Bluetooth IoT

Technology White Paper

1 Overview

Bluetooth positioning technology is a key innovation in TP-Link Omada's business networking solutions, specifically developed for low-cost indoor positioning scenarios. With the explosive growth of Internet of Things (IoT) devices, the high power consumption and high costs of traditional wireless communication technologies (such as Wi-Fi and cellular networks) have become increasingly prominent.

A Bluetooth access point (AP) detects nearby Bluetooth signals and estimates the location of Bluetooth beacon based on signal strength. When multiple APs work together, positioning becomes more precise. The collected signals are transmitted to a dedicated server, where Bluetooth beacon locations are linked with corresponding functions.

This white paper comprehensively explains the background, principles, configuration, key application scenarios, and deployment examples of Bluetooth positioning technology, helping network administrators and system integrators master this technology and implement customized indoor positioning solutions.

1.1 Introduction

Amid the wave of intelligent interconnections, IoT technology has become a core engine driving industrial upgrades. However, with the exponential growth in the number of devices and the diversification of application scenarios, the industry faces multiple challenges:

Device and Protocol Fragmentation: IoT devices from different manufacturers use heterogeneous protocols such as Wi-Fi, Zigbee, and LoRa, resulting in poor cross-platform compatibility and high system integration costs.

Power Consumption and Battery Life Bottlenecks: The high energy consumption of traditional wireless technologies (such as Wi-Fi) limits the long-term deployment of battery-powered devices (such as sensors and wearables).

Insufficient Scalable Networking Capabilities: In smart homes and industrial monitoring scenarios, traditional star-shaped network architectures struggle to support the high-density access and dynamic expansion of massive nodes.

Security and Privacy Risks: The use of plaintext transmission and weak authentication mechanisms in inter-device communications make data leakage and cyberattacks a critical threat to the IoT ecosystem.

These challenges highlight the need for communication technologies that combine low energy consumption, broad compatibility, flexible networking, and enhanced security.

1.2 Background

Against this backdrop, Bluetooth Low Energy (BLE) has emerged as a promising short-range solution. Its advantages in low power consumption, broad compatibility, and flexible networking make it particularly suitable for IoT scenarios requiring scalable and secure connectivity.

In indoor positioning scenarios, the high power consumption and cost of traditional wireless technologies such as Wi-Fi and cellular networks have become increasingly evident, creating demand for cost-effective alternatives.

1.3 Purpose of this White Paper

Detail the principles and advantages of Bluetooth IoT technology;

Provide specific configuration guidelines and application strategies for Bluetooth IoT;

Demonstrate the role of Bluetooth IoT technology in various application scenarios;

Help network administrators and system integrators master Bluetooth IoT technology and implement their own indoor positioning solutions.

2 Introduction of Key Technologies

2.1 Basic Concepts

Bluetooth Low Energy (BLE), introduced in the Bluetooth 4.0 specification in 2010, is defined by its low power consumption. Like Bluetooth Classic, it operates in the 2.4–2.4835 GHz band, but with a lower transmission rate, making it unsuitable for large data transfers and better suited for device discovery and simple communications. According to the protocols, both Bluetooth Classic and BLE can cover up to 100 meters. Common BLE protocols include Apple's iBeacon protocol, Google's Eddystone protocol, and other proprietary protocols from manufacturers, such as Minew.

2.2 Technical Advantages

Ultra-Low Power Consumption: BLE utilizes intermittent advertising and a fast connection mechanism, with standby power consumption as low as 0.01-0.5 milliwatts, significantly increasing the number of button cell battery-powered devices.

Lightweight Protocol Stack: The BLE protocol stack is streamlined (requiring only 192 KB of RAM), suitable for resource-constrained microcontrollers (MCUs) and reducing hardware costs.

Wide Compatibility: BLE is natively compatible with smartphones, tablets, and other terminals, enabling direct device connectivity and data transparency without the need for an additional gateway.

Flexible Topology: Star-shaped, broadcast, and mesh networks (Bluetooth Mesh) are supported, covering diverse scenarios from single-point connections to large-scale sensor networks.

2.3 Market Demand

Maintenance-Free Deployments

Wireless access points with built-in Bluetooth reduce the need for separate IoT gateways or battery-powered sensors. By leveraging the AP's existing power supply, enterprises can deploy Bluetooth-based tracking and sensing solutions without worrying about battery replacement or additional maintenance, improving ROI and ensuring long-term stability.

Lower Complexity and Cost

Integrating Bluetooth directly into APs simplifies network architecture. Instead of installing standalone Bluetooth hubs, organizations can use their existing Wi-Fi infrastructure to support IoT devices. This reduces hardware costs and streamlines deployment, making it easier to scale sensor networks in smart homes, factories, and healthcare facilities.

Sustainability and Efficiency

Built-in Bluetooth functionality eliminates the need for disposable batteries in many IoT scenarios. By centralizing connectivity through APs, companies can reduce electronic waste and energy consumption, aligning with global sustainability goals while extending the lifecycle of IoT deployments.

3 Key technical principles

3.1 Protocol Analysis

iBeacon Protocol

Based on BLE, iBeacon utilizes the "advertising frame," which is a broadcast frame transmitted periodically and received by BLE-enabled devices. iBeacon embeds Apple's proprietary data format in the payload of the advertising frame. The iBeacon data consists of four main elements: UUID, Major, Minor, and Measured Power.

UUID (Universally Unique Identifier) is a 128-bit identifier following the ISO/IEC 11578:1996 standard.

Major and Minor are 16-bit identifiers defined by the iBeacon publisher. For example, a retail chain may use Major to represent the region and Minor to specify the store ID. In home appliances, Major can indicate the product model while Minor conveys an error code, allowing external systems to detect malfunctions.

Measured Power is the reference Received Signal Strength Indicator (RSSI) when the iBeacon module and the receiver are 1 meter apart. The receiver can use this reference RSSI and the strength of the received signal to estimate the distance between the transmitting module and the receiver.

The frame payload of Apple's iBeacon:

Offset	Length	Type	Data	Details
0	1	Data Length	0x02	/
1	1	Flag data type	0x01	/
2	1	Flag data	0x06	/
3	1	Data Length	0x26	/
4	1	Manufacture Data	0xFF	/
5	2	Company ID	0x4C00	(little-endian) 0x004C
7	2	Beacon Type	0x0215	(big-endian) 0x0215
9	16	UUID	0x0112233445566778899 AABBCCDDEEFF0	(big-endian) 0x0112233445566778899 AABBCCDDEEFF0
25	2	Major	0x03E8	(big-endian) 0x03E8
27	2	Minor	0x07D0	(big-endian) 0x07D0
29	1	RSSI at 1m	0xC5	-59dBm

Each iBeacon device has a unique ID (UUID + Major + Minor). When signals are broadcast within a region, the ID information in the signal marks a particular area. UUID is a unique identifier that differentiates your iBeacon device from others. Major is used to group related iBeacon devices together, while Minor identifies a specific individual iBeacon device.

For example, you can deploy iBeacon devices in your chain department stores to provide users with promotional information. As shown below, all your iBeacon transmitters can have the same UUID, but each store will have its own Major value, and each department within the store will have its own Minor value.

Store Location		San Francisco	Paris	London
UUID		D9B9EC1F-3925-43D0-1E39D4CEA95C		
Major		1	2	3
Minor	Clothing	10	10	10
	Housewares	20	20	20

	Automotive	30	30	30

Additionally, iBeacon has a certain level of proximity awareness. The iBeacon protocol categorizes distance into three ranges: Immediate (very close), Near (1-3 m), and Far (further away). This is achieved through the Measured Power parameter, which lays a foundation for iBeacon's ability to roughly estimate the user's location.

As a location-aware technology, iBeacon mainly has two applications:

Detecting whether a user has entered the iBeacon region and pushing relevant messages to them.

Performing indoor positioning based on signal strength and information on iBeacon base stations.

Eddystone Protocol

Eddystone is an open-source Bluetooth beacon protocol developed by Google. It is completely open and supports Android, iOS, and even web browsers.

Eddystone UID: A unique beacon UID.

Eddystone URL: Used to broadcast a uniform resource locator (URL).

Eddystone TLM: Used to broadcast the beacon's own telemetry (i.e., health and status) data.

Eddystone-EID: A new frame type that defines an encrypted mode to broadcast encrypted information, which can only be decrypted by authorized users.

The frame payload of Eddystone:

Offset	Length	Type	Data	Details
0	1	Data Length	0x02	/
1	1	Flag data type	0x01	/
2	1	Flag data	0x06	/
3	1	Data Length	0x03	/
4	1	Complete list of 16-bit Service UUID	0x03	/
5	2	UUID data	0xAAFE	(little-endian) 0xFEAA
7	1	Data Length	17	/
8	1	Service data	0x16	/
9	2	UUID data	0xAAFE	(little-endian) 0xFEAA
11	1	Frame Type	0x20	/
12	1	Version	0x00	/

13	2	Battery Voltage	0x0BB8	(big-endian) 3000mV
15	2	Temperature	0x1973	(8.8 fixed-point) 25.44℃
17	4	Adv Count	0x000003E8	(little-endian) 1000 times
21	4	Seconds Count	0x00000258	(little-endian) 60 seconds

Eddystone also defines a GATT configuration service to enable interoperability between hardware manufacturers and application developers. This allows beacons to report their capabilities to applications, and enables the reconfiguration of beacon's broadcast data. It is necessary when devices need to be securely paired and registered as Eddystone-EID beacons.

Based on the Eddystone beacon, various commercial application scenarios are available as follows:

Indoor Navigation: By installing Eddystone beacons in buildings, people can use their mobile devices to access indoor maps and navigation information.

Retail Promotions: Merchants can place Eddystone beacons near their products to send coupons and promotional information to nearby consumers.

Transportation: Eddystone beacons can be used for vehicle positioning, providing real-time traffic flow information and navigation services.

Proprietary Protocols

In addition to open protocols, many manufacturers have also released some proprietary protocols compatible with their own Bluetooth products. These proprietary protocols often carry a larger amount of information more flexibly. Some widely used proprietary protocols include those from Minew, EnOcean, and MySphera. Here, we will use Minew's protocol as an example.

Minew's protocol is the company's customized Bluetooth iBeacon protocol. Compared to iBeacon and Eddystone, Minew has defined more upload information, such as Local Name, Humidity, Temperature, Battery Level, ACC-axis, Lux Data, Pressure Data, PIR Data, Vibration Data, and AP Data. Minew also sells Bluetooth sensors. With the protocol, its sensors can transmit the data via the BLE iBeacon frame, and the specified receiver can receive and report the data, enabling information collection and updates across the entire area.

The frame payload of Minew's protocol:

Offset	Length	Type	Data	Details

0	1	Data Length	0x02	/
1	1	Flag data type	0x01	/
2	1	Flag data	0x06	/
3	1	Data Length	0x03	/
4	1	Complete list of 16-bit Service UUIDs	0x03	/
5	2	UUID data	0xE1FF	0xFFE1
7	1	Data Length	16	/
8	1	Service data	0x16	/
9	2	UUID data	0xE1FF	0xFFE1
11	1	Frame Type	0xA1	0xA1
12	1	Version Number	0x01	/
13	1	Battery level	0x64	Battery level is 100%
14	2	Temperature	0x1973	(8.8 fixed-point) 25.44℃
16	2	Humidity	0x4864	(8.8 fixed-point) 72.39%
18	6	Mac address	0x009078563412	12:34:56:78:90:00

3.2 Principle Analysis

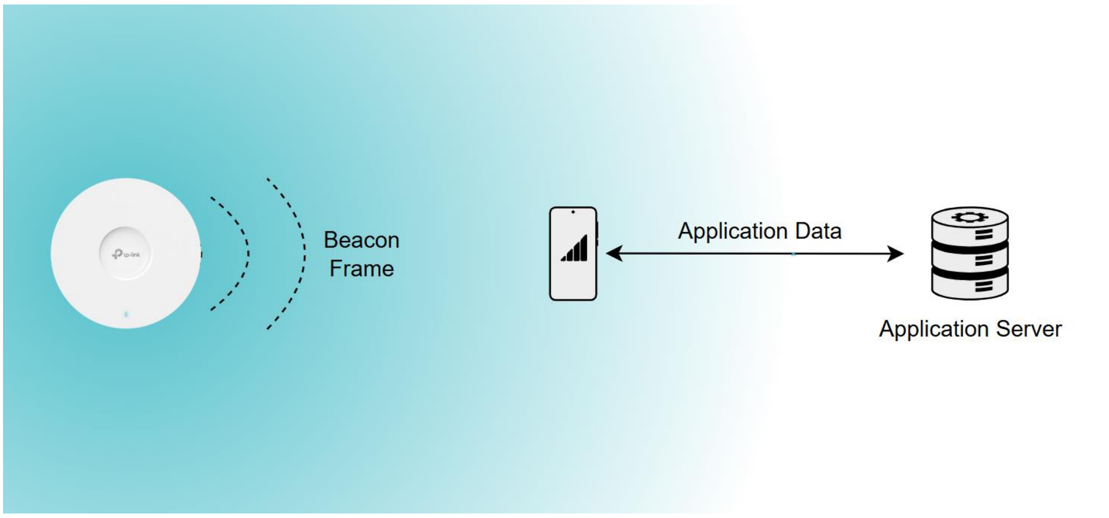
In wireless communication, the farther a signal travels, the more it attenuates. Based on this principle, Bluetooth receiving devices can estimate the distance to the transmitting device by measuring the strength of the received Bluetooth signal. The energy level of the received signal, known as RSSI (Received Signal Strength Indicator), is typically expressed in dBm. A power level of 1 mW corresponds to 0 dBm. Since the transmission power of Bluetooth chips is very low, the RSSI at the receiving end is usually a negative value due to path loss.

In practical scenarios, in addition to the signal transmitting and receiving devices, a dedicated server is often used to process the received Bluetooth broadcast packets and RSSI data, and to perform data aggregation and computation. With the presence of this server, Bluetooth IoT positioning can be customized for different application scenarios.

Active RSSI-Based Positioning

Active RSSI-based Bluetooth positioning, also known as terminal-side RSSI positioning, operates on the principle that fixed-location Bluetooth beacons transmit signals, which are received by Bluetooth-enabled terminal devices. The terminal estimates its distance from the beacon by comparing the actual RSSI value with a predefined reference value (e.g., RSSI at 1 meter).

Under ideal conditions, this method typically achieves meter-level accuracy. In such scenarios, access points (APs) equipped with Bluetooth chips can function as Bluetooth beacons by enabling their Bluetooth Advertising feature. When various terminal devices (such as smartphones and tablets) enter the beacon's broadcast range, they scan for broadcast packets. Upon receiving these packets, the terminal applies positioning algorithms to estimate its location. Deploying multiple APs enables more accurate positioning. Generally, at least three APs are required to achieve usable positioning performance.

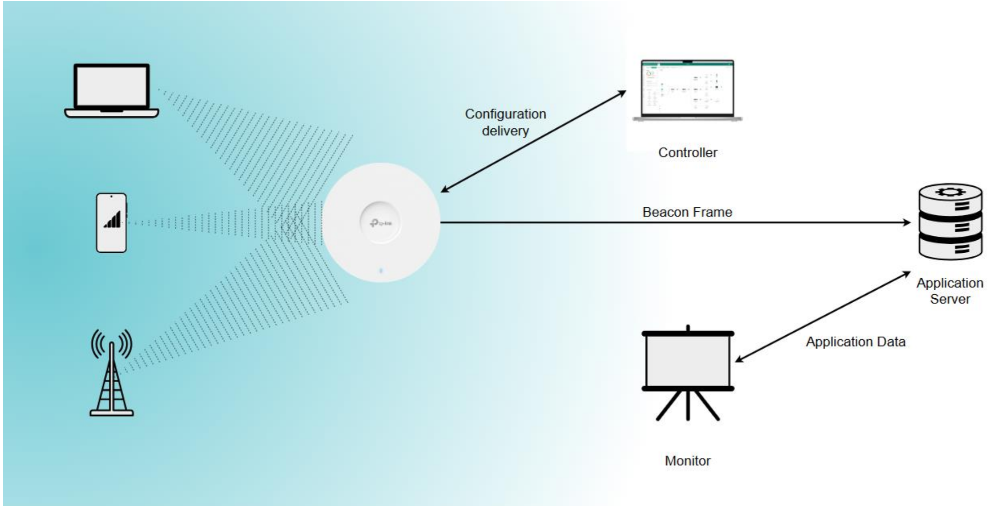


Alt text： Active RSSI-based Positioning schematic diagram

Passive RSSI-Based Positioning

Passive RSSI-based Bluetooth positioning, also known as network-side RSSI positioning, operates on the principle that fixed-location Bluetooth receivers or scanners receive signals transmitted by Bluetooth beacons. These signals are then forwarded to external positioning or mapping servers, which estimate the approximate location of the beacon.

Under ideal conditions, this method typically achieves meter-level accuracy. In such scenarios, access points (APs) equipped with Bluetooth chips can function as Bluetooth receiver by enabling their IoT Transport Streams feature. Once this feature is activated, the APs can transmit the received beacon signals to the positioning or mapping servers. Based on the beacon signal and the known location of each AP, the server calculates the approximate position of the beacon. Deploying multiple APs enables more accurate and wider-range positioning.

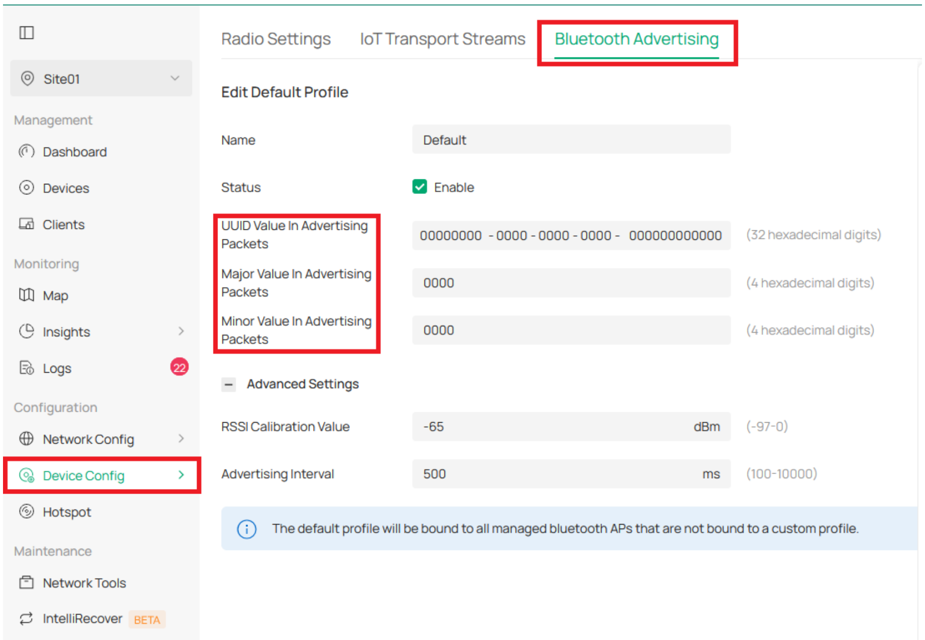


Alt text： Passive RSSI-based Positioning schematic diagram

3.3 Frame Analysis

Bluetooth Advertising

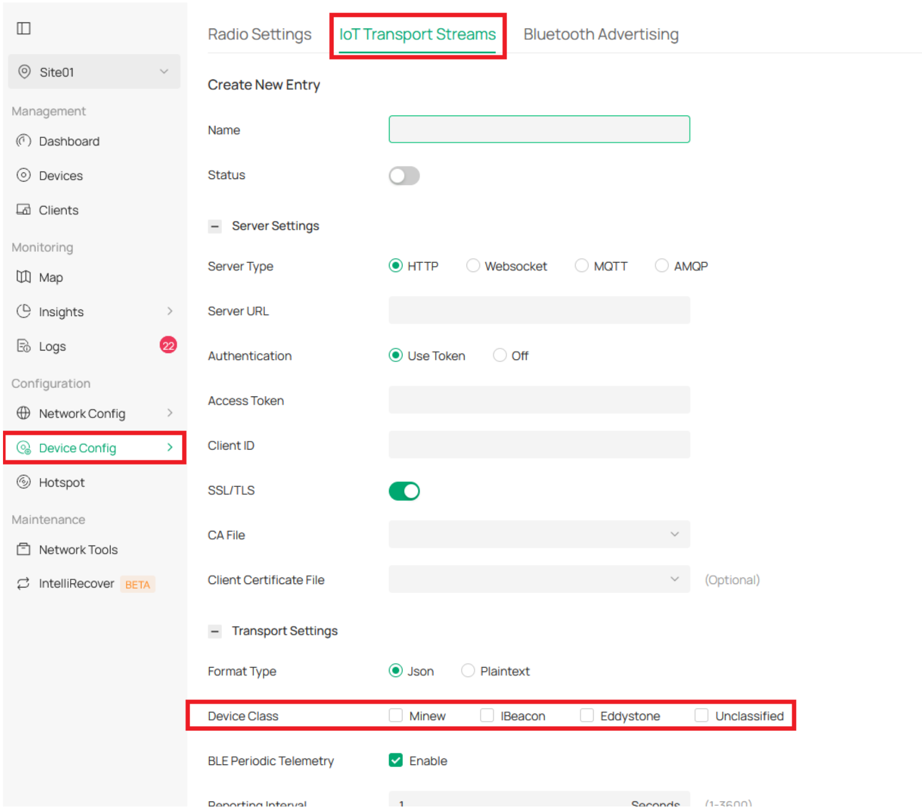
Bluetooth beacons follow standardized protocols (such as iBeacon) to transmit broadcast frames containing specific embedded information. Bluetooth-enabled devices can estimate their own location by analyzing the received beacon information. Currently, EAPs can also actively transmit the corresponding configured iBeacon frames. The UUID + Major + Minor fields in the iBeacon frame can be used to classify the EAPs, and the Measured Power field can be used as a reference for distance estimation. Devices receiving Bluetooth frames can determine their own location from the frame data, enabling specific actions to be triggered at designated positions.



Alt text： The Bluetooth Advertising Features in Omada Controller

IoT Transport Streams

BLE communication is a unidirectional protocol, where Bluetooth beacons transmit specific data by embedding it into broadcast frames following standardized formats such as iBeacon, Eddystone, or Minew. This data needs to be collected and reported by dedicated devices in order to be processed accordingly to enable the corresponding functions. All data on the IoT server comes from what EAPs report, thus demanding high accuracy and stability for the EAPs to collect and report Bluetooth information. The EAPs have to be able to collect the required Bluetooth information and report it based on our settings.



Alt text： The IoT Transport Streams Features in Omada Controller

3.4 Application Scenario Analysis

Bluetooth Terminal Positioning

Mobile phones are the most common Bluetooth terminal. After installing a dedicated application, a phone will receive the iBeacon frames sent by the EAP when it enters the EAP coverage area. The application can extract information from the scanned iBeacon frames and report it to the server. The server can analyze the corresponding data to know approximately the current location of the phone, and then push specific promotion messages based on the location information to achieve specific functions.

For example, in such scenarios as shopping malls and parking lots, besides offering Wi-Fi access, an EAP can also provide Bluetooth terminal positioning service through the built-in Bluetooth module. Users can receive BLE broadcast frames via their phones and upload the data to the positioning server to achieve positioning and navigation functions in conjunction with the application. Shops can deploy BLE devices and push shopping guides and promotional information to users via the application when the users scan the broadcast frames sent by these BLE devices.

As shown in the table below, the iBeacon frames transmitted by the EAPs in different areas of the shopping mall are different. The Bluetooth terminal can roughly locate itself according to the fields of the received iBeacon frame, and the server can push different messages based on this location information.

Store Location		Area A	Area B	Area C
UUID		e2c56db5dffb48d2b060d0f5a71096e0		
Major		1	2	3
Minor	Clothing	10	10	10
	Food	20	20	20
	Games	30	30	30

Bluetooth Passive Positioning

Bluetooth beacon will periodically send Bluetooth frames that conform to the iBeacon, Minew, or Eddystone protocols. The iBeacon frame will carry basic information like TxPower and RSSI reference values. Bluetooth frames of other protocols can also carry sensor data and other information. After collection, an EAP will report the information to a third-party positioning server, which will then comprehensively process all the information reported to determine the approximate location of the Bluetooth beacon and environmental information. This feature is generally used for location monitoring of important equipment and environmental monitoring of important places to achieve positioning of key asset equipment and key personnel. By fixing the BLE beacon on the assets to be tracked and deploying EAPs that can receive iBeacon frames in the office area, the EAPs can report the collected RSSI information to the positioning server, and the asset can be located and tracked through the management platform.

The approximate location obtained based on the processing and reporting of Bluetooth information can also be applied to indoor navigation, personnel management and tracking, and geofencing in such scenarios as shopping malls, scenic spots, and parking lots.

4 Application Scenarios&Solutions

4.1 Personnel Management and Tracking

Small Bluetooth beacons are embedded in employee badges or worn on the wrist. Access Points (APs) capable of receiving Bluetooth beacon broadcast frames are deployed within the target area. These APs collect RSSI and other signal data and upload it to the positioning server. The management platform can then display personnel identity, location, and movement trajectories in real time. This solution is suitable for environments such as hospitals, factories, and industrial parks.

4.2 Asset Location Management

Bluetooth beacons are affixed to assets that require tracking. APs capable of receiving Bluetooth beacon signals are deployed throughout the office area. The APs collect signal data and upload it to the positioning server. The management platform enables asset location and tracking, while users can view real-time asset positions via a mobile app, improving asset management efficiency.

4.3 Proximity-Based Services

In commercial venues, APs are configured as Bluetooth beacons to broadcast advertisement frames. When users enter the coverage area and open the app, the system can trigger push notifications for ordering portals, personalized advertisements, or promotional offers-enhancing user engagement and boosting marketing effectiveness.

5 Future Trends

In the coming years, Bluetooth-enabled IoT will evolve along several important dimensions. Advances in positioning and navigation, particularly through Angle of Arrival and Angle of Departure technologies, are expected to deliver far greater precision in industrial asset tracking and indoor navigation. With firmware upgrades, existing devices will be able to adapt seamlessly to these higher accuracy requirements, ensuring that investments made today remain relevant tomorrow.

At the same time, the convergence of multiple communication protocols—Bluetooth, Wi-Fi 7, UWB, and 5G—is shaping a new hybrid architecture. In this model, Bluetooth provides efficient connectivity for low-power sensors, while Wi-Fi supports high-bandwidth applications, creating networks that can flexibly serve both smart homes and industrial environments. This integration reduces complexity and enables more diverse use cases.

The expansion of application scenarios underscores Bluetooth's growing role across sectors. In consumer electronics and smart homes, technologies such as LE Audio, TWS earbuds, and AR/VR devices are enhancing user experiences, while Bluetooth Mesh networking enables whole-home automation. In industry and smart cities, real-time location systems are being adopted at scale, and new solutions that combine Bluetooth with satellite connectivity are emerging to overcome coverage limitations in remote areas.

These developments point to a future where Bluetooth is not only a cornerstone of consumer electronics but also a critical enabler of industrial efficiency, smart city infrastructure, and healthcare innovation. Its trajectory reflects a broader shift toward more precise, energy-efficient, and seamlessly integrated IoT ecosystems.

6 Appendix

6.1 Glossary

Term	Explanation
BLE	Bluetooth Low Energy
IoT	Internet of Things
RSSI	Received Signal Strength Indicator