WHITE PAPER

Getting started with Bluetooth for high precision indoor positioning

How it works, what you need, and key points to consider for successful deployments

Abstract

The success of satellite-based positioning in outdoor environments has created pent up demand for equally ubiquitous, accurate, and reliable indoor positioning solutions. Bluetooth® has come forward with a strong candidate to fill this gap with direction finding, a recent addition to the Bluetooth specification that makes it possible to determine the direction that radio signals travel from a mobile tag to one or several fixed anchor points. When a constellation of such multi-antenna anchors is deployed, an angle-of-arrival (AoA) methodology can be used to triangulate the precise location of a mobile device or tag.

In this white paper, we provide an introduction to Bluetooth high precision indoor positioning, explore what is needed to deploy such a solution, and share lessons learned trialing the technology in an industrial warehouse.

White paper: Getting started with Bluetooth for high precision indoor positioning
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Introduction

Because of its ubiquity, accuracy, and reliability in virtually all outdoor environments, global navigation satellite system (GNSS) technology has become a part of our daily life in ways we now take for granted. In-vehicle navigation systems, high precision asset tracking, and context-based services are just a few of the most frequently used applications that build on the technology, with many new use cases and application areas ramping up.

Expectations set by the success of GNSS technology have created pent up demand for indoor positioning solutions to complement, with similar precision, those that serve us outdoors. Demand for equally ubiquitous, accurate, and reliable indoor positioning solutions for tracking and navigation has led to the development of numerous standards and proprietary technologies – RFID, ultra-wide band, Wi-Fi sniffing, camera-based positioning – each enabling a subset of use cases and applications.

The global pandemic has further accelerated global progress towards the precepts of the Industry 4.0 – leveraging ubiquitous sensing, wireless communication, and cloud-based applications across all facets of the industrial sector and beyond. During the pandemic, escalating demand for precise control and tracking of goods was paralleled by growing demand for personal navigation solutions and proximity detection to support social distancing in social and professional environments.

These developments have underscored the advantages of global, standardized solutions to meet indoor positioning needs and requirements. Simplicity of deployment, operation, and maintenance have become key design criteria for indoor positioning solutions to be adopted. And interoperability of functionality and components are essential for the components to fit together as an overall system solution.

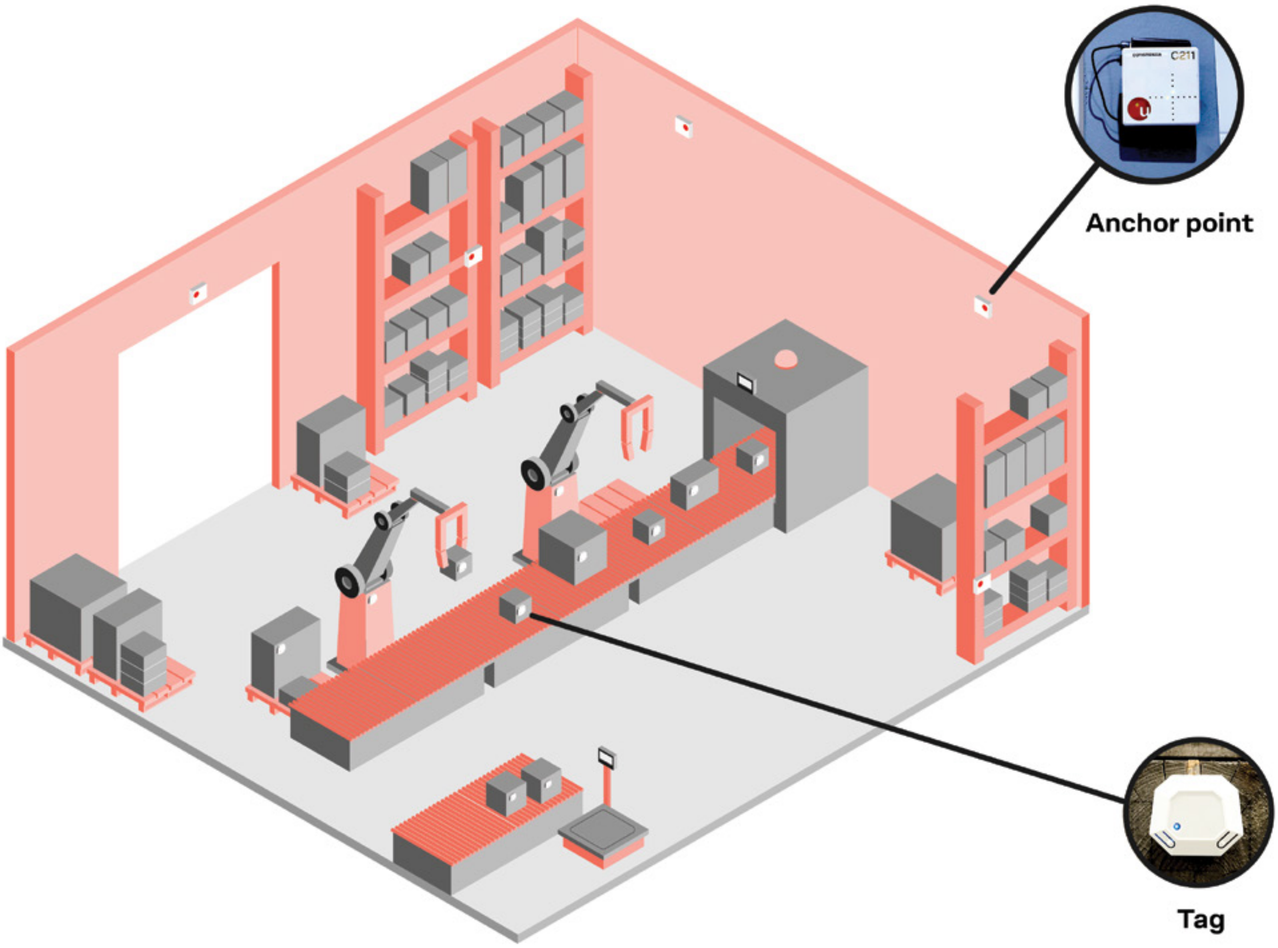


Illustration of an indoor positioning deployment in a production line.

Recognizing the growing demand for more accurate indoor positioning solutions and real-time location services (RTLS), the Bluetooth SIG released Bluetooth 5.1 in January 2019, with Bluetooth direction finding as its main feature. Using a constellation of multi-antenna anchors, Bluetooth direction finding can be used to triangulate the precise location of a mobile device or tag within the covered indoor environment.

In this white paper, we look at how Bluetooth direction finding can be used to deliver sub-meter-level position accuracies. We then present an overview of use cases that benefit from Bluetooth indoor positioning technology. Finally, we share our experience trialing indoor positioning solutions in an industrial warehouse and discuss design considerations to maximize their effectiveness.

From Bluetooth direction finding to indoor positioning

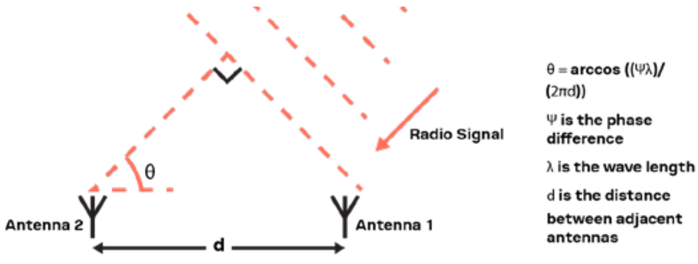
Bluetooth has established itself as one of the most successful global communications standards and technologies. Bluetooth low energy (Bluetooth 4.0) is already widely adopted for basic ranging, proximity detection, and positioning applications, using the received signal strength indication (RSSI) of the Bluetooth signal as its input. Such RSSI-based positioning solutions typically provide accuracy levels of a few meters, allowing, for example, to detect whether people or devices are located inside a room.

Instead of measuring the strength of the Bluetooth signal, Bluetooth direction finding uses anchor points with multi-antenna arrays to calculate the angle of arrival (AoA) of an incident signal or the angle of departure (AoD) of an outgoing one.

Direction finding: Angle of arrival (AoA)

In the case of AoA, the mobile asset is equipped with a tag that transmits a Bluetooth direction finding signal that includes a constant tone extension packet (CTE). In this scenario, measurements made by the antenna arrays are used to calculate the angle of the incoming CTE signals using an algorithm that runs locally in each anchor point. As illustrated below, the signals transmitted by the mobile client reach the antennas that comprise each anchor's multi-antenna array with a slight phase shift relative to the rest. Assuming that the signal propagates a planar wave, these slight phase differences can be used to calculate the signal's angle of arrival.

AoA can be used to implement real-time location services (RTLS) or tracking use cases.

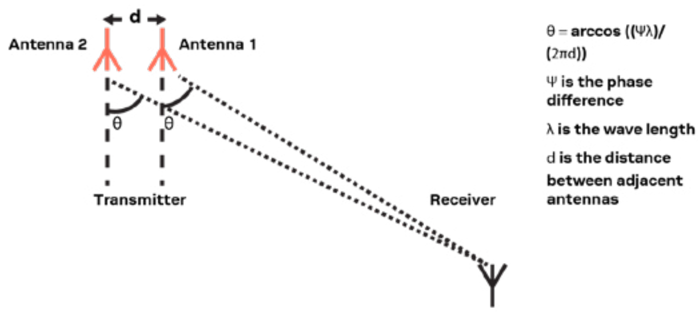


Using phase differences to derive the angle of arrival. Adapted from Bluetooth SIG

Direction finding: Angle of departure (AoD)

In the case of AoD, the mobile client receives Bluetooth direction finding signals transmitted by one or several antenna arrays. Here, the mobile client uses measurements of the incoming signal to compute the signal's direction of departure from the antenna array. Using AoD, the direction-finding signals transmitted by each element of the anchor's antenna array reach the client with a slight phase difference relative to the rest. With information on the geometry of the antenna arrays, the client can calculate the angle of departure of the signal from the antenna array using the measured phase differences.

AoD can be used to implement navigation and wayfinding use cases.

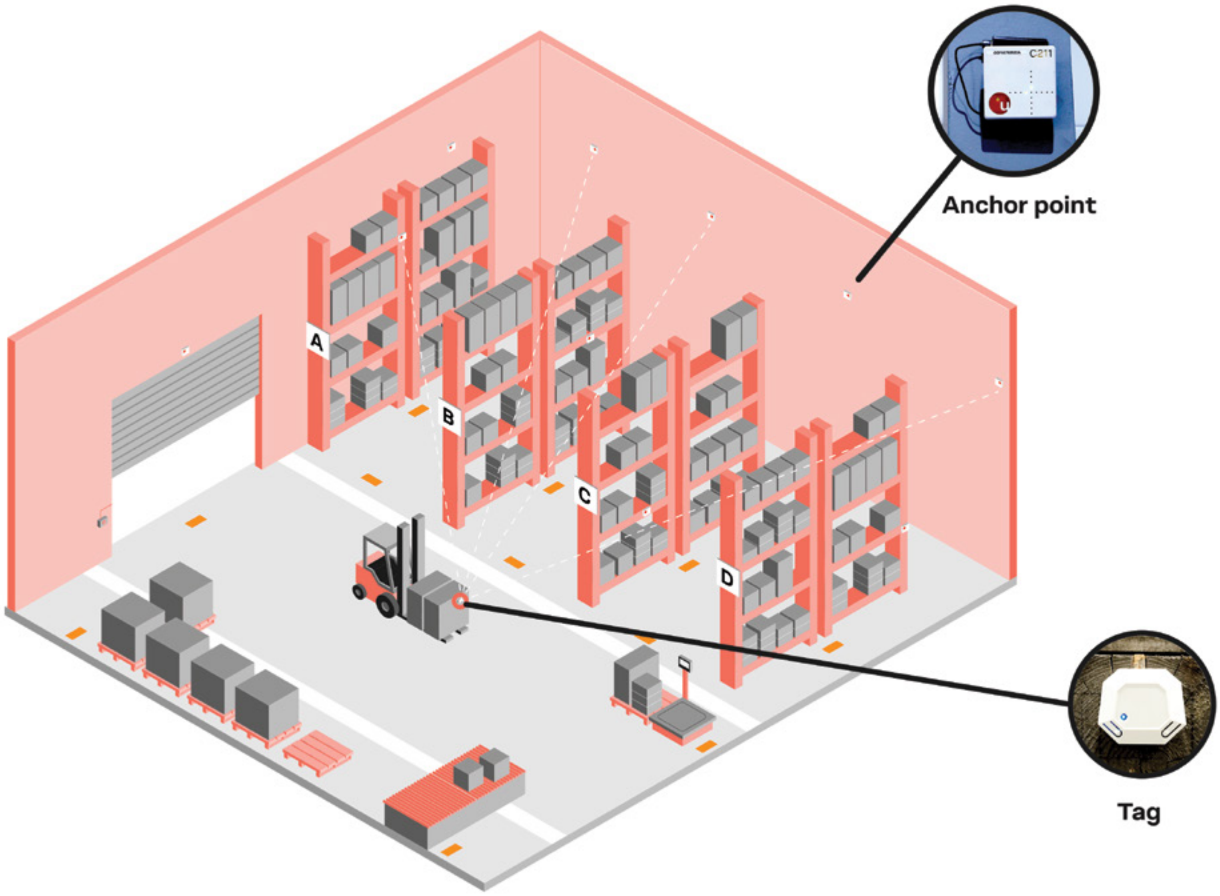


Using phase differences to derive the angle of departure. Adapted from Bluetooth SIG

Bluetooth for high precision indoor positioning

Leveraging Bluetooth direction finding, the position of an asset can be calculated accurately by the positioning engine through triangulation, using the angle of the incoming radio signals from at least three, often more, anchors and determining where they intersect.

Bluetooth 5.1-based indoor positioning systems can deliver high precision position information with sub-meter-level accuracies. Compliance with standards defined by the Bluetooth SIG ensures that the message format used by devices and anchor points is compatible across vendors. The vast Bluetooth eco-system, which provides the basis for global solutions across markets and domains connected devices, promises to facilitate the adoption of direction finding and indoor positioning.



A typical setup to triangulate the precise location of mobile devices or tags in indoor environments comprises several multi-antenna anchors, as illustrated in the image below.

Deploying high precision indoor positioning solutions

Indoor positioning solutions that build on Bluetooth direction finding are made up of five main components:

Tags

The people or assets being tracked need to be equipped with a Bluetooth 5.1 (or more recent) chip or module capable of transmitting a Bluetooth direction finding signal with constant tone extension (CTE) according to the Bluetooth SIG specification.

Anchor points

For accurate results, three or more anchor points each featuring a Bluetooth 5.1 (or more recent) receiver and a multi-antenna array need to be properly deployed to cover the monitored area.

Positioning engine

Hosted on a local device or in the cloud, the positioning engine runs software used to translate the combined input from the anchor points into an accurate position reading, accounting for multipath signals and other disturbances.

Building map

Essential to achieving accurate indoor positioning data, the map (2D or 3D pending on the use case) contains the geometry of the room and the location, height, and orientation of the anchor points.

User interface

Hosted locally or on the cloud, the user interface lets users configure their indoor positioning setup, simplify commissioning of new tags and anchor points, and track the location of the tags in real-time.

Trialing Bluetooth high precision indoor positioning in an industrial warehouse

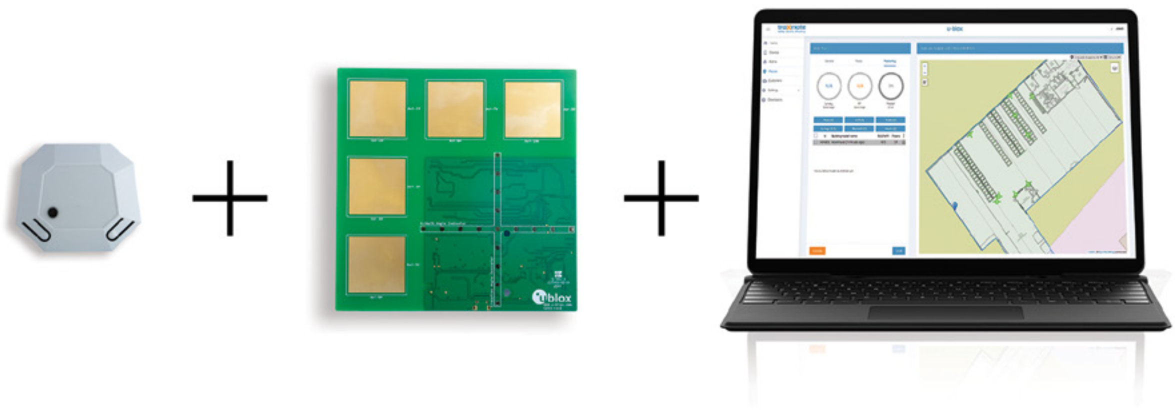
We carried out a realistic trial of Bluetooth indoor positioning technology in a typical deployment scenario for asset tracking: a 30-by-50-meter industrial warehouse that stores equipment and boxes on metal shelves. The trial was made in partnership with Traxmate, a general cloud-based tracking system, as a complement to our u-blox Bluetooth indoor positioning system.

For the trial, we used an end-to-end direction finding and indoor positioning system designed in-house with optimized functionality to achieve high positioning accuracy and update rates to follow any tag movements in real-time. We optimized all important parts of the system: the RF front end and the antennas, the embedded algorithms and the software running in the Bluetooth modules, as well as the transmission of the angles from the anchor points to the positioning engine where the final tag position estimations were made.

We placed a particular focus on the multi-antenna arrays that provide azimuth and elevation data of the incoming CTE signals from the tags to feed the AoA algorithms embedded on the NINA-B4 Bluetooth 5.1 modules comprised in the anchor points. To balance the size and performance of the anchor points, we used five dual-polarized antenna elements laid out in an L-shape configuration as shown below (in picture without the plastic enclosure).

The anchor points featured LEDs to visualize, in three dimensions, the direction of the Bluetooth direction finding signal received from the tag. Once computed, the anchors fed the azimuth and elevation angles of the incoming signal to the positioning engine using Wi-Fi. Software hosted on a PC then carried out the final triangulation and filtering steps.

Our trial used ten anchor points to cover the approximately 1000 square meter footprint in the warehouse in a six-meter-high volume. The complete installation of the positioning system in the warehouse took about two hours. The anchor points were mounted on walls and shelves at a height of 3 to 5 meters and Wi-Fi backhaul from each anchor point to the positioning engine was arranged. The antenna array directions were edited in the map and the positioning engine was configured with the correct coordinates and directions for correct multi-angulation. The editing was performed using Traxmate's software solution, which also provided an API to configure the positioning engine.



Design considerations for the deployment of Bluetooth indoor positioning solutions

The performance of Bluetooth high precision indoor positioning deployments depends on multiple factors that need to be considered on a case-by-case basis. The following design considerations are based on experience we gained during our warehouse trial.

1 The placement of anchor points is important to get good angle estimations from each tag. Antenna arrays should be surrounded by open space to maximize the probability of line of sight (LoS) between all possible tag positions and at least three anchors. In most cases, the best position estimates can be achieved by mounting the anchors high on walls or on the ceiling.

2 To obtain meaningful output, the positioning engine needs to be configured to reflect the coordinates and orientation of the anchor points. This can be simplified using software tools and digital maps. In our trial we used Traxmate, which allowed us to easily enter the positions and three-dimensional orientations of the ten anchor points used and configure the positioning engine correspondingly.

3 Long tag battery life is essential for reliable system operation and to avoid operational expenses for swapping or charging batteries, in particular in deployments using thousands of tags. With their inherent low power consumption, Bluetooth low energy modules offer a clear advantage. The very short transmission of the initial data packets and the CTE allow for a typical coin cell battery life ranging from several months when the highest transmission rate is used (20ms between CTEs) up to a few years when lower transmission rates are deemed sufficient.

4 To reduce multipath effects, we used CTE signals on all three Bluetooth advertising channels, dual polarized antennas in the anchors, and an advanced propagator direct data acquisition (PDDA) method for the angular spectrum search.[1]

5 There is a trade-off between the density of anchor points and the accuracy that can be achieved. In the warehouse trial we used ten anchor points positioned approximately ten meters apart. This setup provided good average positioning performance accuracy and allowed us to follow the tag positions in real time.

6 Once computed, the estimated angles need to be sent to the positioning engine software, which can be implemented in a local PC, a local server, or in the cloud. In our case, the communication backbone used to transmit angle data to the positioning engine was 5 GHz Wi-Fi. This is by no means the only solution: when available, Ethernet can, for instance, be used for the connectivity and transmission of data to the positioning engine.

1. Improved Accuracy for Indoor Positioning with Bluetooth 5.1: From Theory to Measurements, Sesma Santos, Victor LU and Egorov, Victor, http://lup.lub.lu.se/student-papers/record/9027829

Building indoor positioning solutions with u-blox

Building high precision indoor positioning solutions from scratch can be intimidating. To help accelerate the evaluation and deployment of Bluetooth high precision indoor positioning solutions, we designed two “explorer kits”: The u-blox XPLR-AOA-1 explorer kit contains all of the components needed to gain first-hand experience using Bluetooth direction finding.

The more advanced u-blox XPLR-AOA-2 explorer kit includes all the elements needed to achieve sub-meter-level position accuracy in indoor environments – from the tag to the anchor to the cloud:

- Four u-blox C211 antenna boards that act as anchor points.
- Four u-blox C209 tags to tag mobile assets.
- All the software required to leverage AoA technology for diverse applications.

Both the tag and the anchor point use the u-blox NINA-B4 Bluetooth 5.1 low energy module featuring Nordic Semiconductor’s nRF52833 Bluetooth Low Energy System-on-Chip (SoC). Running on the SoC’s embedded MCU, u-blox u-connectLocate software calculates the angles of the incoming radio signals without requiring any additional processing or external components. An external positioning engine software is included to triangulate the position of the tag based on the angles from the anchor points. XPLR-AOA-2 is system agnostic and works with a variety of local or cloud-based tracking solutions.

Now is the time to become an early adopter

Demand for indoor positioning solutions is quickly ramping up, with the aim of complementing GNSS technology that is already ubiquitous in outdoor applications. Bluetooth direction finding, released by the Bluetooth SIG in Bluetooth Release 5.1 and the high precision indoor positioning it enables has the potential to meet this demand.

At u-blox, we have trialed Bluetooth indoor positioning technology in a real-world industrial warehouse environment, reliably achieving sub-meter-level accuracy in three dimensions using tags, anchor points, and positioning engine software developed in-house. Combined in the commercially available XPLR-AOA-2 explorer kit, the solution offers a quick and easy way to evaluate the performance of the technology and paves the way towards efficient installations and large-scale deployments.

To learn more about Bluetooth direction finding, Bluetooth high precision indoor positioning, and evaluating and deploying the solutions, we encourage you to reach out to your nearest u-blox field application engineer or visit the product page for the u-blox XPLR-AOA-2 explorer kit.

About the author

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Peter Karlsson is Head of Technology, Product Center Short Range Radio and responsible for technology coordination among positioning, cellular, service, and short-range product centers at u-blox. He holds a PhD in Electrical and Electronic Engineering from Lund University. Peter has written and co-authored more than 80 journal and conference papers and 3 book chapters in the mobile and wireless communications area over the last 30 years with more than 3900 scientific citations. Peter holds more than 50 filed patents on wireless and mobile systems including both standard essential patents and implementation related patents.

About u-blox

u blox (SIX:UBXN) is a global provider of leading positioning and wireless communication technologies for the automotive, industrial, and consumer markets. Their solutions let people, vehicles, and machines determine their precise position and communicate wirelessly over cellular and short range networks.

With a broad portfolio of chips, modules, and a growing ecosystem of product supporting data services, u blox is uniquely positioned to empower its customers to develop innovative solutions for the Internet of Things, quickly and cost effectively.

With headquarters in Thalwil, Switzerland, the company is globally present with offices in Europe, Asia, and the USA.

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