodically to perform tasks such as advertising or data exchange.

Sleep Mode: Devices enter sleep mode between connection events to minimize power consumption, waking up only when necessary to perform scheduled tasks

This is a huge selling point and a reason that BLE is rapidly growing in popularity.

BLE Security

Pairing: BLE devices can establish secure connections using pairing procedures, which involve exchanging keys and authenticating devices.

Encryption: Secure connections enable data encryption to protect against eavesdropping and unauthorized access.

Privacy: BLE devices may use privacy features to prevent tracking and protect user privacy by periodically changing their identity addresses.

BLE Handling

Automatic Repeat Request (ARQ): The Automatic Repeat Request (ARQ) mechanism is employed in BLE to guarantee the reliable transmission of data packets between devices. When a packet is transmitted from a sender (e.g., a peripheral device) to a receiver (e.g., a central device) and is not received correctly due to noise, interference, or other factors, the receiver notifies the sender of the missing or corrupted packet. Upon receiving this notification, the sender retransmits the packet to the receiver. This process continues until the packet is successfully received or until a maximum number of retransmission attempts is reached. By automatically requesting retransmissions of lost or corrupted packets, ARQ ensures that data is reliably transmitted even in challenging wireless environments with potential packet loss or interference.

Flow Control: Devices use flow control mechanisms to manage data exchange rates and prevent buffer overflow or underflow.

BLE Connection Termination

Graceful Disconnection:

In BLE, devices can gracefully terminate a connection by exchanging disconnection requests and acknowledgments. When a device wishes to end the connection, it sends a disconnection request to the connected device. Upon receiving the disconnection request, the other device sends an acknowledgment to confirm the termination. This process ensures that both devices are aware of the disconnection and allows them to release resources and terminate the connection cleanly. Graceful disconnection is essential for maintaining the integrity of the communication link and preventing data loss or corruption.

Timeouts:

Connection timeout parameters define the maximum duration of inactivity before a connection is automatically terminated. If no data exchange occurs within the specified timeout period, the BLE protocol automatically terminates the connection. Timeout parameters are negotiated during the connection establishment phase and are typically configurable based on application requirements. Connection timeouts serve as a safeguard against prolonged periods of inactivity or communication failures. By enforcing a maximum duration of inactivity, timeouts help conserve power and ensure efficient use of resources in BLE devices.

Use Cases:

Graceful disconnection and timeout mechanisms are crucial for various BLE applications. In scenarios where devices may need to conserve battery power or manage network resources efficiently, these mechanisms help optimize the usage of the Bluetooth connection.

BLE Application Layering

Application Profiles: BLE supports various application profiles built on top of GATT, defining standardized data formats and procedures for specific use cases such as heart rate monitoring, proximity detection, or environmental sensing.

Custom Profiles: Developers can create custom profiles tailored to specific application requirements, defining unique services, characteristics, and data exchange patterns.

BLE Summary

In summary, Bluetooth Low Energy (BLE) operates through a combination of advertising, scanning, connection establishment, data exchange, and connection management mechanisms. It offers low-power operation, security features, and flexibility for integrating with various application profiles, making it suitable for a wide range of IoT, wearable, and smart home applications.

Thank You!

References

Tosi, J., Taffoni, F., Santacatterina, M., Sannino, R., & Formica, D. Performance Evaluation of Bluetooth Low Energy: A Systematic Review.

NovelBits. (Year). Bluetooth Low Energy Advertisements - Part 1. Retrieved from [URL]: [https://novelbits.io/bluetooth-low-energy-advertisements-part-1/].