

# An Introduction to Indoor Positioning



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# Foreword

There's a lot of buzz around indoor positioning systems and not nearly enough information or resources about them. How should we locate this specific asset in that specific environment? What happens if that environment changes? What technologies should we use? Should we purchase an existing solution or try to build our own? Is it even feasible or worth it?

These are some of the questions that may come up as you begin to learn about indoor positioning. While we won't be able to answer all of your questions, this eBook aims to equip you with the basic tools and knowledge necessary to guide your discovery process as you dive deeper into indoor positioning. You'll leave with a better understanding of where indoor positioning systems are used, how they work, and what you should consider before implementing one.

At Leverage, we're committed to amplifying human potential. We firmly believe that everyone is made better by openly sharing knowledge, so we've created this resource for you. We've seen firsthand that many organizations don't know enough even to begin asking the right questions. We hope to demystify indoor positioning so that you can start asking the right questions and finding the right answers.

If you still have questions after reading this eBook, please don't hesitate to reach out. IoT may seem hard, but it doesn't have to be.

- Team Leverage

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# Introduction

# Introduction to Indoor Positioning

**Imagine if you could go into a grocery store, take what you need, and walk out.**

Imagine if you could go into a grocery store, take what you need, and walk out. In fact, you don't need to imagine it; Amazon has already done this with their [Amazon Go](#) stores. This new form of retail is possible because of something called "indoor tracking" or "indoor positioning." Indoor positioning applications range from smart retail (e.g. Amazon Go) to finding a package out of thousands in a warehouse to tracking cars in a parking garage. The overall benefits of indoor positioning are vast—lower operational costs, better coverage, arrangement optimization, etc. However, tracking assets indoors is application specific and quite difficult. Let's go through some technologies that could help you implement an indoor positioning solution.



## 1. Global Positioning System (GPS)

Let's first go over the Global Positioning System (GPS) technology. GPS has become ubiquitous over the past decade. Everyone with a smartphone has GPS at their fingertips, and consumers can buy GPS modules for less than \$50. Many real-time IoT asset tracking applications are now possible with the widespread availability of GPS.

Nonetheless, GPS still struggles in one key application—indoor positioning. GPS technology struggles to track well indoors because GPS signals may not be able to penetrate through built structures. You can use an indoor gateway to boost signals and give more accurate positions, but GPS is generally inaccurate for indoor positioning applications.

## 2. Radio Frequency (RF)

The next set of technologies is radio frequency (RF) indoor positioning, which uses beacons to communicate via WiFi or Bluetooth signals depending on the application. WiFi and Bluetooth technologies use parameters such as the Received Signal Strength Indication (RSSI), Angle of Arrival (AoA), and Time of Arrival (ToA) to determine the location of a broadcasting device.

The RSSI value is inversely proportional to distance, so a device's distance from a given radio beacon can be approximated. AoA describes the angle of a wave at radio beacon. ToA refers to the time at which a wave arrives at a beacon. AoA and ToA are difficult to determine indoors because radio travels at the speed of light.

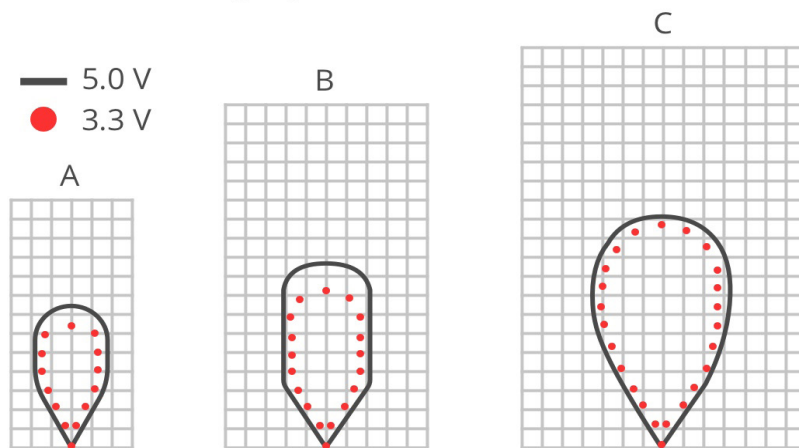
Given the obstacles an indoor scenario presents, you often need

multiple receivers for these measurements. WiFi and Bluetooth receivers aren't typically built to deal with this level of precision, so RSSI is the primary metric used for RF indoor positioning.

## 3. Ultrasonic

Ultrasonic sensors could be used in a sensor array to figure out where an asset is in an indoor space. Much like RF, we can use the sound waves to determine the RSSI, AoA, and ToA of a device. However, it's much easier to determine distance because sound travels much slower than light, so the calculated distance using the ToA is typically much more accurate than RF. However, ultrasonic sensors are very limited in terms of the width of the beam pattern, which means they can detect assets far away, but neither too far left nor right of the ultrasonic beam.

**Note:** for people detection the pattern typically falls between charts A and B.



**Beam Characteristics are Approximate**

Beam Pattern drawn to a 1:95 scale for easy comparison to our other products.

Image Credit: [Maxbotix](#)

## 4. Computer Vision

Indoor positioning uses computer vision much like any other computer vision application. A computer vision algorithm will identify the asset that needs to be tracked and follow it as it moves through the environment. This is part of the technology that Amazon uses in its Amazon Go stores to track customers as well as items for sale. However, this technology is very use case specific. For an RF application, it doesn't matter whether a person or your pet dog is wearing the tracker. However, this makes a huge difference for a computer vision system.



Image Credit: [Towards Data Science](#)

## 5. Algorithms & Tuning

There are numerous computer vision algorithms, so I'll just go over algorithms that are relevant to RF and ultrasonic indoor positioning technologies. Trilateration and triangulation are mathematical algorithms that use three beacons to determine the location of an asset. Trilateration



and triangulation use distance and angles, respectively. These algorithms aren't foolproof because RF and sonic waves don't travel unobstructed to beacons. To account for obstruction, we can use empirical models to consider the time of day, number of assets, etc., to determine location more accurately. However, even using those aiding data, indoor positioning remains difficult. RF is only accurate to two or three meters—a significant area in a small office space, grocery store, or retail environment.

The final step here is to combine multiple sensor types using a technique called "sensor fusion." An example of sensor fusion is using a BLE tag with an accelerometer and gyroscope. The accelerometer and gyroscope can give you the general movement and direction of a given asset, which can help you track it with RF technologies. With empirical models, you can get a better idea of an asset's location compared to traditional RF tracking.

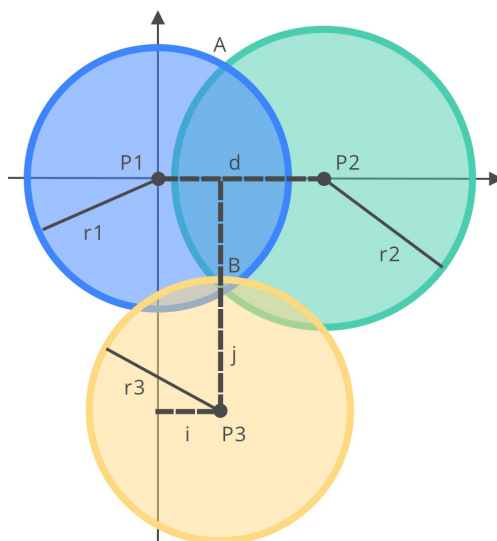


Image Credit: [Wikipedia Commons](#)

### Limitations

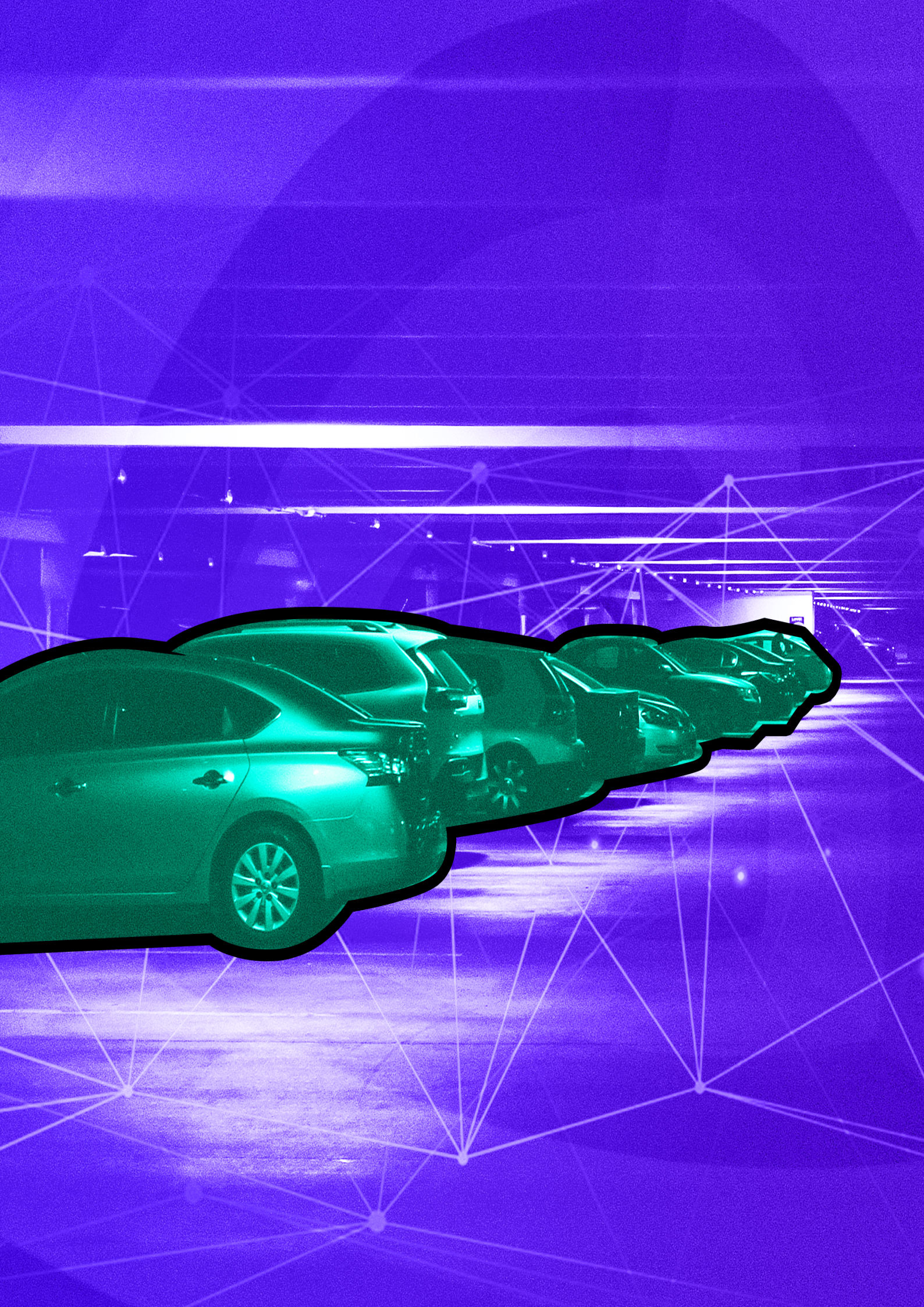
Indoor positioning is quite difficult for two reasons: technology isn't extremely accurate, and the environment is constantly changing. With both of those factors influencing outcomes, indoor positioning solutions can run awry quickly. RF tracking is accurate up to a few meters, however, some indoor spaces are only a few meters. In contrast, ultrasonic tracking is much more accurate, but the width of its beam pattern is quite constrained. Sensor fusion provides one promising solution by leveraging multiple sensor inputs to get more accurate data.

Indoor environments often change. RF and ultrasonic waves can absorb and reflect off of various surfaces, which will change key characteristics of these waves and, therefore, the derived calculations—RSSI, AoA, and ToA. In a static environment, you can create an empirical model that accounts for unique scenarios. However, we generally want to track people and things that are moving. As a result, the surfaces move and change. The empirical model you use must be more sophisticated and multivariate to deal with these changes.

### Conclusion

There are numerous technologies such as WiFi, Bluetooth Low-Energy (BLE), Ultrasonic, Computer Vision, etc., which can be deployed to track assets indoors. However, indoor positioning is difficult because of accuracy limitations due to the underlying technology and because of shifting indoor environments. Methods such as empirical models and sensor fusion can be used to account for these issues, yet robust and flexible deployments remain a huge challenge.







# Triangulation vs. Trilateration

When talking about indoor asset tracking, it's important to keep in mind that it's made up of a loosely woven group of technologies, each of which can calculate position using one of two methods: triangulation or trilateration. The two are distinct in important ways even though both can theoretically contribute to a single indoor positioning solution.

## What Is Triangulation?

Triangulation is a method for calculating a position that relies on a known distance between two measuring apparatuses and the measured angles from those two points to an object. This works using the angle-side-angle triangle congruency theorem to find the location of an object.

## What Is Trilateration?

Trilateration is the more common method for position calculations. Trilateration uses the known distance from at least three fixed points in 2D space or four fixed points in 3D space (as if on the surface of the Earth) to calculate the position of an object. Trilateration works by finding the intersection of a series of circles (imagine in a Venn diagram).

### Triangulation and Trilateration in Practice

In the asset tracking space, trilateration is currently much more common. Most companies that use BLE or Ultrasonic technologies rely on trilateration because of how easy it is to implement. Take for example a BLE-based tracking solution. All a solution needs are three (the “tri” of trilateration) BLE beacons and a BLE tag. When the tag starts reporting RSSI values, those values can be converted to distances and used to locate the tag. This isn’t perfectly accurate, having [roughly 1-2m accuracy](#), but it’s relatively simple since it uses common hardware and requires relatively simple math.

On the other hand, triangulation is hard. It requires knowledge of not just the location but also the spatial rotation of BLE beacons. The calculations aren’t much more complex than trilateration, but the measurements themselves are significantly more sensitive due to how they are measured. While trilateration relies on signal strength as an analog for distance, triangulation relies on timing differences in the reception of tags’ signals. Because these signals travel at the speed of light, the time differences in transmission are very small. This makes measuring instruments more expensive.

### Combining Triangulation and Trilateration

As hard as it is, triangulation is likely to catch up to trilateration over time. Ultimately, in many applications, the two will likely be used in tandem for added accuracy and redundancy. As we mentioned previously, trilateration taps out at ~1-2m accuracy, [but triangulation shows promise](#) of reaching accuracies of ~0.5m. Their combined power holds potential for even higher accuracy applications—specifically when higher costs aren’t an issue.

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# Core Technologies



# WiFi

Whether you're at your local coffee shop, at home, or in the office, WiFi is everywhere. Being able to track assets using WiFi is very exciting because the network infrastructure is already commonplace and fully standardized. WiFi networks are relatively cheap, easy to set up, and inconspicuous. For spacious indoor locations where GPS is inaccurate, WiFi offers a great alternative. In this section, we'll do a deep dive into what WiFi is and how indoor positioning systems can leverage WiFi connectivity.

## What Is WiFi?

WiFi describes a local wireless network that uses radio waves to communicate data, typically from the Internet. To be considered WiFi, the radio signal must use the IEEE 802.11 standard to communicate. There are multiple versions of WiFi as defined in the IEEE specifications, which include common ones such as 2.4 GHz and 5GHz frequency radio waves. WiFi is typically used to transfer large amounts of information. It has transfer speeds of up to several gigabits per second for certain versions.

## How Does WiFi Track Location?

There are several methods for tracking an asset indoors using WiFi. The two primary methods are RSSI and a technique called "fingerprinting." RSSI (or Received Signal Strength Indication) of a WiFi signal is inversely proportional to distance. In combination with trilateration, RSSI can be used to approximate an asset's location. However, the measured RSSI of a signal can be decreased

due to obstructions and/or reflections, leading to inaccurate RSSI measurements and, therefore, imprecise location determinations.

Fingerprinting can be used to improve this accuracy significantly. Fingerprinting is a technique that uses historical RSSI information as well as known locations to determine the position of an asset given its current RSSI values. Fingerprinting is highly dependent on the environment. If a chair or table is moved, the fingerprint will need to be updated. In addition to RSSI and fingerprinting, Angle of Arrival (AoA) and Time of Flight (ToF) can be used to determine location. While these methods are accurate, they require expensive equipment and methods such as multiple antennae and clock synchronization.

## Advantages

The major advantages of WiFi are accessibility, large range, and a high data throughput rate. WiFi is also widely available and fully standardized. In some cases, there may be several WiFi access points in a room or floor. In general, the more WiFi access points there are, the higher the accuracy of the indoor tracking will be. For some applications, there could be little to no infrastructure costs for implementing a WiFi network for asset tracking. Additionally, WiFi has a very long range up to 150 meters—much longer than Bluetooth. Compared to Bluetooth, WiFi also has a much higher data transfer, which could be useful should your asset need to transfer a large amount of data (e.g. images, video, or uncompressed audio).

## Disadvantages

One of the major disadvantages of WiFi is its inaccuracy. With an accuracy at the higher end of 15 meters, it's ill-suited to indoor positioning applications that require precision. Bluetooth excels by comparison with its 2-4m accuracy. However, the accuracy of WiFi can be as low as 2-3m with fingerprinting, a significant amount of WiFi access points, and/or combining tracking data with other technologies (i.e. sensor fusion). Oregon State University, in collaboration with Intel, is working on SAIL—a WiFi indoor tracking technology that "achieves a location accuracy better than 1m."

Another disadvantage of using WiFi is security. WiFi is such a common technology that it is subject to countless hacks and reactive security patches. Security will always be a concern for WiFi. At the same time, however, there will always be cybersecurity firms working to harden WiFi from attackers.

## Conclusion

WiFi is a viable solution for indoor asset tracking. For a business office, shopping mall, or university campus, WiFi is an ideal, low-cost solution for tracking assets indoors. While accuracy and security issues may hinder WiFi, these drawbacks can be mitigated using techniques such as fingerprinting, sensor fusion, and security hardening. Hopefully, indoor tracking will be more prevalent given the widespread use of WiFi.



# Bluetooth Low Energy (BLE)

## What Is BLE?

Bluetooth Low Energy (BLE) is a low energy implementation of Bluetooth. Created in 2001, BLE was an attempt to fill the gap that the Bluetooth SIG perceived in contemporary wireless offerings for low energy and low-cost wireless protocols. BLE was slow to take hold, but it accelerated exponentially after its first inclusion in a smartphone in 2011.

BLE was designed from the ground up to have a similar range to Bluetooth “Classic” (about 330 feet) while using significantly less power than its predecessor. In order to conserve power, the data transfer rate for BLE is about one tenth and the latency is about five times that of standard Bluetooth. While BLE isn’t a powerhouse for transferring tons of data, it’s an excellent technology for applications with low data transfer requirements—like indoor tracking—where data can be sent in small chunks periodically.

## How Does BLE Track Location?

All configurations for a BLE network rely on two major components: BLE beacons and a BLE hub for sending data to the internet. These components can then be combined in two different ways. The first configuration places the low powered beacons in the environment and relies on mobile hubs (e.g. smartphones) to send data and signal strength measurements to the internet. The second layout places the hubs in the environment and positions the low-power tags on trackable assets such as a crate of inventory in a warehouse.

Once a configuration is chosen, the means of calculating location are essentially the same. For rough proximity calculations—such as whether a person carrying a hub is near a forklift, or whether a person is walking through a large room—the existence of a known tag or hub in that area can be used.

When more precision is required, BLE relies on RSSI values to calculate how close a beacon is to a hub using a complex formula called trilateration. The formula relies on knowing several defining characteristics of the BLE hub being used. These distance calculations are then combined across at least three hubs to triangulate a location. Unfortunately, RSSI distance calculations are tricky and can be unreliable. Most commercial systems aid these calculations with additional information. The most common way of aiding these calculations is to map the RSSI values in a building after setting up all the hubs and then to use this known set of values to assist your triangulation calculations.

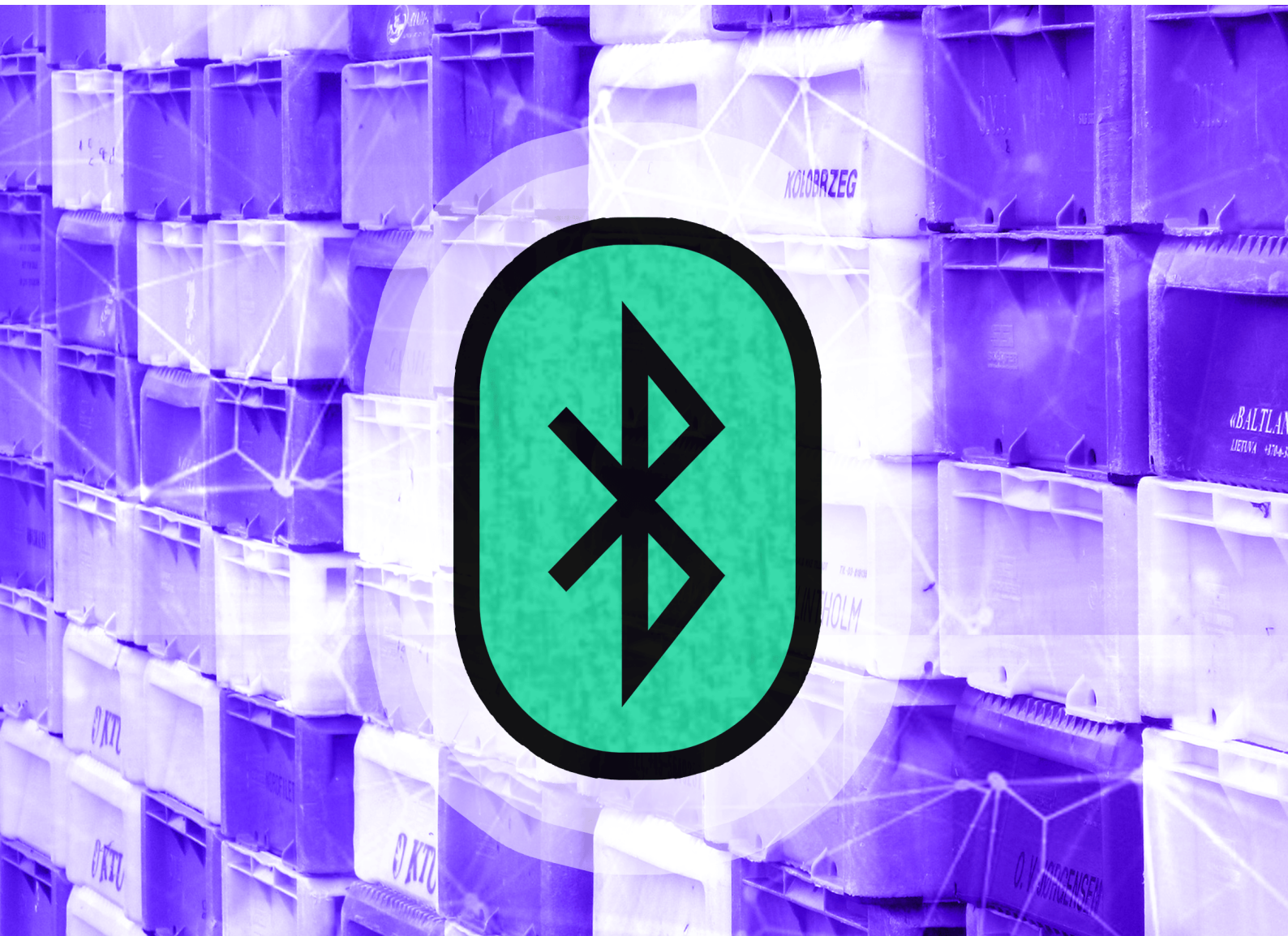
### **A Software Problem**

The hardware for BLE tracking is relatively commonplace. Getting started is as simple as picking up some BLE beacons and provisioning them through a smartphone. On the other hand, the software for BLE tracking is where all the magic happens. Several companies that provide BLE tracking as a service already exist. Each has their own flavor of implementation. Very few of these applications rely purely on BLE. Typical technology pairings include Ultra-Wideband (UWB) and Ultrasonic tracking. Combinations like these are common because each technology has its strengths and weaknesses. No single indoor tracking method works perfectly on its own—yet.



### Conclusion

BLE is a relatively well-established method for indoor positioning, but the indoor positioning space is still quite new and uncertain. Technological fragmentation and a lack of any “one-size-fits-all” solution means that implementation can be messy. With low power consumption, relatively high range, and potential for 1-2-meter accuracy, BLE is an excellent option among many. BLE still works best when complemented with other technologies that help it become as effective as possible. It’ll be interesting to see the role BLE takes in shaping the future landscape of indoor positioning.



# RFID

The venerable RFID tag traces its ancestry to the “friend of foe” transponder systems developed for military aircraft beginning in WWII. Since then, RFID has earned and retained its status as a reliable asset identification system. Recently, it has been marketed as a solution for real-time indoor positioning. In this section, we’ll explore how RFID works, how it might be used for indoor asset tracking, and how it compares to alternatives.

## How RFID works

An RFID system—RFID stands for “radio-frequency-identification”—comprises two components: a transponder (or tag) containing data that can be read over RF and an interrogator (or reader) that can read the transponder’s data.

The specific means by which these components communicate (i.e. their “coupling mechanism”) determines the range, complexity, and cost of the system. (“Coupling” in this context refers to an energy transfer between tag and reader.) Currently, three types of coupling mechanisms compete in the market: inductive, capacitive, and backscatter.

### *Inductive Coupling*

Inductive coupling has been present since the early days of RFID when the systems involved bulky tags with complicated antenna mechanisms used to track large objects (e.g. cars or cattle). An inductively coupled tag draws energy from the magnetic field created by the reader and modulates



it. The reader then measures the perturbation produced by the tag and decodes it as data. The magnetic fields used in these systems drops off rapidly, affording inductive coupling an effective range of about 1cm to 1m.

### **Capacitive Coupling Systems**

Capacitive coupling systems were created to lower the cost and size of RFID when large inductive systems were the only option on the market. They employ conductive patches on both reader and tag to form a capacitor and signal data by varying the capacitance of the circuit. These systems are extremely close range—1cm—and the orientation of the patches matters, so a typical application would be an ID card that must be inserted into a reader.

As inductive circuits shrank, so too did the market for the more limited capacitive systems. Indeed, most RFID systems today use some version of inductive coupling. However, they're still limited by magnetic fields' rapid drop in strength at a distance. To achieve longer range reliably, RFID systems must use higher frequency signals and rely on the electric side of the electromagnetic signal.

### **Backscatter Coupling**

Backscatter coupling employs a reader that sends out a UHF or microwave signal that impinges on a tag and then reads patterns in the reflected energy. Whether the increased range is an advantage or disadvantage depends, of course, on the use case. Scanning pallets as they pass through a large warehouse gate? Great. Unlocking doors or disseminating payment information? Probably less desirable.







## Types of RFID Tags

The RFID market delineates systems according to how RFID tags are powered. Whether or not a tag has onboard power available affects its size, price, read range, and whether it can support additional sensors.

### *Passive Tags*

Passive tags have no internal power source. They work by siphoning some of the power in the interrogator's signal to modulate their response. This allows them to be cheap, durable, and quiet (in the radio spectrum). Lacking consistent energy, they can't contain volatile memory, meaning they can't be used to write and store sensor data. They have a lower range than powered alternatives and require high power, high cost readers.

### *Semi-Passive Tags*

Semi-passive tags (also known as "semi-active" and "battery-assisted" tags) have an onboard battery. Like passive tags, they only transmit in the presence of a reader's signal. The battery can power a sensor as well as an antenna. A powered antenna allows more signal to reflect back to the reader, which provides a longer range than wholly passive tags. They are bulkier and more expensive than passive tags, and they have a battery-limited lifespan.

### **Active Tags**

Active tags have a local power source (e.g. battery or photovoltaics) and broadcast their own signal. Despite their marketing label, these aren't technically RFID devices since they don't depend on receiving and modulating a reader's signal. Instead, they're short range radios. From an operations perspective, this distinction is probably not that important, so we follow the market and include them here. Compared to passive and semi-passive tags, active tags have significantly greater range (up to 1km) as well as increased memory capacity, size, and cost, and they can work with weaker readers.

### **Tracking Assets with RFID**

Before assessing RFID's merits as an indoor asset tracking technology, we need to clarify what we mean by "tracking." RFID has, since its inception, been used to track assets in a sort of spreadsheet sense. It makes it simple to identify and log which tracked items are nearby. If your goal is to make sure all the train cars that went through gate A also made it through gate B, or whether an employee swiped into a building, then RFID is a well-tested and proven solution.

In such use cases, RFID competes most directly with barcodes or QR codes. It offers the obvious advantage of being readable at a distance. Active or semi-active RFID tags can provide valuable sensor information. On the other hand, passive readers are very expensive, and powered tags are costly and have a limited lifespan.

A more challenging type of tracking is knowing the (nearly) real-time location of a tracked asset. Although this is a relatively recent use case for RFID, there are already quite a few commercial solutions on the market.

The way these systems work varies. Some systems use RFID purely for object identification while leveraging another technology for ranging. Those that rely purely on RFID almost exclusively use active RFID tags. There's some exciting research that uses passive RFID tags, but the cost of passive readers and the low range of these systems makes them commercially prohibitive.

Real-time location systems (RTLS) that use active RFID tags behave similarly to competing technologies—Bluetooth, Bluetooth Low-Energy (BLE), WiFi, Ultrasonic, and Ultra-Wideband (UWB). The RFID versions are largely based on the LANDMARC system, which determines location by comparing the Received Signal Strength (RSS) of an active tag's signals with the RSS of reference tags with a known location.

Active RFID has a much greater range than BLE. It's capable of spanning a kilometer in open air. Compare that to BLE's ~70m. This is less important in indoor environments with obstructions (e.g. walls or floors), but in warehouses or barns, active RFID's range might allow businesses to make do with fewer readers, cutting costs and reducing potential failure points.

## **A Problem (Bleed-Through) and a Solution (Hybrid Systems)**

RFID has a few drawbacks as a tracking solution. Like all RF / RSSI based solutions, it suffers from bleed-through. Since RF signals can penetrate walls, it becomes difficult to determine from which room a tag is transmitting. The high bandwidths used by active trackers—especially long-range trackers—are highly subject to interference. And, compared to BLE, both the tags and the readers are very expensive.

RFID finds its greatest success as part of a hybrid system. It provides reliable identification, which can supplement systems that rely on ultrasonic, infrared, or ultra-wideband for location information.

## **Conclusion**

Currently, RFID technology isn't ready to provide a standalone solution for indoor positioning. It's not alone in that respect. As part of a multi-technology system, however, RFID brings to indoor positioning its decades-long history of reliable identification.







## Ultra-wide Band (UWB)

Although there are [numerous technologies that are appropriate for use in indoor positioning applications](#), UWB's low-frequency and high-bandwidth mean that it can pass through both walls and other obstacles and that it can exist in harmony with other radio signals such as those from cellular telephones. Altogether, this makes UWB ideal for indoor positioning applications in multi-room environments, or in places like hospitals within which radio-frequency interference is a big safety concern.

### What Is Ultra-Wideband?

Put simply, Ultra-Wideband is a radio signal at a frequency greater than 500 MHz. In the US, the FCC has approved UWB for commercial use at a ranges between 3.1 GHz and 10.6 GHz. Unlike most traditional radio signals, UWB doesn't use power, frequency, or phase modulation to encode the information that its signals carry. Instead, UWB uses frequent pulses at specific time intervals to carry information. This allows transmission across a wide bandwidth while avoiding interference with other radio signals in the same spectrum.

These characteristics allow UWB to transmit a large amount of data using relatively low power consumption. Although transmission is limited to a short range, with the use of multiple well-position receivers, UWB can be considered for most indoor position tracking applications.



## How Does UWB Track Location?

The primary method used to determine location in Ultra-Wideband systems is Time Difference of Arrival or TDOA. This means that in a UWB system, several networked receivers (a minimum of 3 for 2D location and 4 for 3D location) are placed at known locations throughout a space. The asset or assets to be tracked are outfitted with UWB transmitters, which emit an omnidirectional signal at a given interval. The signal arrives at nearby receiver units at differing times due to the distance from transmitter to receiver. You would then compare the varying times of arrival (and hence, distances) to each receiver and determine the location of the transmitter.

## Conclusion

Ultra-Wideband technology promises unparalleled accuracy, the ability to penetrate walls and other obstacles, and low power consumption—all in one package. Although UWB isn't as ubiquitous or inexpensive as other indoor tracking technologies (e.g. Bluetooth Low-Energy), in recent years, UWB equipment has seen increased uptake and reduced cost of components. This makes UWB a technology to consider when planning any indoor location tracking project.

# Ultrasonic

Commercial ultrasound tracking solutions claim to have the potential to pinpoint an object to within a few centimeters. The internet is saturated with white papers and research presentations on ultrasonic. It can be difficult to separate the merely possible applications of this technology from the proven deployments. In this section, we'll sort through the ambiguities by providing an overview of what ultrasonic is, how ultrasonic tracking works in principle, and how currently available solutions can support an end-to-end indoor tracking solution.

## What Is Ultrasonic/Ultrasound?

Ultrasound defines a spectrum of sound waves with frequencies too high for humans to hear—typically above 20 kilohertz (kHz). Exploiting the ultrasonic range for location reckoning is a common trick in nature. Bats famously rely on echolocation to detect insects, emitting ultrasonic pulses as high as 200 kHz. [They're sensitive to extremely subtle differences \(as low as .0001 kHz\)](#). Many cetaceans and some fish use ultrasound to navigate, hunt, and communicate. On land, dogs and cats are sensitive to the ultrasonic spectrum. [Shrews can also use ultrasound](#) at close ranges to detect objects through grass and moss.

## From Biomimicry to Technology

Research into whether these evolutionary phenomena can translate into a technological success [stretches back decades](#). The research projects wear their biological inspiration on their sleeves. They sport names like [Active Bat](#), [Cricket](#), and [DOLPHIN](#)—animals that use echolocation. In short, these technologies determine location by measuring the time of flight (ToF) from one or more emitters to one or more receivers. This allows them to discern [an object's location to within a few cm](#) using [trilateration](#).

In the Active Bat system, a tracker tag emits ultrasonic pulses from two transmitters to increase the coverage area. A grid of ceiling-mounted receivers listens to these signals and sends data back to a central system that uses multilaterate based on three or more receivers to determine the transmitter's position, boasting an accuracy of within 3cm. To detect the periodic ultrasound pulses reliably, the system requires many receivers positioned at very specific angles. A network of receivers makes the system useful in a lab environment but expensive to deploy in a large building.

The closely-related DOLPHIN project improves upon Active Bat by requiring only a few sensor nodes to have specifically-known locations; the other sensors infer their locations from these nodes' signals.

[MIT's Cricket system](#) inverts the Active Bat structure by mounting the emitters to the infrastructure and having the tracker listen for signals. The emitters send both radio frequency (RF) signals and ultrasound. The receiving trackers calculate their distance from a given emitter by measuring the time between receiving the RF signal and subsequent ultrasound signals to gauge the sound's ToF. The trackers use these data to determine which emitter is nearest.

They infer their location based upon that proximity data and data from the other emitters it detects. It can communicate this back to a central server, but it doesn't have to do so if privacy is a concern.

One drawback of the Cricket system is the amount of power the transmitters consume. Because the system can only listen to one signal at a time, keeping track of a moving target is more difficult for Cricket than it is for Active Bat, which collects multiple data points simultaneously (rather than linearly). Despite these shortcomings, it's possible that Cricket could have become a commercial contender. It seems that Cricket ceased active development in 2005 before ever launching a commercial product.

## Commercial Solutions

Unlike WiFi or [Bluetooth Low Energy \(BLE\)](#), walls, doors, and windows can obstruct ultrasound. This can be an advantage in indoor tracking scenarios. A WiFi sensor will be ambiguous between rooms. The device might be in a far corner of this room while the signal could have been detected through a couple of walls in that room way over there. Since ultrasound generally cannot escape the room, you can rest assured that any emitter/receiver pairs that are communicating with each other are within the same room—provided you've confirmed that the wall, door, and window materials do obstruct the ultrasonic signals. If you're trying to locate an asset in a building—finding a service cart in a hotel or a wheelchair in a hospital—it's probably much more useful to know which room contains the asset than exactly how many feet from a beacon it is.

[Sonitor](#), currently the only maker of ultrasound-based indoor tracking systems, uses a system of relatively few detectors (currently one per four rooms) to listen to a specific signal from a tracker and to

identify which trackers are in which rooms. Sonitor's systems are currently deployed in several hospitals, where they're used to track the locations of doctors and nurses as well as medical equipment.

Unlike the biomimetic research projects outlined above, Sonitor's technology doesn't work exclusively by measuring ToF from emitter to receiver. The solution is more closely related to radio frequency (RF) tracking solutions that [measure received signal strength \(RSS\)](#) and calculate doppler changes to determine proximity to a sensor node. In addition to guaranteeing which room contains a given tracker, Sonitor claims their solution can also determine a tracker's position to [within a few feet](#).

Such a system faces several technical hurdles. In tight spaces, ultrasound won't penetrate obstacles, but it will echo, scattering signals across the space. To overcome this, the technology will need to find some way of balancing the high signal density needed to ensure a device hears the signal while also blocking the noise from reflected, scattered signals. Unlike RF, sound waves are also affected by constructive and destructive interference, as well as the relative orientation of the emitter and receiver.

It would be quite a feat if Sonitor were to deploy such a product at scale. Until it has been deployed in a real-world setting, however, it's probably best to remain cautious about reported results.



## Conclusion

While ultrasonic excels at providing information in spaces with multiple rooms, like hospitals and hotels, it has yet to prove itself in wide-open environments like warehouses. It's worth noting that tracking solutions don't need to be purely ultrasonic—these technologies can be used to complement one another. In fact, [some solutions](#) use ultrasonic for room-level definition to help resolve ambiguities generated by other technologies in end-to-end solutions.

We'll have to wait until we see more actual deployments of ultrasonic tracking—and in more varied environments—before judging how it compares to more mainstream indoor positioning technologies.



# Computer Vision

Computer vision is already a crucial component in several technologies. It supports self-driving cars and drivers through features like lane detection and blind spot detection. In retail, computer vision is used to count customers, find out what interests them, and recommend similar products. In industrial settings, computer vision can be used for product quality assurance at scale. Computer vision can also be used to track assets effectively, by identifying unique objects or people in the frame of a photo or video.

## Three Computer Vision Algorithms

There are several different algorithms that can be used to implement computer vision. The first is used to determine what a picture contains. The picture is divided into many smaller squares, each of which gets assigned probabilities that correspond to the likelihood that the picture is of a certain object. Those probabilities are the result of feeding many, similar images through a machine learning model to “train” the algorithm. These probabilities are then multiplied together to calculate the probabilities of what the whole picture represents. This algorithm is used in a more complex process called Object Detection, in which the algorithm scans over the picture and detects various objects in the picture using a trained implementation of the algorithm described previously.

The second algorithm, called Object Tracking, expands on Object Detection. Object tracking examines videos or a series of pictures using Object detection to identify objects. A tracker then traces those objects' movement through the frames.



Image Credit: [Analytics India Magazine](#)

The third algorithm, Semantic Segmentation, examines the image and assigns each pixel in the image to an object in the picture.

In terms of hardware, computer vision can be less expensive and easier to install than other solutions. In some cases, cameras that were used as a security system can be repurposed to implement asset tracking solutions. In other cases, employees can use phones to take pictures of assets' locations. Installing a camera system for computer vision asset tracking can be comparable to the cost of most other solutions. Cameras prices for hardware and installation are comparable to the costs for other solutions.



## Computer Vision is Bandwidth-Heavy

Computer vision can be very computationally expensive compared to other asset tracking solutions. Of the three algorithms mentioned above, the first—Object Detection—takes the least computational resources and can fit the needs of asset tracking. Even still, the algorithm requires a lot of resources. To identify the object in the image, many subsets of the initial image need to be examined by the machine. Using something easily identifiable to a computer like a QR code or barcode would reduce the amount of resources required.

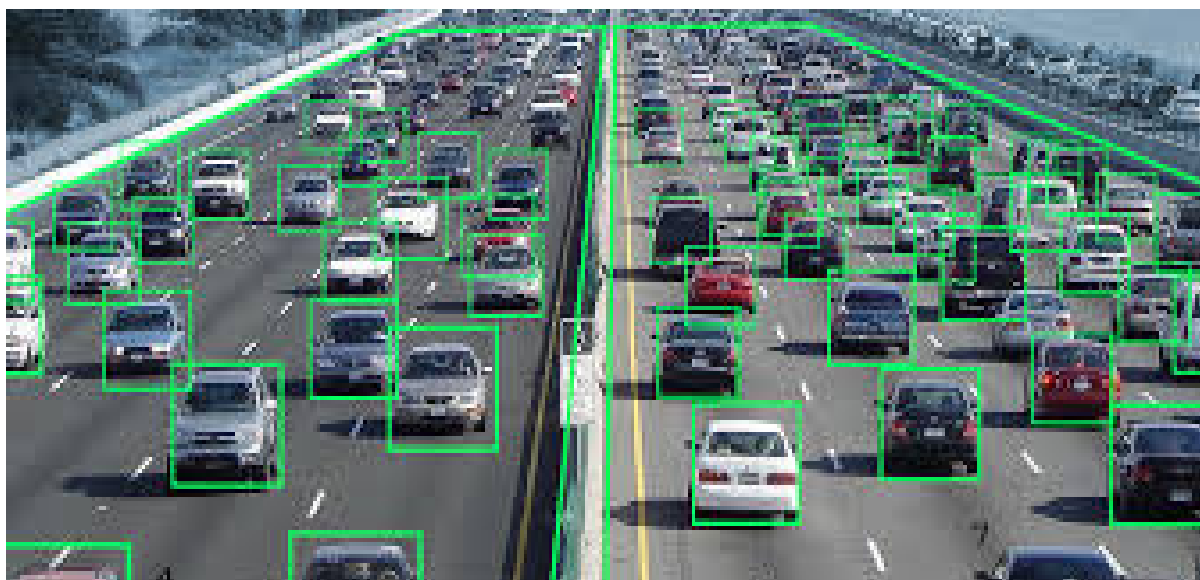


Image Credit: [Applied Computer Vision Lab](#)

A computer vision asset tracking solution would have very high accuracy—limited only by the software implementation—compared to other solutions like Bluetooth or WiFi, which rely on signal strength which has low accuracy. In addition, the image itself is much more useful to a human than a signal strength value because, for example, the same image can be used for multiple interlocking systems.

The main disadvantage of computer vision asset tracking is the huge data throughput. The integer-based signal strength value that a Bluetooth or WiFi solution would use is only a couple bits. A gray scale image uses 8 bits per pixel, so a 200px by 200px image would use 320 kb, which is four orders of magnitude larger. This adds a large problem to the scalability of such a solution. It requires a large amount of bandwidth to upload and download images constantly. Although this may be solved through edge computing, it also requires significant investment in software, as well as the physical and digital infrastructure to support the system.

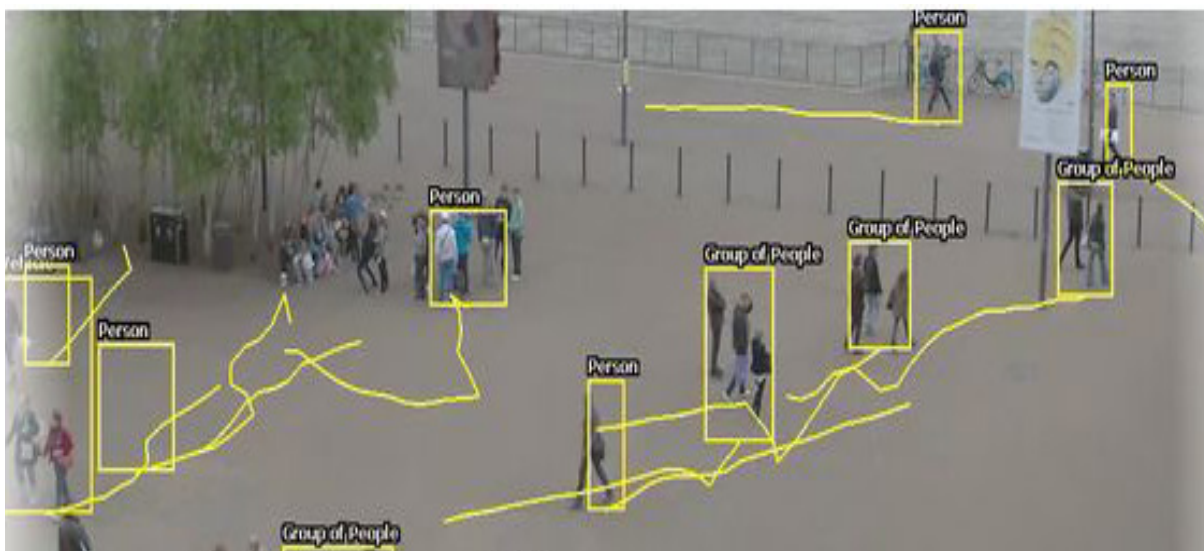


Image Credit: [C-Sharp Corner](#)

## Conclusion

Computer vision can provide asset tracking solutions with high accuracy and reliability. Such solutions would have advantages over other asset tracking technologies like Bluetooth and WiFi. Unfortunately, the sheer amount of data being transferred limits the use cases within which computer vision would be effective or practical.



# **Market & Product Needs**

# Market Research Guidelines

Indoor positioning solutions [can take on many forms](#), depending heavily on the particularities of each use case. You probably have some idea of what you're tracking and why that might be important, but it's even more important to be thorough and exhaustive in conducting preliminary market research before involving an engineering team. In this section, we'll introduce some key considerations that should be well-defined before attempting to build or buy your own solution.

## Understanding Your Use Case

There are two types of questions that help flesh out early stage product development. These questions will help guide user expectations without overpromising. They'll also ensure that product requirements are both reasonable and feasible. Moreover, what people say they want and what they may actually want can vary and change over time.

From a user/customer perspective, what's the unmet need? We recommend using a [human-centered design \(HCD\) approach](#) when conducting early market research and performing user interviews. Although explicit asks like "built-in sensors" or "small form factor" may seem straightforward, the nuance is usually hidden beneath the details.

For example, [Life Alert](#) is an asset tracking product and emergency notification system for the elderly living at home. Accessibility and ease of use are critical design features. By contrast, tracking large containers in a warehouse may instead require frequent reporting of relative location to improve supply chain management.



## Market Research Guidelines

From a technical perspective, within the realm of possibility, what can be built? Although interviewing is a good tool to scope out product requirements, conversations can quickly be derailed by asks that are technologically infeasible or physically impossible. A customer may specify the use of GPS underground, or WiFi/Bluetooth underwater, not realizing that the product simply would not work under those circumstances due to signal attenuation. The uninitiated often get swept away by the marketing buzz around certain tracking technologies without fully understanding how that technology fits into a complex, interlocking landscape of tracking technologies in which each tracking technology has pros and cons and the best solution often arises from unique combinations of several technologies rather than attempting to choose one over all others.



## Key Questions for Refining Use Case Requirements

The purpose of asking questions is to establish a baseline for who is using the product, how the product is being used, and what the product needs to do.

- What kind of assets are being tracked?
- How many floors, level, split-levels, and ramps are there in the tracking location?
- What region (globally) is your application being built for? (There are different radio frequency specifications across the globe. A LoRa product designed for North America won't work in France or Australia.)
- GDPR in the European Union may affect the type of data that can be collected and how it must be managed. How will your solution be affected if at all?
- What is the layout of the space in which assets will be tracked? What kind of accuracy is needed vs. desired?
- Which connectivity technologies and configurations best suit the use case? There are tradeoffs to each indoor tracking technology (e.g. Bluetooth transmits poorly through walls and underwater) and physical limitations to what can be achieved in certain spaces.

## Establishing Criteria for Success

Well-defined success criteria are critical to product management both externally with customers and internally as development progresses. These are often presented as Key Performance Indicators (KPIs)—a set of well-defined terms with associated quantities and units (e.g. device weight in kg) as well as numerical “acceptance criteria” (e.g. must weigh less than 1.5 kg). KPIs should be mutually intelligible by both business development and engineering teams because they provide both the ability to align customer needs with internal metrics for progress and success.

Important KPIs for indoor asset tracking:

- **Position solution time:** Is position “real-time” or post-processed?
- **Position solution accuracy:** Average accuracy is more important since optimal conditions are rare and unrealistic.
- **Position solution error:** What is the expected error with respect to distance? A distribution function can help illustrate this.
- **Battery life:** How long do the batteries last? How often do they need to be recharged? How will they be replaced and maintained?
- **Coverage:** Is coverage needed on the full premises or only in certain spaces (e.g. conference rooms)?
- **UI update lag:** Is there significant time delay between moving in real time and position updates on the UI? How much lag (if any) is acceptable for the use case?







## Defining Return on Investment (ROI)

ROI is typically the first and last factor in determining whether a product is worth developing. Because indoor asset tracking depends on custom hardware and software, the cost of R&D can quickly stack up. Cost factors can range from UI work (web/mobile) to optimizing data flow and battery consumption at the device firmware level.

In addition to R&D costs, there are recurring Operational Expenditures (OpEx) associated with continued customer support and data management in the cloud. These must be properly accounted for. The computational resources required to handle large volumes of data can become fairly expensive at scale.

Ultimately, location data provides tremendous added value in many use cases. It's often worth the cost. This is especially self-evident for living "assets," such as employees or family members or pets, but it's also true of expensive assets like medical devices or vehicles that may easily be misplaced or mismanaged. To estimate the ROI of an indoor tracking solution, five questions must be answered.

## Five Questions for Determining a Solution's ROI

1. What costs will be eliminated by implementing this solution?  
Is indoor asset tracking the best and/or only way to cut those costs? Examples include jobs for menial tasks like inventory management, as well as anticipated inventory loss.
2. What sources of revenue will this solution help generate?
3. Is the tracking data valuable to third parties? Can it be analyzed to improve existing processes?
4. What is the cost of the product?
5. Compared to the cost of the product, how much direct and indirect value is added from its use?

## Conclusion

Market research for indoor asset tracking solutions requires careful consideration of many different and codependent factors to set the foundation for a successful product or service. The results of this research should be formally compiled and used as a reference document for external customer work and internal R&D.

# Product Research Guidelines

After product requirements get passed through user research and business development teams, engineering teams are responsible for assessing feasibility and practicality. They also determine the best approach in order to meet as many success criteria as possible. It's important to acknowledge that the technologies used—from the edge to the cloud—all have trade-offs that affect the cost, accuracy, and responsiveness of a system. In this section, we will take you through the primary considerations in architecting an indoor asset tracking solution.

## Core Technologies

All [indoor positioning solutions](#) rely on one or several core technologies to provide accurate real-time location data. Some examples, which we've discussed previously, include [Bluetooth Low Energy \(BLE\)](#), [Ultrasonic](#), and [RFID](#). Each of these has specific tradeoffs that dictate features such as signal range and penetration, which are important considerations when devising a solution for particular use cases.

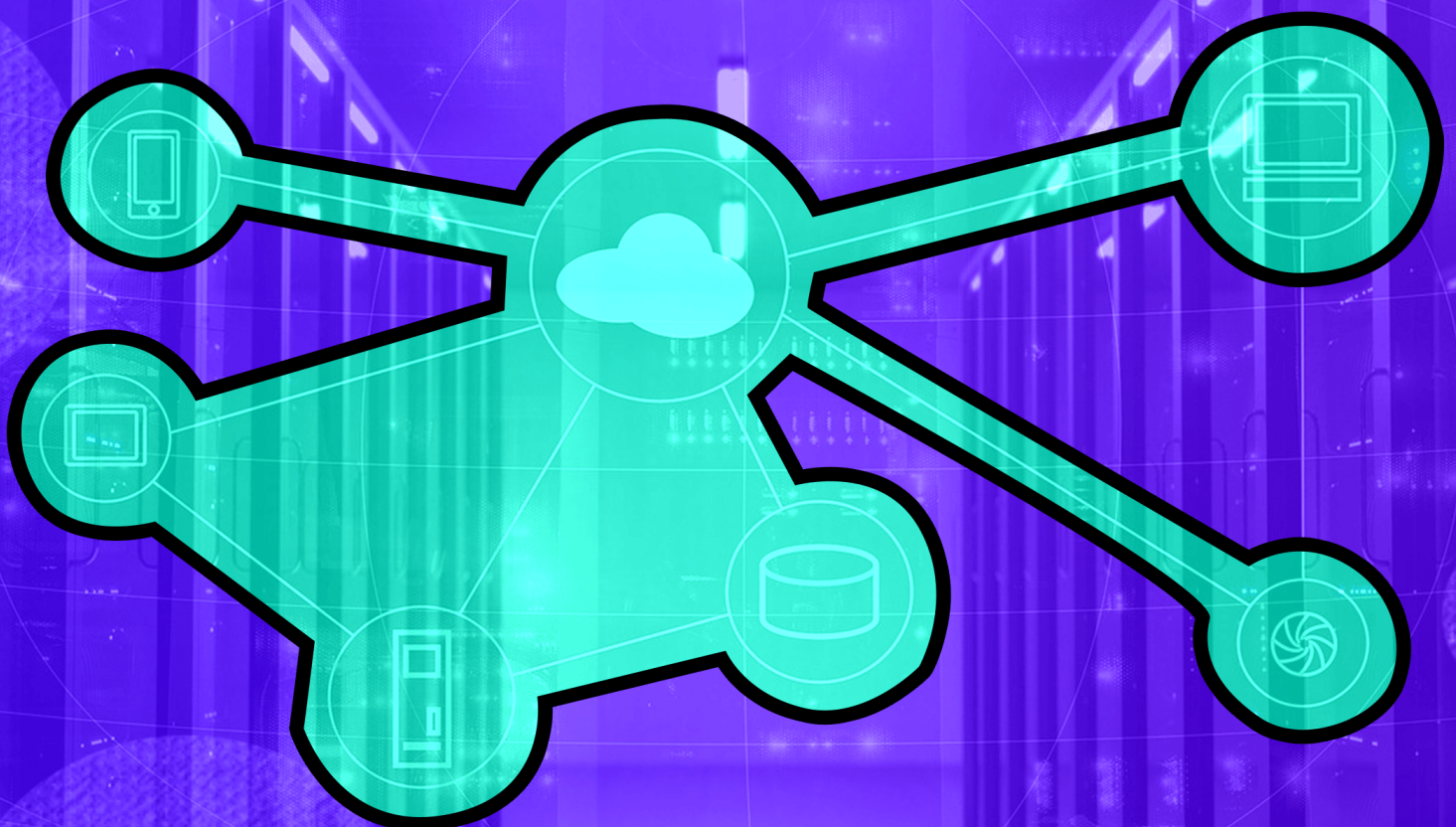
In addition to [the core tracking technologies](#), indoor positioning solutions may be aided by supplementary data from sensors, such as accelerometers, gyroscopes, magnetometers, and environmental sensors. The first three (accelerometers, gyroscopes, and magnetometers) can be used to estimate position through dead reckoning, which may be valuable in scenarios where precise tracking in complex environments is needed. On the other hand, environmental sensors, such as those that monitor temperature, air pressure, and humidity, can be used to determine details such as what floor someone is on, or where in a given space someone might be located

## Transmitting Data

Once you have determined which technologies to use and what data to collect, you need to decide on how you plan to transmit that data to the cloud. Depending on the volume of data being collected, there are two options:

1. When possible, we recommend [edge computing](#) to reduce both latency and cloud usage costs. There are also cases in which edge computing is necessary for a responsive system, such as when analyzing images or video.
2. Directly stream all data to the cloud for analysis.

This is typically achieved through gateway devices that communicate via LoRa or WiFi to the cloud. It's also possible to stream data from each node or sensor device directly to the cloud; however, this may overload the IT infrastructure or fail in crowded environments such as shopping malls.





## Transforming Data

Finally, you need to determine how to translate raw data into meaningful position information. There are three things that must be built to achieve this transformation:

### **1. Measurement Engine**

Raw data tends to be noisy. It requires some degree of processing before it's usable. What filtering and data transformation are needed? A good measurement engine is key to accurate positioning.

### **2. Positioning Engine**

How will you determine location? What level of accuracy is required? How complex is the algorithm, and will it be affected by hardware limitations (e.g. smartphones or gateway devices)?

### **3. User Interface**

What is being tracked, and where is it being tracked? How will location be visualized for the user? What level of interactivity is required?

### **“Gotchas”**

Sometimes, despite all prior considerations, there are things that consistently emerge as pain points in system deployment. Here are some that industry experts see often and work hard to anticipate:

- Map inaccuracies and inconsistencies
- Change detection
- Signal attenuation
- Geo-referencing a large building properly is very hard. Oftentimes, there are image adjustments or distortions designed to represent wide areas from an aerial view, which affects where map features appear to be versus where they actually are.
- Many signals are easily absorbed, blocked, or reflected by obstructions like human bodies or nearby furniture. These variations can cause inconsistencies or inaccuracies in the data.
- Because systems are often tuned up for specific environments and use cases, changes in room configuration or the accidental movement of beacons or other hardware can affect consistency of results.
- Physically crowded environments
- We recommend performing site surveys during off hours to reduce variability in data due to human bodies randomly moving around.
- Changing or incomplete requirements

It's cheaper to do it right the first time. This highlights the importance of good research to understand what the requirements and needs are of the use case.

The “full-stack” for indoor positioning systems spans multiple technical fields—from hardware and firmware engineering, to cloud solutions architecture and data science, to front-end design and development. The considerations discussed here should be used as a guide and a tool when exploring approaches to building an indoor positioning solution.

# 4

## The Future of Indoor Positioning



# The Future of Indoor Positioning

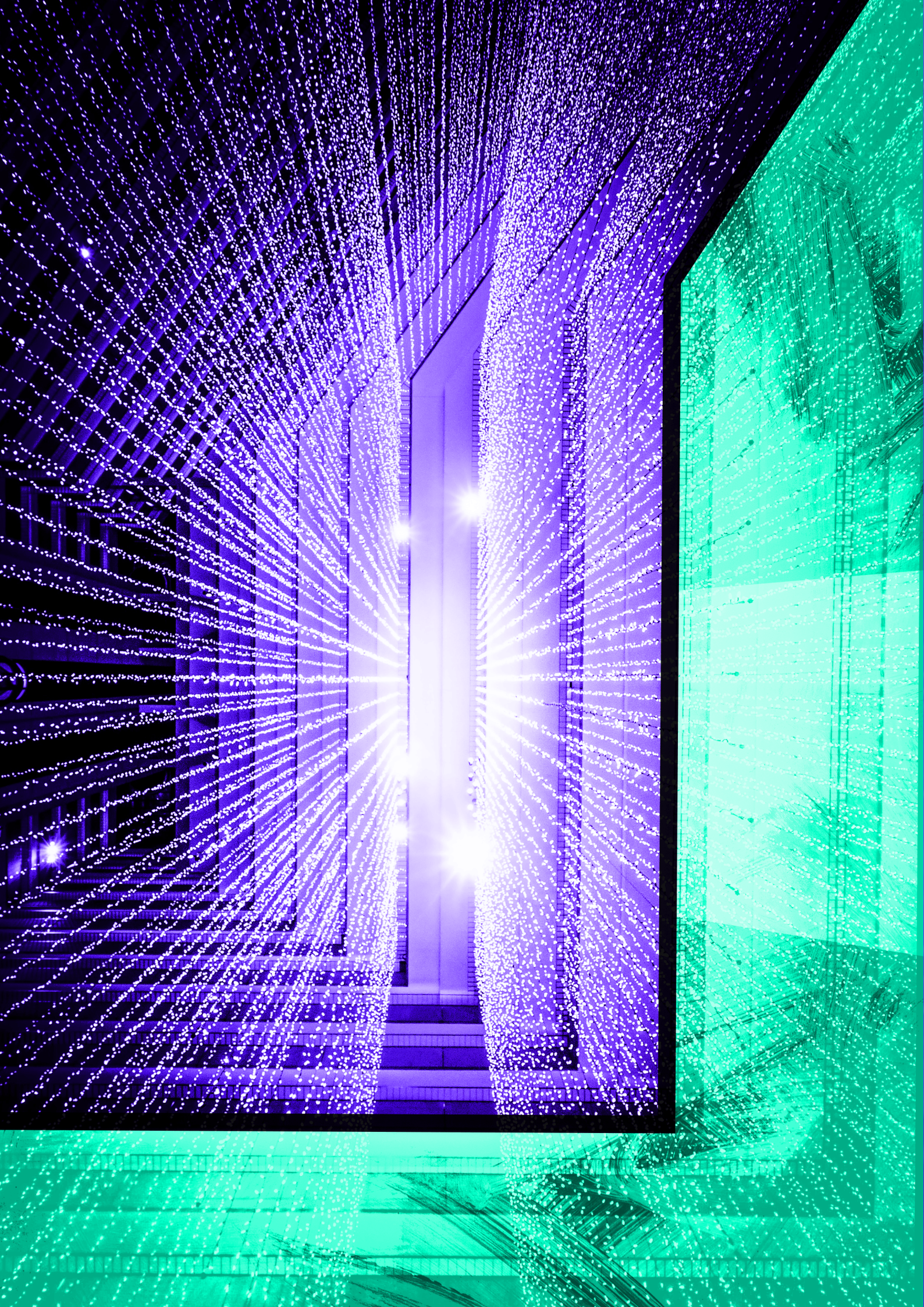
Although modern indoor positioning systems are still relatively young, they're already beginning to add value in a wide range of use cases from managing hospital personnel to tracking product shipments in warehouses. As these systems and technologies continue to evolve, they'll become increasingly integrated into everyday life.

At this point, you should know enough about indoor positioning technologies to understand how and when they can be best used. You've also been equipped with the ability to assess potential use cases from both a business development and an engineering perspective. We hope that this eBook has prepared you to start taking advantage of indoor positioning systems.

At Leverage, we see IoT and related technologies as the building blocks of the future. We live and breathe IoT every day. We also strive to make these technologies more accessible to everyone by sharing the knowledge we've gained through our decades of experience. Our goal is to empower all businesses and people to unlock new value within and beyond their organization.

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