Bluetooth Indoor Positioning Systems: Implementation Features & Alternatives

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Andrey Solovev
Chief Technology Officer, PhD in Physics and Mathematics

Anna Petrova
Writer

Many people worldwide regularly use positioning systems. The most popular of them are location services relying on geographic data and satellite navigation (GIS and GNSS). However, these systems only work efficiently outdoors and don't work so well in enclosed areas. Indoor

In this article, we'll give you a basic idea about indoor positioning systems and describe how Bluetooth positioning services work, what methods they use, and how you can implement them in your project.

Contents

What Is an Indoor Positioning System and What Is It Used for?

An indoor positioning system or IPS is a network of transmitting and receiving devices (separate or two-in-one) that can communicate together indoors.

As the name suggests, the major purpose of an IPS is to **detect the position** of an object that can be both animate and inanimate. Once it is detected, the system can **keep track** of the object's location and **identify** it from the set of like objects.

Having this information at hand can improve work processes and help with solving problems in many fields. Here are some IPS applications and purposes the system may serve:

- **Healthcare** (track patients and personnel at hospitals);
- **Mining** (ensure the safety of people working underground);
- **Shopping malls** (use an IPS for item finding, navigation, and product promotion);
- **Airports**, **railway** and **bus stations** (use the system for informational purposes and wayfinding);
- **Warehousing** (monitor the handling of goods);
- **Parking lots** and **garages** (use an IPS for navigational and security purposes).

IPS applications

To sum up, you can use indoor positioning in any business area and for a variety of purposes as far as your fantasy and budget permit. For example, wayfinding is an important feature suitable for lots of places, such as museums, exhibitions and

Technologies Used for Indoor Positioning Systems

Indoor localization employs technologies different from satellite-based systems, such as GPS and Galileo. Building materials stand in the way of radio waves, so satellite signals cannot reach the receivers in surface and underground facilities. Indoor positioning technologies use various types of signals that can fall into the following categories:

- IPS using radio signals

Such systems detect object locations with the help of radio signals propagating from transmitters to receivers. They include **NFC**, **RFID**, **Wi-Fi (WPS)**, **Bluetooth**, **Thread**, **ZigBee**, **ultra-wideband (UWB)**, **Radio Detection and Ranging (RADAR)**.

- IPS using sound signals

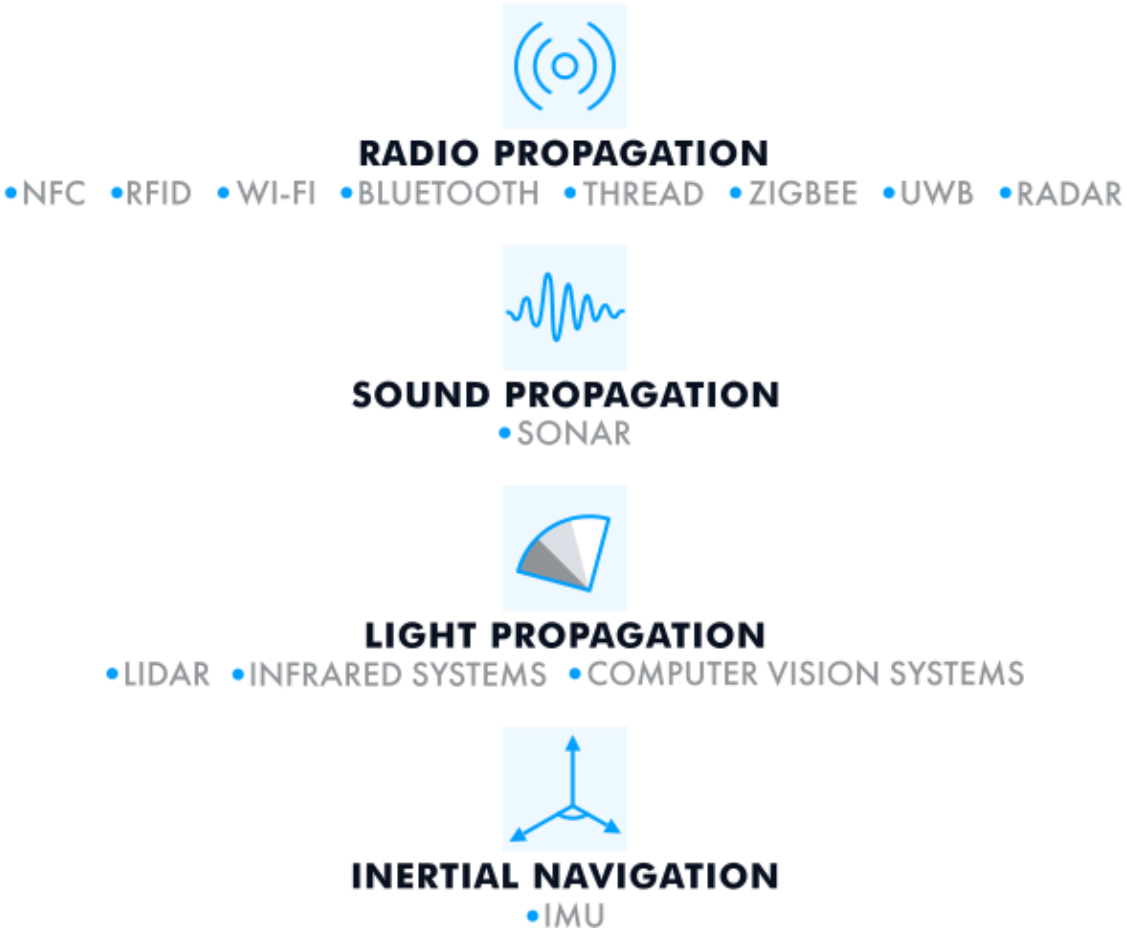
These systems rely on echolocation and the measurement of the time period during which an emitted ultrasonic signal returns to a receiver. For example, **Sound Navigation and Ranging (SONAR)** is used to position underwater objects.

- IPS using light signals

This IPS type comprises light-emitting and light-reflecting objects and includes **Light Detection and Ranging (LiDAR)**, **infrared systems**, and **computer vision systems**.

- IPS using inertial navigation

These systems include **inertial measurement units (IMUs)** that use a set of sensors such as an accelerometer, a gyroscope and, sometimes, a magnetometer to track



IPS classification

To implement an indoor positioning technology, you might need different hardware and software solutions as well as positioning methods. Thus, you can use a **tag** to track a moving object and a **beacon** if the object is stationary. Tags are normally smaller and lighter than beacons; however, both of them have various configurations that differ in price and complexity. You can program the devices according to your needs, for example, to provide two-way communication.

Smartphones, tablets, and other smart handhelds can act as receivers, getting signals from tags or beacons and converting them to the object's position data, or coordinates. At the software level, you might need to create a mobile application, SDK, library, communication protocol, and other components. Depending on the IPS type and technology it uses, you can implement different positioning methods that may include:

These methods rely on measuring the angle at which the signal sent by the transmitter reaches the receiving device. They require multiple sensors and consequently additional costs for the hardware; and because of that, they provide better accuracy. AoA and AoD are commonly implemented in positioning systems using Bluetooth.

- Received signal strength indication (RSSI)

RSSI allows for estimating the location of the object by the intensity of the signal it emits. This method can show poor results because the stationary and moving objects surrounding the transmitter can affect the signal negatively. RSSI is popular among such wireless networks as Wi-Fi, Bluetooth, ZigBee, and Thread.

- Trilateration (multilateration)

This method works when the network comprises three or more transmitting devices. Once you know the distances between some reference objects, you can measure the distance to the target object. Trilateration involves mathematical models and is often used to increase positioning accuracy in ultrasound, Wi-FI, UWB, and Bluetooth positioning systems.

- Triangulation

This is another method based on mathematical calculations. As its name implies, triangulation involves measuring the distance to the object by building triangles between the reference points around it. Bluetooth, Wi-Fi, and UWB systems use triangulation as an additional positioning method.

- Dead reckoning

This is an indoor location tracking method mostly used by IMUs. To detect the position of the object through dead reckoning, you should know its previous

- Simultaneous Localization and Mapping (SLAM)

SLAM algorithms use data taken from the sensors or camera to build a map of the place where the object is located. IMUs and computer vision systems turn to this method to track the position and movements of the object.

Positioning methods

To achieve better accuracy (and if the chosen technology permits), you can combine different positioning methods or implement your own solutions, for example, customize beacon firmware or develop bespoke algorithms.

The differences between indoor positioning technologies lie in their implementation, cost, positioning accuracy, and other performance features. All of them have their own advantages and weak points.

For example, an inertial measurement unit and a computer vision system can ensure high positioning accuracy only when used in combination with other

reliable, you can implement the necessary filters and add a sufficient number of transmitting devices.

An infrared system also needs multiple tags installed in the facility. In addition, such a system cannot track an object moving from one room to another because of the limited capabilities of the light signal.

Radio-based technologies are very common because of their availability, simplicity, and ability to track objects in real-time, so you can use them in **real-time locating systems (RTLS)**.

RFID is a cheap and easy-to-implement solution used in many industries. However, it's suitable only for short-range positioning, just like NFC. A Wi-Fi network can cover large areas, but it consumes a lot of power and cannot always provide stable connections. UWB systems show very high accuracy and generate strong signals in different environments, but they are not common and have an expensive and complex implementation.

A Bluetooth indoor positioning technology is a popular choice for locating and tracking objects in different types of facilities. Like other systems, it has certain drawbacks and strengths. In this article, we'd like to take a closer look at this technology and figure out what is good about it and how to implement it in your project.

Reasons to Use Bluetooth in Indoor Positioning

The earlier versions of the Bluetooth indoor location technology allowed for its use as a **proximity solution** that rested on the RSSI method, supported by trilateration. So there were no high expectations about its positioning accuracy, which could be from 1 up to several meters. Despite the inaccuracy, Bluetooth positioning could still offer some competitive advantages back then.

consumption. The BLE-based IPS could comprise multiple devices that had:

- reduced size;
- low production costs;
- extended lifetime.

The largest semiconductor manufacturers, including **Texas Instruments**, **STMicroelectronics**, **Qualcomm**, **Nordic Semiconductor**, integrated Bluetooth LE into their products, making BLE indoor positioning widely available.

Bluetooth chip manufacturers

As time passed, the technology acquired new features and upgrades. In 2017, **Bluetooth 5** made it possible to create highly-scalable **mesh networks** that offered non-hierarchical many-to-many communications. A mesh network can be integrated into an indoor positioning system to extend its capabilities and increase location accuracy.

allowed the system to use AoA and AoD supported by triangulation and detect an object's position with much higher accuracy. Thus, in addition to proximity solutions, Bluetooth 5.1 opened the door to the wide use of the technology in IPS and RTLS solutions.

Bluetooth has some apparent advantages over other radio-based solutions. First, Bluetooth indoor positioning is highly **energy-efficient** and can ensure a long lifespan for a wireless system. Second, its latest versions offer advanced positioning techniques that provide **increased accuracy** (up to centimeter-level).

Third, Bluetooth is **omnipresent**. According to the **2020 Bluetooth market update**, annual shipments of Bluetooth location services devices have grown from **4 million in 2015 to 186 million in 2020**. This number is expected to **reach 538 million in 2024**.

BLE is found in the majority of chips and preinstalled in most modern smartphones and other mobile devices. This simplifies the implementation and deployment of the technology to a great extent.

The closest competitor of a Bluetooth indoor positioning system is a Wi-Fi-based IPS, which is also very popular and has similar characteristics. However, the **range of Bluetooth is a little longer** because it has a lower data rate. Wi-Fi has a more complex implementation while BLE-enabled devices are **easier to program**. In addition, Bluetooth is way ahead of Wi-Fi in terms of power consumption.

To sum up, Bluetooth is a reliable technology that you can use for various **location solutions**, including:

- wayfinding;
- point of interest (POI) information;
- item finding;

For example, we integrated Bluetooth beacon indoor positioning into our **tracking solution to ensure the safety of people working underground**. How do Bluetooth beacons work? They broadcast data packets with unique identifiers recognized and differentiated by a receiving device. So, the beacons installed in the mines sent out signals, and the gateway devices read the signals and determined their proximity.

People and asset tracking solution to ensure mine safety

How to Implement Bluetooth Indoor Positioning in Your Project and Challenges You Can Meet

Implementing a Bluetooth Low Energy indoor positioning project will depend on your technical capabilities, specifications, and budget. First of all, it's necessary to decide whether you should build an IPS from scratch or integrate it into your existing solution. This will determine the choice of positioning methods.

- sharing information;
- finding items and points of interest;
- promoting products and services.

In one of our projects, we developed a **BLE indoor positioning solution for large shopping malls**. Business owners could use it for marketing purposes, informing visitors of promotional offers and discounts. The customer asked us to create an IPS with **BLE beacons** that could communicate with a mobile application via Bluetooth 4.0. After determining the location of the app users, the system could provide them with the relevant information.

We built a mobile SDK that read signals from the transmitters and sent the beacon data (ID and RSSI) to the cloud. To support the RSSI measurements, we used trilateration to calculate the location of the app user. As a result, the positioning accuracy could reach up to 1 meter.

RSSI with trilateration

The position calculations can take place either in the app or on the cloud server. The mobile device performs this function if the Internet connection is unavailable or unstable. This can be a hard and energy-consuming task, but in this case, you

on the server-side.

The positioning accuracy will also depend on the number of beacons you install in the facility. So, to locate the object's position correctly, make sure the beacon density is high enough. The IPS we developed could support an unlimited number of beacons with a density of at least 3-4 devices per 200m^2.

For this project, we used **Apple's iBeacon protocol** that works well for Bluetooth beacon indoor positioning solutions. iOS devices can natively read the iBeacon format of data packets. Android-based devices will also receive the packets, but to unpack them, you'll have to integrate additional software components into the app.

Alternatively, you can either use other protocols such as **AltBeacon** and **Google's Eddystone** or develop a custom solution. Sometimes it's hard to find an off-the-shelf product that could fully meet customer needs. It happened to our partner who implemented indoor location tracking using Bluetooth proximity beacons. By **customizing beacons for the asset tracker**, we extended the beacon battery life, added new features, and improved the efficiency of the system.

If your system supports the latest Bluetooth Specification version, you can use the direct finding techniques. With the AoA and AoD methods, you can achieve pinpoint accuracy in Bluetooth location services' deployments, such as wayfinding and real-time locating or tracking.

In the AoD method, the receiver with a single antenna reads signals from multiple antennas of the transmitter. Each signal arrives at a certain angle and has a certain **time of arrival (ToA)**. Knowing the distance between the transmitter's antennas and the time intervals between the signals (**time difference of arrival, or TDoA**), we can measure the AoD and the distance between the transmitter and the receiver. This information allows the IPS to detect the position of the object.

receiving device.

The AoA and AoD methods

If the network comprises several devices, you can increase the accuracy by using triangulation as a supporting positioning method. To keep the inaccuracies in the position calculations to a minimum, you can crosscheck the data with the help of filtering algorithms, for example, the Kalman filter.

Like any IPS, indoor positioning with Bluetooth is not a perfect solution as it can also have errors and implementation challenges. The biggest challenge you'll have to face is to **detect signals in noisy environments**.

It is easier to deploy a local positioning system in a static environment. The conditions stay unchanged to a certain degree, so the position calculations will not require considerable corrections. If a **Bluetooth IPS** works in a room or facility full of moving objects, it's much harder to maintain the signal integrity, and thus locate the object correctly. To improve the situation, you can **increase the number of beacons per square meter** in the facility.

plan to apply the direction finding techniques in your system, make sure **all devices in the network support the Bluetooth 5.1 specification**. Otherwise, you'll have to use the methods available under your current version.

Sometimes, implementing an IPS from the ground up makes more financial sense. The advanced solutions streamline the workflow, making your business more efficient.

To ensure the proper work of your BLE-based indoor positioning system, you should create a detailed map of the place where you're planning to deploy it. We highly recommend you choose a user-friendly software tool to map out the room and convert this information to the processing algorithm of the cloud solution, mobile application, or firmware of the receiving device. The task is no big deal, but it still takes some time and effort.

If you need to position and track people or objects both inside and outside the building, you can combine different technologies and switch between the modes. For example, you can use a Bluetooth location tracker indoors and shift to GPS for outdoor positioning. Integra implemented such a **solution for a location-aware service for the enterprise**. The system could switch automatically between GPS and Bluetooth beacons, providing real-time tracking with high accuracy and low power consumption.

Conclusion

An indoor positioning system is a multipurpose solution that can find its application in many business areas. For example, by using an IPS, hospital personnel can monitor patients, passengers can find a terminal number in an airport, and museum visitors can learn about artifacts.

There are plenty of indoor location technologies that can use different positioning methods. When choosing a technology, you should take into account various factors, including:

- budget;
- functional and technical specifications;
- type of facility;
- environmental conditions;
- technical expertise of the development team.

Bluetooth is a widespread IPS technology that can provide connection stability with minimum power consumption. The latest features enable Bluetooth to locate and track objects with high positioning accuracy and thus expand its application area.

If you want to make sure that a BLE-based IPS is a viable option for your project, **feel free to get our professional advice**. We have extensive experience in customizing beacons, building SDKs, libraries, mobile apps, cloud platforms, and other solutions necessary to deploy a location service.

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