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Qorvo Special Edition

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Ultra-Wideband

Qorvo Special Edition

by Mickael Viot, Jervais Seegars, Kenneth Dwyer, Ciaran Connell, David Pittenger, David Schnaufer, Alexis Bizalion, and Alexis Mariani

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Introduction

Imagine your smart TV automatically switching from your kid's Netflix profile to yours the minute you enter the living room. Or your laptop waking up to greet you when you enter your home office. Or your car automatically unlocking its doors as you walk toward it, and then locking them again as you walk away. All of that and more is coming in the near future, thanks to ultra-wideband (UWB).

UWB is a radio technology used to measure distance and location with unprecedented accuracy — within a few centimeters — by calculating the time it takes radio signals to travel between devices. The applications are almost limitless.

Today's new smartphones have UWB that provides connectivity, when combined with Internet of Things (IoT) technology, and offers a multitude of new secure services for businesses and consumers. Currently, it's being used for spatial awareness and things like AirDrop on the iPhone, securely transmitting data like pictures between phones near each other.

Foolish Assumptions

When we were writing this book, we made a few assumptions about you, the reader:

- Mainly, we assume that you're a stakeholder in the wireless telecommunications industry with more than a passing interest in the IoT or UWB technology. Most likely, you're an engineer, a technician, a technology leader, a salesperson, a marketing person, or an investor.
- I also assume you have some knowledge in mobile communications or industrial or consumer electronics. This is exactly the type of person this book has been written for.

If any of these assumptions describes you, this book is for you! If none of these assumptions describes you, keep reading anyway. It's a good book and when you finish reading it, you'll know enough about UWB technology — where it came from, where it's going, how it works, and where it's used — to be dangerous!

Icons Used in This Book

Throughout this book, we occasionally use icons to call attention to important information. Here's what you can expect.

TIP

When we give you some information that'll save you time or money or just make your life (at least as related to UWB) easier, we mark it with this icon.

REMEMBER

This icon points out the key takeaways that you'll want to file away in your mind for later recall.

TECHNICAL STUFF

Anything marked with this icon is fairly technical, like a list of standards or an explanation of the inner workings of something.

Beyond the Book

Although this book is full of good information, we could only cover so much in 48 pages! So, if you find yourself wanting more after reading this book, just go to `www.qorvo.com/design-hub` or `www.qorvo.com/go/uwb` where you can get more information about UWB and how Qorvo is helping make it happen.

IN THIS CHAPTER

- Surveying the history and evolution of location technology
- Realizing the value of location data
- Understanding the need for a new location technology
- Identifying the benefits of UWB
- Comparing UWB to other standards

Chapter 1
Exploring Ultra-Wideband Technology

This chapter explains how location technology in general started out and how new developments continue to revolutionize our world today. You find the basic facts about UWB and its benefits, as well as the kinds of industries and devices that are poised to take advantage of it.

How Location Technology Is Changing the World

Believe it or not, location information wasn't readily available to the public as recently as 20 years ago! Location navigation from the Global Positioning System (GPS) began to be used by the public in May 2000 for purposes like finding the nearest ATM or gas station. Prior to the year 2000, people used traditional ways to navigate through the world, like reading printed maps, asking for directions, or simply getting lost until they found their way.

Ten years ago, indoor navigation came onto the scene, too. Think Google Maps for malls, airports, and other large buildings. Location data became even more valuable thanks to new location-based services that helped people find stores and enabled targeted marketing.

Today it's hard to imagine life without being able to easily navigate anywhere in the world — both indoors and outdoors. Just think how difficult it would've been for major e-commerce companies to efficiently deliver goods without GPS technology. Would Amazon have been able to grow into a trillion-dollar company without GPS technology? And that's just one industry.

REMEMBER

Today we're witnessing the rise of a new generation of location technology: micro-location-based systems. These systems are able to pinpoint locations more accurately than ever before. Why this evolution? Because people and businesses want more reliable and accurate ways to find almost anything — their keys, the remote control, or the exact location of their favorite gluten-free bread on aisle 9 at the local grocery store. Both business-to-business (B2B) and consumer retail industries already understand the added value that a more reliable and accurate indoor location system can bring. For example, it can help consumers navigate indoor venues, add more intelligent automation in homes and commercial buildings, and drive operational efficiencies for businesses by giving them real-time insights into operations, assets, and employees.

The Value of Determining "Where"

Existing embedded technologies already enable devices to determine *what* and *when* and report that information to their users. Sensors tell us *what* is happening, accurate system clocks tell us *when*, and the information is communicated from one device to another using wireless radio frequency (RF) connections.

TIP

Adding the *where* dimension into a device's capabilities is like giving it a sixth sense. Location information can provide startling new insights and enable developers to create context-aware products and services that weren't previously possible.

REMEMBER

Here are potential benefits of being able to sense "where":

- **Efficiency:** In factories and warehouses, knowing where assets are located in real time can improve their utilization rate, reduce the time it takes to find them, and open the door to a new level of "just-in-time" efficiency.
- **Safety:** Knowing the location of people, automatic guided vehicles, and robots in real time would help prevent accidents by controlling their interactions and by keeping people away from unsafe areas.
- **Decision support:** Real-time knowledge of a person's or object's location also enables contextual decision making, such as automatically adjusting your stereo as you move between rooms or allowing you to control objects by simply pointing at them.
- **Security:** Knowing where people and assets are in real time can also provide new levels of security. If someone's presence can't be faked, their location can be used as a security credential. That information can be used to restrict access to specific areas and protect physical assets, data, and communications.

As you can see in Figure 1-1, knowing the *where* opens many application opportunities, in healthcare, security, smart homes, fitness, smart cities, automotive, industrial, and more. The use cases will only grow as more applications help spark new innovative ideas enabled by the real-time *where* of UWB technology.

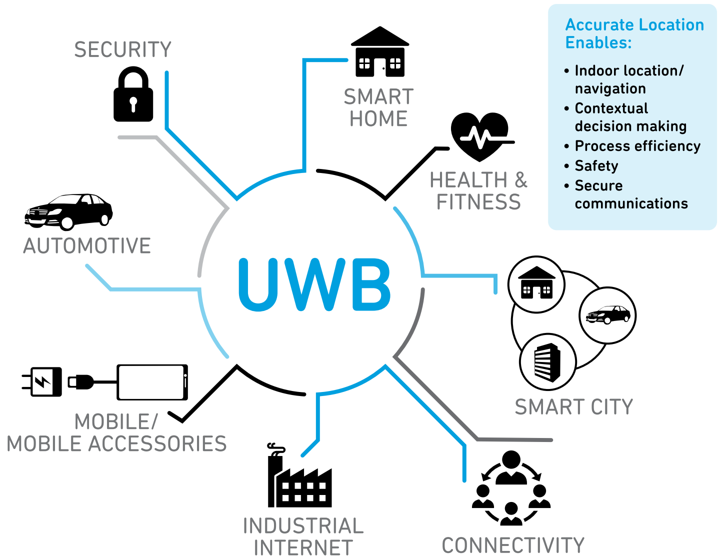


FIGURE 1-1: Sensing the *where* of objects and people.

Why We Need a New Real-Time Location Technology

In order for location services to live up to their potential, we need a technology that's in line with the needs of the applications and their environments. Increased accuracy is an obvious need: Locating and navigating objects and people requires an accuracy in the centimeter range, whereas traditional location technologies like GPS measure their accuracy in meters.

But accuracy alone isn't enough. The technology must also:

- Offer great reliability, even in harsh environments
- Be scalable enough to address the thousands of people and assets in large venues
- Consume very little power
- Be affordable
- Be embeddable in anything from high-end complex devices like smartphones to low-end simple devices like asset tags
- Operate in real time, because location is about movement

REMEMBER

Bluetooth Low Energy (BLE) and Wi-Fi are great technologies that are already used for location-based systems. However, they weren't designed for *real-time* micro-location services. For example, BLE is a good technology for applications that involve low-power data communications. However, despite all the efforts of the engineering community, BLE and Wi-Fi fall short on delivering what's needed to build accurate, reliable, real-time location service. For example, BLE accuracy is in the meters and its reliability is highly dependent on its environment.

But, because of their popularity over the years, Wi-Fi and BLE technologies are the first that come to mind. They've also been deployed in beacons and access points for the past few years.

TIP

Beacons are small wireless transmitters that use Bluetooth technology to send signals to other smart devices nearby, connecting and transmitting information to make location-based searching and interaction easier and more accurate.

However, their value for location-based applications is limited by the fact that they require a great deal of processing and measurement to obtain even one good location point. Using these technologies takes time — not real-time — and it also increases power consumption.

Because of all these factors, the time is right — and the markets are ready — for UWB, a technology standard developed specifically to address the needs of real-time location applications.

Introducing Ultra-Wideband

UWB is an IEEE 802.15.4a/z standard technology optimized for secure micro-location-based applications. It's the ideal technology to deliver on all the requirements outlined in the preceding section. Like GPS, UWB has the potential to have a major global impact by significantly increasing the value of location information.

As shown in Figure 1-2, UWB is

- **Extremely accurate:** UWB can pinpoint people and things within a few centimeters. This makes it 100 times more accurate than Wi-Fi and BLE. Accuracy is very important when tracking/locating small objects or if your application requires you to know whether something is on one side of a wall or the other.

- **Reliable:** UWB has high immunity to both multipath and interference. Indoor location measuring is extremely challenging for RF systems, due to reflections and other interferences.
- **Low-latency:** UWB is 50 times faster than GPS, with updates up to 1,000 times per second. That's 3,000 times faster than a BLE standard beacon! Low latency makes UWB ideal for fast-moving object applications like drones, and it opens the door for many cool use cases.
- **Affordable and low power:** UWB is affordable and low power compared to other mainstream electronic technologies. Many UWB devices use coin-size batteries to operate, making them both convenient and affordable.
- **Single-point oriented:** UWB requires single measurements to determine your position accurately and reliably, whereas other RF technologies require multiple samples plus filtering to get to a location result.
- **Secure:** UWB leverages distance-bounding communication techniques defined by the IEEE to provide a level of security that makes it extremely difficult to hack.

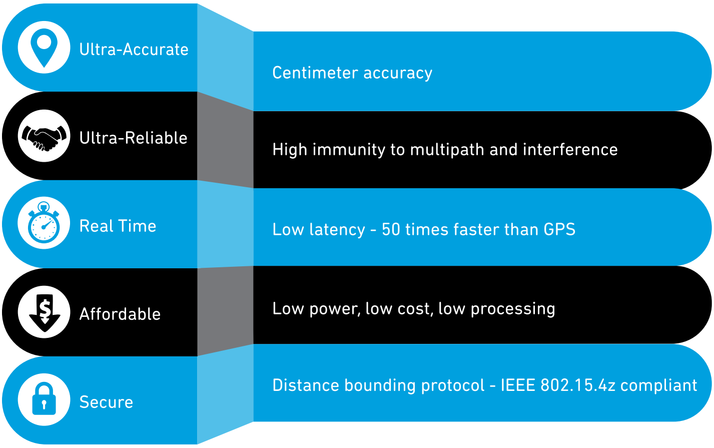


FIGURE 1-2: Features of ultra-wideband.

Comparing UWB to Other Standards

When designing indoor location systems, there are many things to consider. You need to choose the location technology that best meets the needs of each application. As shown in Table 1-1, the technologies available differ in range, accuracy, reliability, and other aspects.

TABLE 1-1 In-Door Location-Based Technologies

	Ultra-wideband (UWB)	Bluetooth	Wi-Fi	Radio-frequency identification (RFID)
Accuracy	5 to 10 centimeters	1 to 5 meters	5 to 15 meters	15 centimeters to 1 meter
Reliability	Strong immunity to multi-path and interference	Very sensitive to multi-path, obstructions, and interference	Very sensitive to multi-path, obstructions, and interference	Strong immunity to multi-path and interference
Range/ coverage	Typically 50 to 70 meters	Typically 10 to 20 meters	Typically 40 to 50 meters	Typically 1 meter
Data communications	Up to 27 Mbps	Up to 2 Mbps	Up to 1 Gbps	N/A
Secure ranging	Very secure	Can be spoofed using relay attack	Can be spoofed using relay attack	Can be spoofed using relay attack
Location service latency	Typically less than 1 millisecond	Typically more than 3 seconds	Typically more than 3 seconds	Typically 1 second
Scalability	More than tens of thousands of tags or unlimited based on solution	Hundreds to a thousand tags	Hundreds to a thousand tags	Unlimited tags
Infrastructure cost	$	$	$$$	$$$

The following sections review some of the differences between these technologies in greater detail.

Range and cost of infrastructure

These two parameters are linked because the operating range dictates the number of infrastructure devices needed to deploy a real-time location system in an area like a building. Greater range means fewer devices, and fewer devices means lower cost.

For example, UWB's RF range is 50 to 70 meters, whereas Bluetooth's range is only 10 to 20 meters for location applications and Wi-Fi is 40 to 50 meters. Also, the accuracy of Wi-Fi and Bluetooth drops rapidly as the devices get farther away from the infrastructure, whereas UWB's accuracy is constant whatever the distance.

Both overall range and accuracy influence the ultimate practical range between each anchor. So, as shown in Figure 1-3, covering a similar area using UWB (left) versus Bluetooth (right) and Wi-Fi (bottom right), fewer wireless anchors are required when using UWB. This drastically reduces infrastructure, deployment, and maintenance costs.

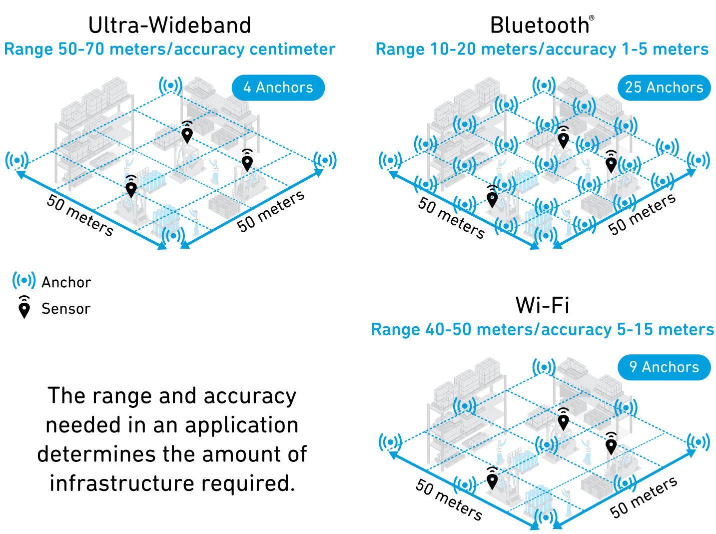


FIGURE 1-3: Comparing the UWB, Wi-Fi, and Bluetooth anchors required for a typical factory floor.

Data communication speed

An indoor location system must also be able to collect data from sensors embedded in the devices simultaneously. You wouldn't want to use multiple technologies, because that would make the system overly complex and expensive. UWB, in addition to its location capability, offers a data communication pipe of up to 27 Mbps, making it ideal for fast and power-efficient collection of sensor data. Additionally, engineers are working with standards bodies to further increase data rates well above 27 Mbps.

Scalability

An important factor when considering large-scale deployments is the number of devices (that is, sensors and actuators) that can operate simultaneously in a venue. As an example, factories usually need to locate thousands of assets simultaneously to be able to build automated systems. Thanks to their very short data packets, UWB systems can handle thousands of devices, whereas Wi-Fi and Bluetooth struggle beyond a few hundred.

Latency

Whether you want to build a real-time location system for a warehouse or you want to build a hands-free access control system, one of the key parameters is going to be your *system latency* — in other words, the delay between location reports — because the devices you're locating are most likely moving. Thanks to its very short data packets and accurate and reliable location measurements, UWB enables latencies of less than 1 millisecond. This allows "true" real-time location detection, whereas other technologies take seconds before they can acquire and compute the location information needed by your application.

Picturing Ultra-Wideband in Action

You may not know it, but UWB is already being implemented in more than 40 different industries, including the following applications shown in Figure 1-4:

- **Consumer applications** include connected home, retail, robots, TV/set-top boxes, artificial reality (AR)/virtual reality (VR), sports, and drones.

- **Automotive applications** include smart car secure passive entry and passive start.
- **Industrial applications** include building control, healthcare, agriculture, safety, security, factory automation, robotics, and mining.

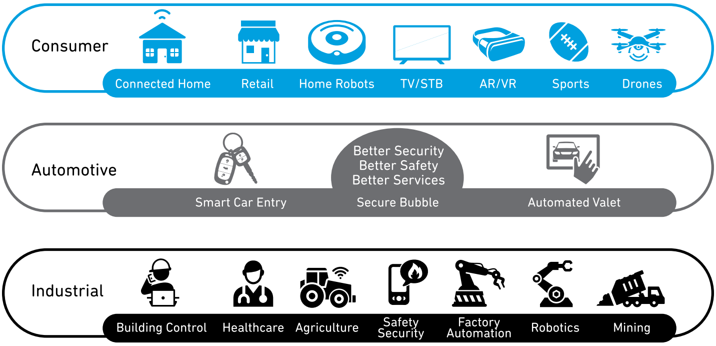


FIGURE 1-4: UWB is deployed in more than 40 markets.

In situations like Industry 4.0 for manufacturing, industry logistics, around the home, and in our automobiles, UWB enables full visibility of object and people positioning, thus driving operational efficiencies, safety, security, and asset tracking.

Here are a few interesting and useful applications of UWB:

- **Home security/connected home:** Current alarm systems require user interaction to activate and deactivate the system. With UWB, the user experience can be seamless. You no longer need to use your key to unlock your home doors or use a touchpad to disarm your security system. When you have your smartphone in your pocket, the system simply *knows* when you're approaching or leaving your home. Other applications include smart remote controls and smartphones that know which object you want to control by simply pointing at it, using the location and orientation of the remote control to enable the correct function.
- **Industry 4.0:** UWB improves operational efficiencies, safety, security, and asset tracking by providing accurate and reliable location information for objects and people.

Sites can leverage UWB technology to enhance safety by warning workers when they approach hazardous areas. If there's an emergency, UWB can track whether all workers have been safely evacuated.

UWB is also applied in "digital twin" manufacturing applications that use a near-real-time digital image of a physical object or process to optimize business performance. (A *digital twin* is a virtual representation of a real-world product or asset. It's being used to manage performance, effectiveness, and quality of a manufacturer's fixed assets like manufacturing machines, lines, and plants.) UWB tags track forklifts and tools to provide a real-time view of the work in progress, helping to increase workflow efficiency and eradicate bottlenecks.

- **Automotive:** Key fobs that use UWB technology provide secure communication and distance measurement to deter car theft. UWB is a proven technology that prevents relay attacks because UWB uses time of flight (TOF) combined with other security measures as per the IEEE 802.15.4z standard.
- **Robotics:** UWB enables very accurate robot navigation systems. For example, you can have a lawnmower that autonomously cuts the grass efficiently, accurately, and safely. Or you can have an automated guided vehicle (AGV) deliver spare parts to a specific workstation on an assembly line. A personal transport robot can even follow you carrying whatever heavy parts or equipment you need to move.
- **Sports:** Because UWB has centimeter accuracy and low latency, it's ideal to use for sport analytics. You can track stats of athletes who are moving very quickly and not worry about measurement inaccuracies. UWB is already used in many professional sports, helping teams prevent injuries and improve their athletes' performance.
- **Enterprise:** UWB enables reliable social-distancing solutions to deliver workers on-site safely. With its accuracy and reliability and the fact that it's real time, UWB is the perfect technology for enterprise applications.

  UWB is also used to implement hands-free access control so employees no longer need to swipe their badges. This not only brings convenience, but also adds security in environments like hospitals.

TECHNICAL STUFF

How is UWB able to achieve all this? Simple — it's physics! UWB outperforms other location technologies like Wi-Fi and Bluetooth because it transmits over a very wide bandwidth (more than 500 MHz) and uses ToF instead of narrowband communications and received signal strength indicator (RSSI). We cover all of this in more detail in Chapter 2.

IN THIS CHAPTER

» Contrasting UWB and narrowband location tracking methods

» Looking at UWB system considerations

» Reviewing and selecting UWB topologies

Chapter 2 Taking a Look under the UWB Hood

Spoiler alert: Ultra-wideband (UWB) is the best location tracking technology, and you should use it. The end. Thanks for reading our book.

Just kidding, of course. It's one thing for us to say that UWB is the best, most advanced location-based technology today, but where's the proof? To answer that question, we need to get down to the nitty-gritty.

This chapter delves into the inner workings of UWB technology and outlines the differences between UWB and narrowband location methods. It also explains how to choose the best system architecture for different applications or use-case scenarios.

Comparing UWB and Narrowband

Several technologies are appropriate for use in indoor and outdoor positioning applications, but UWB is the most accurate, reliable, and cost effective; it's generally more scalable, too. Comparing UWB's technology with that of the most popular narrowband methods makes this clear, and that's what we do in this section.

It's all about the bandwidth

From the beginning, impulse radio UWB was designed to enable highly accurate ranging estimates while concurrently performing two-way communication. This enables it to collect sensor data and to control actuators.

TECHNICAL STUFF

Impulse radio is a form of UWB signaling, that has properties making it ideal for location and communication services in dense multipath environments.

In addition to its location capabilities, Qorvo's UWB technology is based on the IEEE 802.15.4a standard and the recently released IEEE 802.15.4z standard. Therefore, in addition to centimeter-level ranging accuracy, developers have emphasized making the technology robust and immune to various forms of interference, assuring a high level of reliability. The standard was also designed with low power and low cost in mind, as well as the ability to support large numbers of connected devices. The engineers who created the standard had a vision: to make every connected object "location aware."

TECHNICAL STUFF

The Federal Communications Commission (FCC) defines the UWB radio frequency range as being from 3.1 GHz to 10.6 GHz with the minimum signal bandwidth of 500 MHz (see Figure 2-1). Unlike other radio technologies, UWB doesn't use amplitude or frequency modulation to encode the information that its signals carry. Instead, UWB uses short sequences of very narrow pulses using binary phase-shift keying (BPSK) and/or burst position modulation (BPM) to encode data. The use of narrow pulses results in a transmission exhibiting wide bandwidth, which results in improved range, reduced sensitivity to narrowband interference, and the ability to operate in the presence of multi-path reflections.

The limitations of RSSI

In many of today's applications, location tracking is done using received signal strength indicator (RSSI). In RSSI applications, the radio signal's strength varies according to the inverse square of the distance from the transmitter in free space, as shown in Figure 2-2. As the signal moves away from the source, the signal strength decreases in intensity.

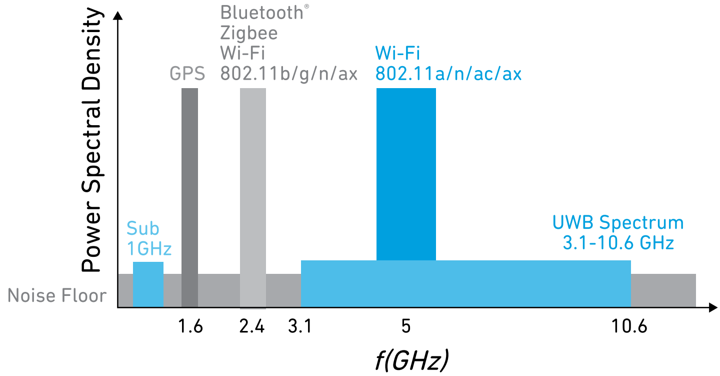


FIGURE 2-1: The UWB frequency spectrum.

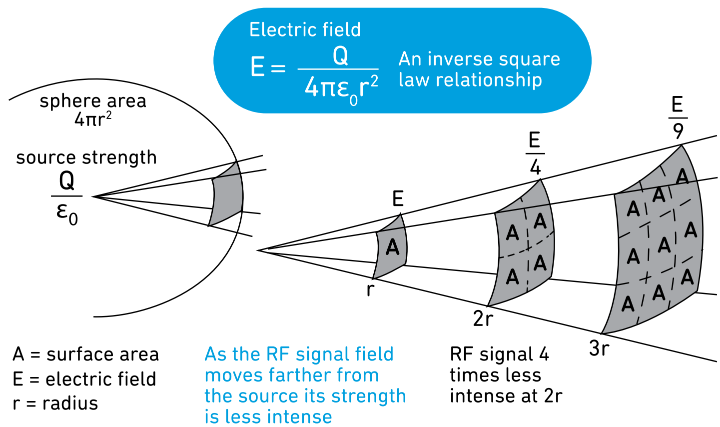


FIGURE 2-2: Electric field of signal source point.

RSSI is used with both Wi-Fi and Bluetooth 802.11 standards. It can yield a predictable indication of the distance between the devices when combined with a known transmit power from the originating device. However, there are drawbacks in these types of measurements, as we discuss next.

Location tracking using Bluetooth

Bluetooth location tracking, such as Bluetooth Low Energy (BLE) found in beacons, works well in some scenarios. Beacons are mainly used for proximity detection. They detect when a device (such as a phone) is in range and estimate range by distinguishing weak or strong signal strength (RSSI).

The problem with such an approach is that signal strength is a poor indicator of distance. If signal strength is low, does that mean the phone is far from the beacon or that there is a huge pillar between the beacon and the phone? As shown in Figure 2-3, each beacon can have good or poor line-of-sight (LOS) to the receiving phone; each obstacle alters the overall accuracy measurement of distance.

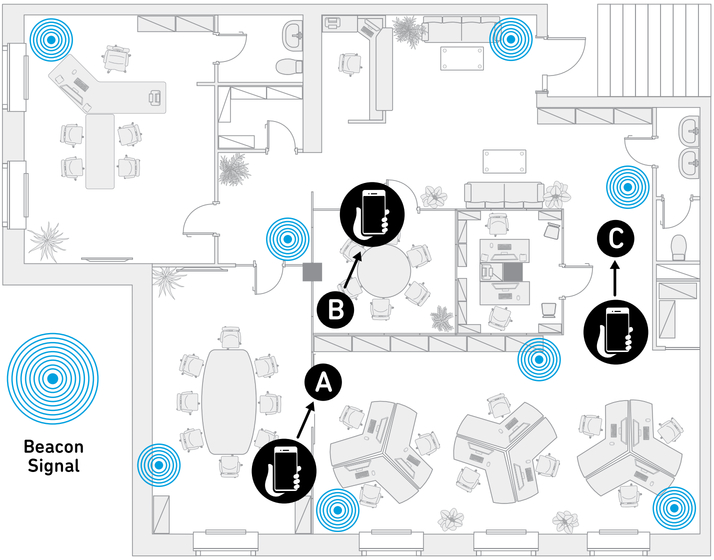


FIGURE 2-3: Beacon signal application showing beacon and mobile device.

Device A receives a very strong signal from the beacon on the ceiling in the conference room, but the wall significantly attenuates the signal coming from the beacon in the nearby corner outside of the room, which is at roughly the same distance. Device B is not in LOS of any beacon, so all signals are significantly attenuated, whereas device C is in LOS of several beacons in the open cubicle space. So, the signal strength is stronger because it's less attenuated.

One workaround solution to this problem uses an approach called *fingerprinting.* Beacons installed in fixed locations a few meters apart measure the strength of the signals from other beacons at known locations. These sets of signal strengths are saved in a fingerprint database. Then the beacon can determine the distance and location of a device by comparing its signal strength to the fingerprint database. The closest match is used to provide a location measurement.

Fingerprinting has many variations that use algorithms with a wide range of sophistication. It's important to remember that these systems are just a workaround. They don't truly solve the distance-measuring problem with the accuracy of a technology like UWB.

Location tracking using Wi-Fi

Wi-Fi is the most common radio signal used for indoor location positioning. It's still the most widely used indoor-location technology, and it's often used in conjunction with BLE. Wi-Fi's main advantage is that it's available in most public or private places.

Estimating distance using Wi-Fi signal strength, however, suffers from the same challenges as described for Bluetooth. Some companies have developed alternative algorithms, attempting to measure distance more precisely using the time of flight (ToF) or time of arrival (ToA) of Wi-Fi signals, but this can't be done in a straightforward manner using standard Wi-Fi hardware.

TECHNICAL STUFF

ToF is a method for measuring the distance between two radio transceivers by multiplying the ToF of the signal by the speed of light. ToA is the time instant when a radio signal coming from a transmitter reaches a remote receiver.

It's possible to increase RSSI fingerprint accuracy to some extent by adding more beacons to the network. Although this may improve accuracy a bit, it doesn't increase the overall reliability of the measurement. Plus, if there are any changes to the floor plan, the fingerprint database needs to be updated as well, which can become costly and time consuming.

Why UWB is best for indoor location tracking

REMEMBER

UWB's inherent characteristics mean that it can provide much more accurate indoor location and distance measurements than other technologies.

As shown in Figure 2-4, the UWB pulse (center and right images) is only 2 nanoseconds (ns) wide, making it highly immune to reflected signal (multipath) interference and noise. The UWB radio-frequency (RF) pulse also has clean edges, allowing precise determination of arrival time and distance in the presence of signal reflections and multi-path effects, which are commonly found in everyday environments.

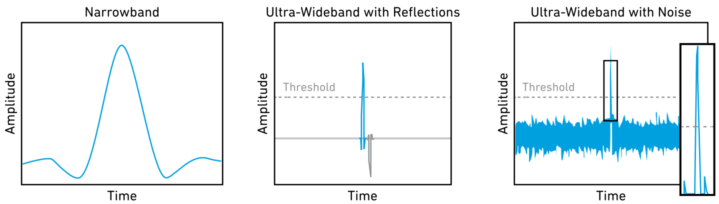


FIGURE 2-4: Comparing narrowband signal, impulse radio with direct (blue) and reflected signal (red).

Looking at UWB as a solution, the reflected signal (gray) does not affect the direct signal (blue). The IR-UWB signal (center and right) has much faster rise and fall times (edges) than standard narrowband signals (left), making it possible to precisely measure the time of arrival of the signal. This also helps UWB signals maintain their integrity and structure in the presence of noise and multi-path effects.

Even under noisy conditions, as shown in Figure 2-4 (right), the time that this 2ns-wide impulse radio–UWB pulse arrives is barely affected. In contrast, as shown in Figure 2-5, the narrowband noise significantly affects the signal.

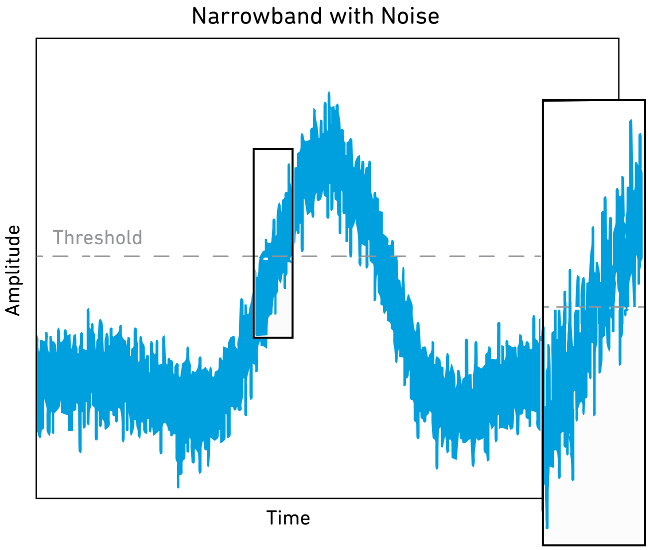


FIGURE 2-5: How noise affects a narrowband signal.

The ToF-based approach has also been tried with narrowband radio technologies. As shown in Figure 2-6, a narrowband signal is very sensitive to multi-path, because the reflected signal (dark gray) combines destructively with the direct signal (light gray) to produce the resulting signal (blue) at the receiver. This impacts the time when the signal crosses the threshold used to measure the ToA, resulting in poor accuracy.

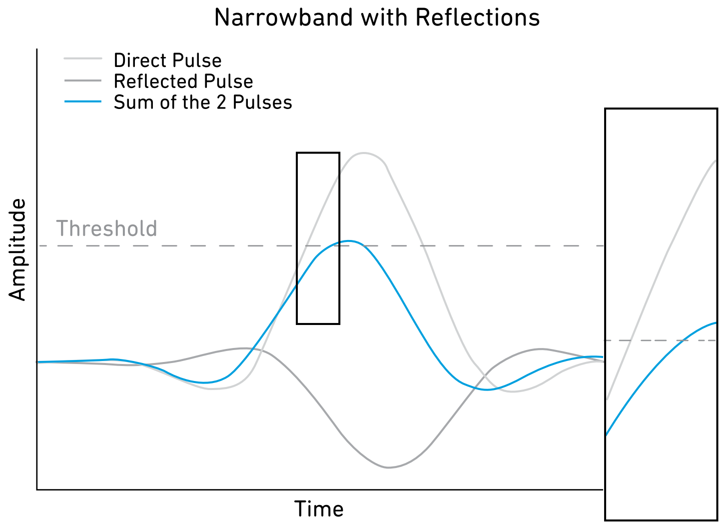


FIGURE 2-6: Narrowband signal with reflections.

The accuracy advantages of UWB are clear. UWB is very capable of measuring distance and location with a precision of 5 to 10 centimeters. In contrast, Bluetooth, Wi-Fi, and other narrowband radio standards only provide accuracy within meters. Moreover, because UWB radio pulses are extremely short, multi-path effects typically won't overlap with the true signal and, therefore, don't damage its integrity and strength.

REMEMBER

The takeaway here is that UWB is

- **Ultra-accurate,** offering centimeter accuracy, 100 times better than BLE and Wi-Fi

- **Ultra-reliable,** maintaining signal integrity in the presence of multi-path reflections
- **Real-time,** with a latency that is 50 times lower than the Global Positioning System (GPS) and 3,000 times lower than that of standard beacons

Reviewing UWB's System Considerations

In this section, we take a quick look at the system components for UWB and how hardware and software choices impact the system's performance.

Anchors and tags

REMEMBER

To understand UWB systems, you need to know the terms *anchor* and *tag.* An *anchor* is generally a fixed UWB device. A *tag* generally refers to a mobile UWB device. An anchor and tag exchange information to establish the distance between them. The exact location of a tag can be determined by communication with multiple anchors.

Some devices can act either as an anchor or as a tag. For example, when two mobile phones use UWB to calculate the distance between them, they may switch roles during the process, alternately acting as tag and anchor.

Memory and processing

A typical UWB device requires some level of processing power and certain capabilities. For a simple tag, a processor is required with a small amount of *flash memory* (programmable nonvolatile memory) and data memory (volatile random-access memory, or RAM). For an anchor application, such as those used in time difference of arrival (TDoA), a processor with more flash memory and RAM may be needed, as well as a backhaul medium in many cases.

Figure 2-7 depicts a common architecture for a tag (with motion sensing) or anchor (with backhaul interface such as Ethernet or Wi-Fi). In the case of anchors, different classes of processors may be required, depending on the scale of the system and workload/throughput requirements.

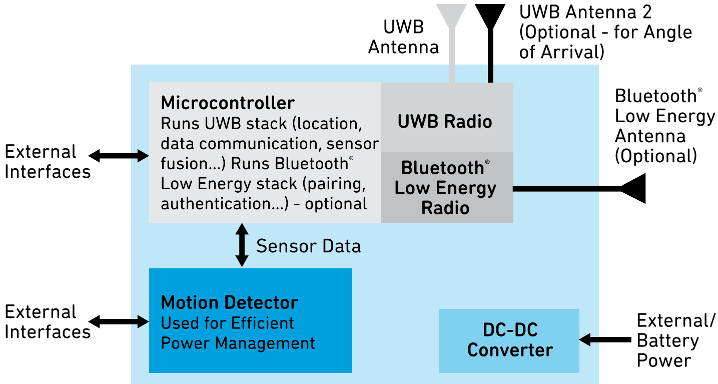


FIGURE 2-7: A typical UWB architecture for anchor and tag.

Antenna

Another system consideration is the antenna. Again, depending on application, different antennas may be required. For example, in the case of a tag, a small omnidirectional antenna is typical. In the case of an anchor, a directional antenna may be useful, depending on the topology.

Software stack

An important interconnect between the UWB radio and the application is the UWB software stack, shown in Figure 2-8. The software stack helps orchestrate interoperability and coexistence with external devices. Moreover, software provides the communication between the UWB radio and the internal microcontroller. For example, software helps coordinate communications when controlling the link between a smartphone and an automobile.

The software can also manage multiple applications and use cases at the same time. For example, a solution may be part of a smart home ecosystem that can control loudspeakers, lighting, heating systems, and so on. It might communicate to all UWB tags and UWB-enabled devices, while at the same time using the location information to control the environment, lock and unlock doors, enable and disable alarm systems, and so on. The UWB software stack can handle all these different use cases simultaneously.

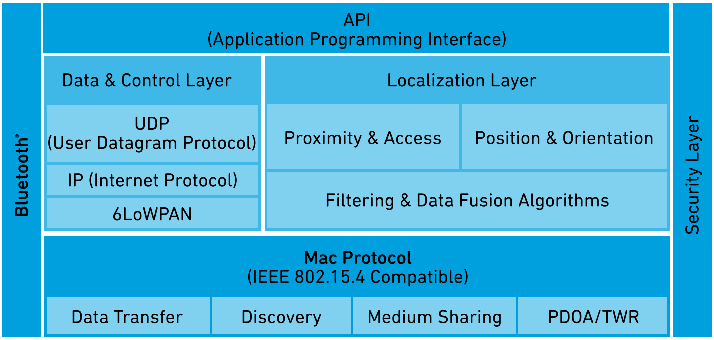


FIGURE 2-8: Qorvo's example of a UWB software stack.

Using the UWB software stack ensures that the UWB radio will meet the needs of many different applications. Plus, tapping into the many functions of the software makes things easier for end users and overall system design.

PRIORITIZING FUNCTIONS

TIP

Some use cases require prioritizing one function over another. For example, let's assume there is a use case where power management and battery life are more important than location update rate or data throughput. In this case, the software can be used to optimize power consumption, setting it to turn off the device when not in use and turn on the device when communication is required.

Another case is when the sensor LOS signal is not optimal or appears to be coming from different directions. In this case, software can be employed to average the results to achieve an accurate distance; it can also smooth those signals that are noisier than others. For even more accurate results (especially in fast-moving applications) or to add information about the orientation of the device, the software can also combine the data coming from the UWB chipset with the data from an inertial measurement unit (which may include an accelerometer, gyroscope, and magnetometer).

Comparing and Selecting UWB Topologies

UWB leverages ToF, which is a method for measuring the distance between two radio transceivers by multiplying the ToF of the signal by the speed of light. From this basic principle, UWB-based localization can be implemented in different ways based on the target application's needs.

The best topology is mostly determined by the application. This means the first step for a design engineer is to align application and topology. The individual methods to choose from are:

- **Two-way ranging (TWR):** As shown in Figure 2-9, the TWR method calculates the distance between a tag and an anchor by determining the ToF of a UWB RF signal and then multiplying the time by the speed of light. A keyless car entry system is an example of an application using the TWR method. TWR creates a secure and accurate bubble, making it precise and impenetrable when used in these applications.

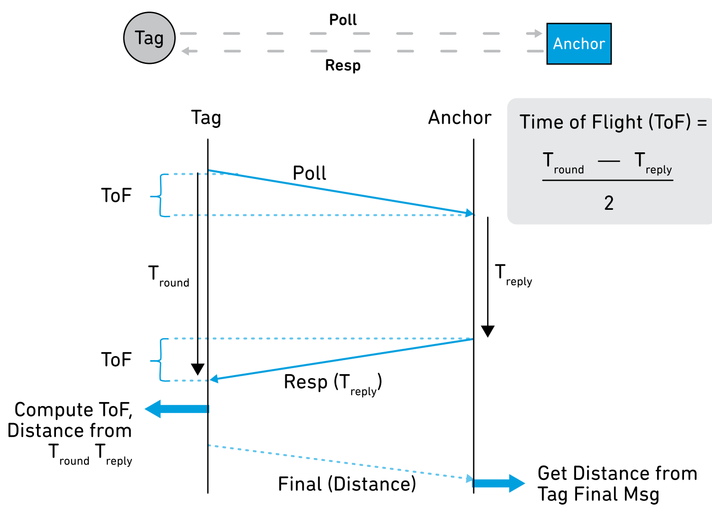


FIGURE 2-9: Secure distance calculation by UWB tag and anchor in a secure bubble.

TECHNICAL STUFF

If you apply the TWR scheme between two devices, you'll get the distance between the devices. Based on the TWR scheme, you can also implement 2D or even 3D location measurements between your mobile tags and fixed anchors; this is called *trilateration.*

With the TWR method three messages are exchanged. The tag initiates TWR by sending a poll message with a known address of an anchor. The anchor records the time of poll reception and replies with the response message. The tag, upon reception of the response message, records time and composes a final message. The anchor can use the information provided in the final message to determine the ToF of the UWB signal.

The TWR method can also be used in the scenarios shown in Figures 2-10 and 2-11 with 2D/3D assets. Figure 2-10 shows two-way ranging with a listener, and Figure 2-11 shows TWR with data tag backhaul. As shown in Figure 2-11, the data going to backhaul can be done using several methods (such as Wi-Fi, NB-IoT, LTE-M, and others) that are used to take the data to the cloud.

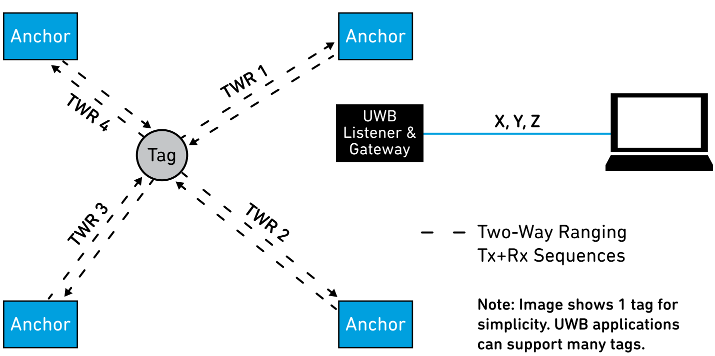


FIGURE 2-10: TWR with 2D/3D assets and listener.

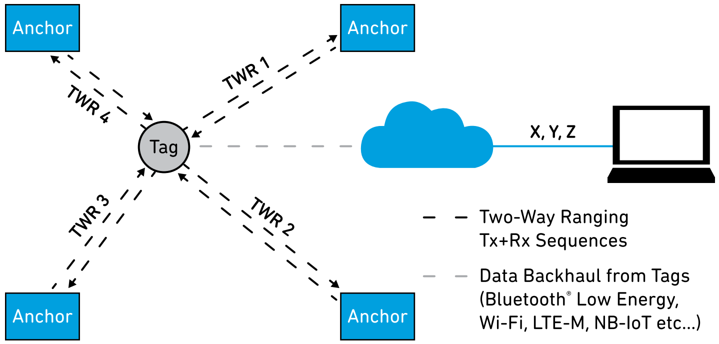


FIGURE 2-11: TWR with 2D/3D assets and data tag backhaul.

- **Time difference of arrival (TDoA) and reverse TDoA:** The TDoA and reverse TDoA methods are like GPS. Multiple reference points, called *anchors,* are deployed in a venue in fixed and known locations and are tightly time synchronized. In the case of TDoA, the mobile devices will *blink* (that is, periodically send message), and when an anchor receives the beacon signal, it will timestamp it, based on the common synchronized time base. The timestamps from multiple anchors are then forwarded to a central location engine, which will run multilateration algorithms based on TDoA of the beacon signal at each anchor. The result will be a 2D or 3D location for the mobile devices, as shown in Figure 2-12.

  Reverse TDoA is most like GPS. In this system, anchors transmit synchronized beacons (with fixed/known offsets to avoid collisions), and the mobile devices use TDoA and multilateration algorithms to compute their location, as shown in Figure 2-13.

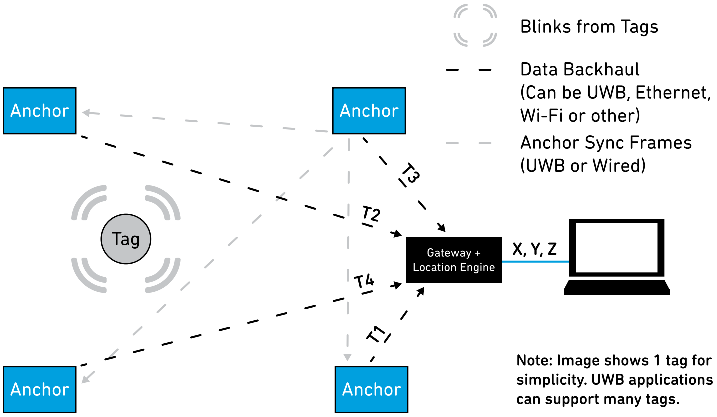


FIGURE 2-12: TDoA.

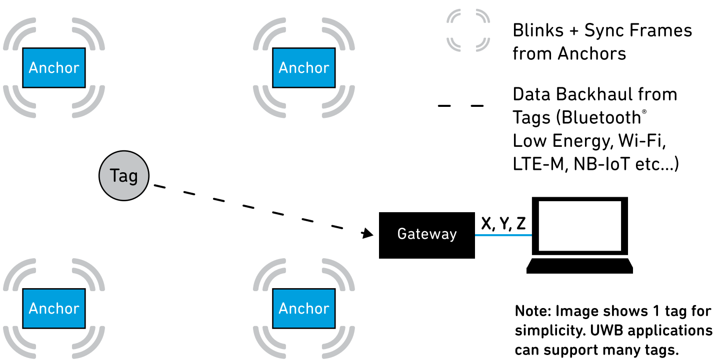


FIGURE 2-13: Reverse TDoA.

» **Phase difference of arrival (PDoA):** Another UWB topology is PDoA. PDoA combines the distance between two devices with a measure of the bearing between them, as shown in Figure 2-14. The combination of distance and bearing enables the relative position of two devices to be calculated without any other infrastructure. To do this, one of the devices must carry at least two antennas and be able to measure the difference in the phase of the carrier of the arriving signal at each antenna. The phase is quite impervious to antenna distortions and can be measured to an accuracy of better than 10 degrees, which allows the bearing of the transmitter to be determined to less than 5 degrees.

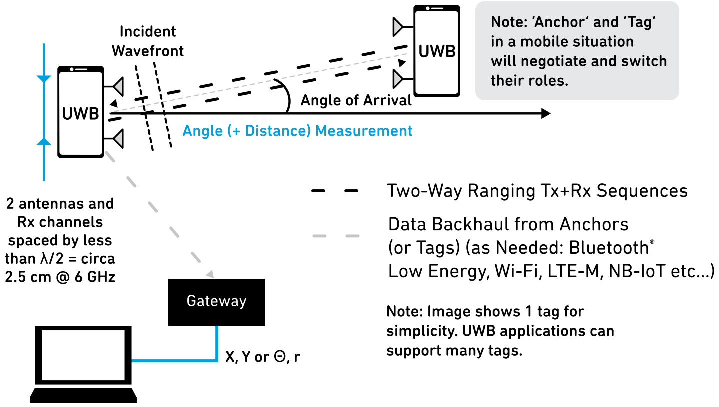


FIGURE 2-14: PDoA location navigation services.

Which application is the best fit for each of the topologies? The use cases primarily focus on three different areas: hands-free access control, location-based services, and device-to-device (peer-to-peer) applications. Figure 2-15 details the optimal applications for TWR, TDoA, reverse TDoA, and PDoA topologies.

Topology Design	TWR (for Ranging & Secure Bubble)	TWR (w/Tag Data Backhaul or UWB Listeners)	TDoA	Reverse TDoA	PDoA (w/TWR)
Main applications	**Secure bubble & access control**	**General purpose RTLS***	**Asset & people RTLS***	**Navigation**	**General purpose & peer-to-peer tracking**
Tag density	Hundreds	Hundreds	Thousands	Unlimited	Hundreds
Battery lifetime - tag side (**)	1-12 months	1-12 months	5 years +	Days/week or more	1-12 months
Location engine (software) runs...	In the tag or anchor	In the tag or anchor	In a master anchor, or in a server of cloud	In the tag	In the tag or anchor
RTLS* scalability	N/A	Low/medium	High	High	Low/medium
Ideal for...	Security (payment, identification, access control) & safety	2D & 3D RTLS* with seamless installation & scalability. Access control & secure transactions.	2D & 3D asset & people RTLS* in large-scale deployments	Drones, robotics, sport analytics, RTLS* with battery powered infrastructure	Access control, P2P, tracking and follow-me drones & robots
Benefits	• Defeats relay attacks • Compliance with CCC specifications	• Seamless implementation • No need for anchor syncing/backhaul channel)	• Very low power tag • High amount of tags can be used	• 'GPS-like' • Infinite amount of tags can be used • Low-power anchors (can be battery-powered)	• Peer-to-peer localization • Polar coordinates • Spherical coordinates possible with 2 instances of IC's/module
Applications	• Distance measurements • Door locks physical access control • Car keyless entry • Car immobilizers	• 2D/3D asset & people tracking • Industry 4.0 • Warehouse logistics • Healthcare • Retail	• 2D/3D asset & people tracking • Industry 4.0 • Warehouse & logistics • Healthcare • Agriculture	• 2D/3D navigation • Robotics • Valet parking • Lone worker protection	• 'Follow me' robots, drones, etc. • Platooning (trucks) • Door locks & access control

*RTLS Real Time Location Systems
** Indicative - actual bettery lifetime figures depend on exact RF & RTLS configuration and on battery type & capacity.

FIGURE 2-15: Ideal applications for common UWB technologies.

IN THIS CHAPTER

- » Understanding why UWB is poised for mass adoption
- » Discovering how alliances and partnerships help drive adoption
- » Imagining a day in a UWB-enabled world

Chapter 3 Looking at the Road Ahead

Ultra-wideband (UWB) technology is poised for mass adoption worldwide. It's already being deployed in more than 40 vertical marketplaces across industrial, enterprise, automotive, and consumer markets. In the applications where it has been implemented so far, UWB has delivered operational efficiencies and improved worker safety in multiple industries. It has also enabled secure transactions like keyless car access and new applications based on tracking the locations of people and objects.

In this chapter, we review the adoption of UWB in mobile phones and how that adoption will soon make UWB soar in popularity. We also look at the ways that industry alliances will contribute to the rapid global proliferation of UWB and investigate some forward-looking use cases that leverage the capabilities of UWB.

Adding UWB Technology to Smartphones

REMEMBER

The recent inclusion of UWB technology in smartphones is the key stepping-stone toward the mass adoption of UWB worldwide. Smartphones represent a major market in themselves, with more than 1.3 billion shipments per year. As a result, smartphones will act as the gateway to broader use of UWB in people's daily lives, helping with activities such as car access, retail transactions, and home control, as shown in Figure 3-1. UWB-enabled phones will trigger the development of a broad ecosystem of new devices and applications that could not be implemented with other technologies.

FIGURE 3-1: The market segments influenced by UWB enabled smartphones.

Predicting the exact future of UWB adoption is extremely difficult, but history can give us some hints about its possible trajectory. For example, Wi-Fi started as a proprietary wireless communications solution for cash registers. Apple's endorsement of Wi-Fi in 1999 was a major support for the technology, leading to its rapid adoption. This adoption spurred the development of a rich ecosystem of devices and triggered a network effect that led to annual shipments of billions of units. Bluetooth's success story is similar: Its early use for hands-free calling in mobile phones and cars ultimately led to massive adoption across many applications and markets.

The same market adoption is happening with UWB, as you can see from Figure 3-2. The explosion of shipments of phones, wearables, and connected home devices could lead to an even faster ramp-up than with Wi-Fi and Bluetooth. There are even projections of it passing the 1-billion-unit mark in the next few years.

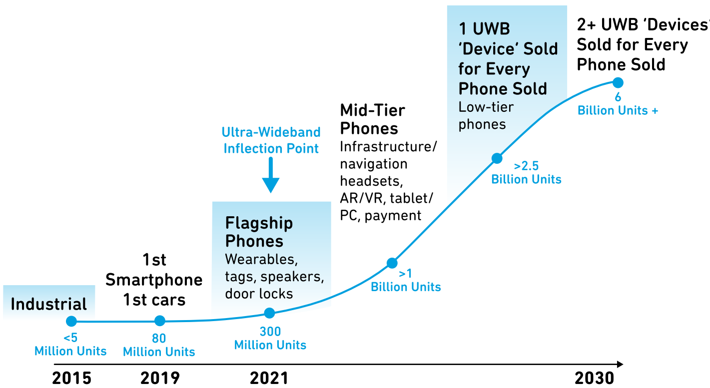


FIGURE 3-2: Projections for UWB adoption.

How Alliances and Partnerships Are Helping Adoption

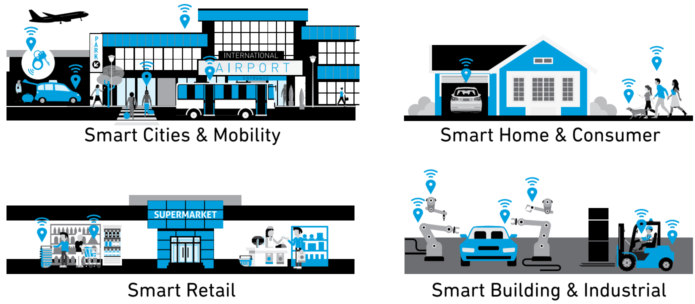
Interoperability (the ability of products, systems, applications, and services from different vendors to work together reliably in a predictable fashion) is another key ingredient for enabling the mass adoption of a new technology. It's vital because every user expects their electronic devices to easily connect and operate with minimal or no effort. Different players within the UWB industry — from semiconductor suppliers to device manufacturers and test equipment vendors — have already started to address the need for interoperability.

Key alliances working to ensure interoperability of UWB products include the following:

- **UWB Alliance (**`https://uwballiance.org`**):** The UWB Alliance is working with global regulation bodies and organizations to provide a favorable regulatory and spectrum management landscape to maximize UWB's market growth. The UWB Alliance is also involved in optimizing spectrum sharing to minimize interference from other new and existing standards.

- **Car Connectivity Consortium (CCC;** `https://carconnectivity.org`**):** The CCC is a cross-industry organization advancing global technologies for smartphone-to-car connectivity solutions. The CCC includes many stakeholders such as car original equipment manufacturers (OEMs), tier 1 suppliers, phone manufacturers, semiconductor suppliers, and app developers. CCC is developing the *Digital Key,* a new open standard that allows smart devices, like smartphones and smartwatches, to act as a vehicle key. This standardized ecosystem enables mobile devices to store, authenticate, and share digital keys for vehicles over UWB in a secure, privacy-preserving way that works everywhere.
- **FiRa Consortium (**`www.firaconsortium.org`**):** FiRa stands for *fine ranging,* a term that highlights UWB technology's unique ability to deliver unprecedented accuracy and security when measuring distance to a target or determining position. As an industry consortium, FiRa believes UWB technology will transform the way people experience connectivity and is committed to the widespread adoption of UWB applications. The FiRa Consortium is envisioning many use cases as outlined in Figure 3-3. Use cases include hands-free access control, indoor location, and navigation, as well as peer-to-peer applications.

These groups are collaborating to create protocols that ensure your car can talk to your phone, your phone can talk to your door lock, and your phone can communicate with location infrastructure.



Smart Cities & Mobility	Smart Building & Industrial	Smart Retail	Smart Home & Consumer
Parking garage control & access	Physical access control	Shopping behavior analytics	Logical personal device access
Vehicle digital key	Employee indoor navigation	Target marketing	Augmented reality gaming
Rider ID services	Employee emergency tracking	In-vehicle payment services	Gesture-based control
Ride sharing positioning	Equipment location	Automatic in-store payment	Virtual reality gaming
Driverless valet park & pickup	Patient tracking	Tradeshow attendee managing	Location of people/pets
V2X (autonomous driving)	Patient data sharing & location	Drone delivery services	Presence device activation
Reserved seat validation	Logical access control		
Transportation fare payment			
Electronic ID validation in dense crowds			

FIGURE 3-3: Use cases envisioned by FiRa Consortium.

Looking Forward to a UWB-Enabled Future

No one could have anticipated the breadth of services and applications that Wi-Fi and Bluetooth have enabled thanks to the creativity and genius of engineers and entrepreneurs. Based on the multifaceted value of UWB described in this book, we can anticipate the advent of new applications and services that were simply impossible to implement with existing technologies.

As shown in Figure 3-4, the UWB-enabled smart home could include the following:

- A door that unlocks automatically as you get home
- An alarm that deactivates as you step in without the need to tap on the keypad
- A personal assistant that gives you personalized information because it knows you're the one entering the home
- Your favorite music that follows you from speaker to speaker as you walk from room to room
- Lights that turn on to your preferred settings
- A wireless node that reminds you that you forgot your tennis bag as you pass the door on your way out

The potential to build a *truly* smart home environment is huge!

Personal navigation

Imagine how UWB can transform the experience of navigating buildings. Ever struggle to find a specific product at the store? What about finding a meeting room at the office? A friend in a crowd? Or your taxi in the line at the airport? UWB will put an end to all those not-so-pleasant, and sometimes stressful, experiences by guiding you to exactly where you need to go.

When UWB is combined with augmented reality (AR), instead of struggling to understand exactly where you are and the direction you should go based on the orientation of a map on your smartphone, UWB can show your exact location and the right direction as a visual overlay over the real world.

In-person delivery

Another cool application could be in-person delivery. Hungry at the mall but not in the mood to walk all the way to the food court? Place an order on your phone, continue shopping, and get it delivered to wherever you happen to be!

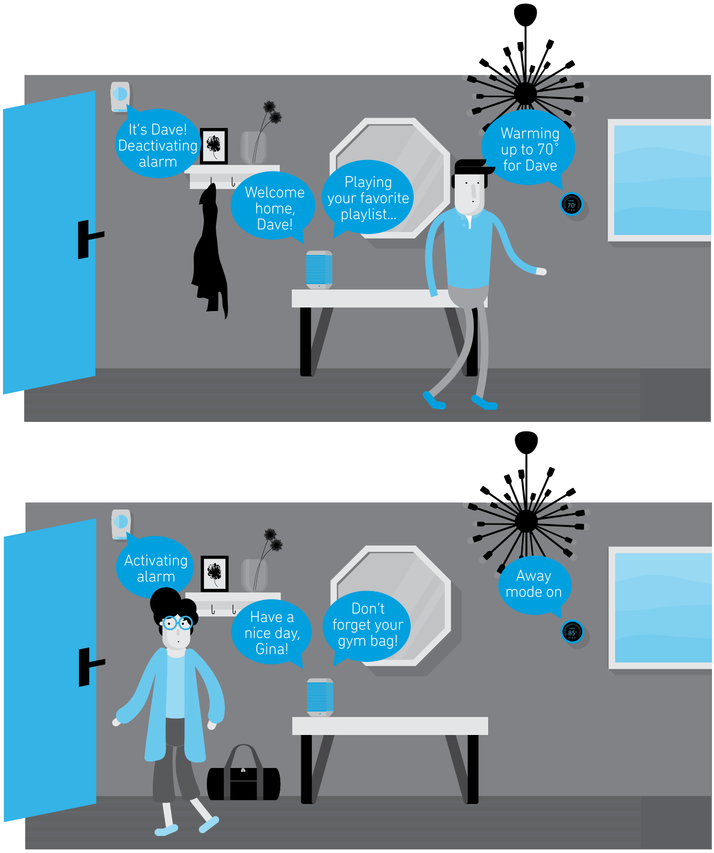


FIGURE 3-4: How UWB customizes and personalizes the smart home.

Secure transactions

One more area where UWB is likely to change the way we interact with our environment is in seamless secure transactions. For example, public transit has made a lot of progress in making payment more convenient — instead of needing cash or tickets, oftentimes now you can pay with a transport card or with your phone.

Now imagine, wouldn't it be even more convenient if you could pay automatically without having to pull your phone out of your pocket and tap it on a payment reader? Imagine how lines and waiting times could be a thing of the past in crowded subway stations. Likewise, automatic checkout lines at the store could be even faster because you'll no longer need to pull out your phone to make a payment!

REMEMBER

The potential for UWB is endless. Even though we can't imagine all future applications, you can be sure that tomorrow there will be an engineer designing a next-generation product that will — yet again — make our lives better.

IN THIS CHAPTER

- » **Understanding how important UWB will be in the near future**
- » **Reviewing the benefits of UWB**

Chapter 4

Ten Key Takeaways

No time to read the whole book? Just skim these bullet points to get the essential facts about ultra-wideband (UWB):

- » **UWB is the next big location technology.** It's already enabling solutions for more than 40 vertical markets in consumer, mobile phone, transportation, and industrial applications.
- » **Alliances are poised to help.** The UWB industry is driving success and interoperability through collaborating alliances, such as the Fine Ranging (FiRa) Consortium, the Car Connectivity Consortium (CCC), and the UWB Alliance, and working closely with the Institute of Electrical and Electronics Engineers (IEEE).
- » **UWB is super accurate.** It's 100 times more accurate for distance and location measurement than Bluetooth Low Energy (BLE) and Wi-Fi, offering accuracy to within a few centimeters.
- » **Rolling out UWB opens many new possibilities.** It adds the "where" to contextual decision making, process efficiency, and safety applications.
- » **UWB is reliable.** It beats the alternatives in reliability because it has high immunity to multipath interference.
- » **UWB has low latency and is 50 times faster than the Global Positioning System (GPS).** It's also capable of working outdoors *and* indoors, unlike GPS.

- **UWB is standards based.** It's based on the international standard IEEE 802.15.4a rolled out in 2020 and its amendment IEEE 802.15.4z.
- **UWB is very secure.** It complies with the security requirements outlined in 802.15.4z, which enhances 802.15.4a with additional cryptographic coding options and improvements to increase integrity and accuracy of ranging measurements.
- **UWB is ready to roll.** The technology is ready for widespread adoption because it's small, low power, and affordable — all features that make it very appealing to device manufacturers.
- **UWB is the most promising of all existing technologies for location and distance measurement.** That's because it offers a unique combination of accuracy, speed, safety, and cost-efficiency. UWB is poised to take over the location-based technology solutions of today and into the future.

Glossary

automated guided vehicle (AGV): A portable robot that follows along marked long lines or wires on the floor, or uses radio waves, vision cameras, magnets, or lasers for navigation.

anchor: In a real-time locating system (RTLS), electronic devices that detect UWB pulses emitted by UWB tags and forward them to the location server for calculating tag positions.

augmented reality (AR): A technology that superimposes a computer-generated image on a user's view of the real world, providing a composite view.

business to business (B2B): Business that is conducted between companies, rather than between a company and individual consumer.

Bluetooth Low Energy (BLE): A variation of the Bluetooth wireless standard designed for low power consumption.

burst position modulation (BPM): The modulation method defined in 802.15.4a. where the convolutional parity bit that determines the burst phase is ignored.

binary phase shift keying (BPSK): A two-phase modulation scheme, where the zeros and ones in a binary message are represented by two different phase states in the carrier signal: for binary 1 and for binary 0. In digital modulation techniques, a set of basic functions is chosen for a particular modulation scheme.

Car Connectivity Consortium (CCC): A cross-industry organization advancing global technologies for smartphone-to-car connectivity solutions.

device-to-device (peer-to-peer): A distributed application architecture that partitions tasks or workloads between peers.

digital key: A feature that allows the use of smart devices as keys. A digital key can be used in the same way as a physical key or a key fob. It's used mainly for locking and unlocking doors.

Ethernet: A system for connecting several computer systems to form a local area network (LAN), with protocols to control the passing of information and to avoid simultaneous transmission by two or more systems.

Federal Communications Commission (FCC): An independent agency of the United States government that regulates communications by radio, television, wire, satellite, and cable across the United States.

Fine Range Consortium (FiRa): A nonprofit organization that promotes the use of ultra-wideband technology (UWB) for use cases such as access control, location-based services, and device-to-device services.

flash memory: A kind of memory that retains data in the absence of a power supply (programmable nonvolatile memory).

Global Positioning System (GPS): An accurate worldwide navigational and surveying facility based on the reception of signals from an array of orbiting satellites.

hands-free access control: An advanced solution that makes it easy and convenient for employees to gain access to secured zones throughout your building or facility without requiring them to dig into their pockets to present a badge.

Institute of Electrical and Electronics Engineers (IEEE): A technical professional organization that promotes the advancement of technology.

Industry 4.0: The ongoing automation of traditional manufacturing and industrial practices, using modern smart technology. Large-scale machine-to-machine communication (M2M) and the Internet of Things (IoT) are integrated for increased automation, improved communication and self-monitoring, and production of smart machines that can analyze and diagnose issues without the need for human intervention.

interoperability: The ability of products, systems, applications, and services from different vendors to work together reliably in a predictable fashion.

Internet of Things (IoT): A system of smart, connected devices.

location-based services: Software services that utilize geographic data and information to provide services or information to users.

line of sight (LOS): A characteristic of electromagnetic radiation or acoustic wave propagation that means waves travel in a direct path from the source to the receiver.

Long Term Evolution for Machines (LTE-M): A telecommunications standard for high-speed wireless communication, developed by the 3rd Generation Partnership Project (3GPP).

low power wide area network (LPWAN): A wireless telecommunication network designed to allow long-range communications at a low bit rate among connected battery-operated sensors and devices.

megahertz (MHz): A measure of frequency. One megahertz is equal to one million hertz.

narrow band Internet of Things (NB-IoT): An LPWAN standard that enables a wide range of devices and services to be connected using cellular telecommunications bands.

nanosecond (ns): One billionth of a second.

original equipment manufacturer (OEM): An organization that makes devices from component parts bought from other organizations.

phase difference of arrival (PDoA): Where the delta between phases of the received carrier is used to estimate the angle for the same frame.

radio frequency (RF): The oscillation rate of an alternating electric current or voltage or of a magnetic, electric, or electromagnetic field or mechanical system in the frequency range from around 20 kHz to around 300 GHz.

radio frequency identification (RFID): Uses electromagnetic fields to automatically identify and track tags attached to objects.

random access memory (RAM): A form of computer memory that can be read and changed in any order; typically used to store working data and machine code (volatile random-access memory).

real-time locating system (RTLS): A system used to automatically identify and track the location of objects or people in real time, usually within a building or other contained area.

received signal strength indicator (RSSI): In telecommunications, a measurement of the power present in a received radio signal.

tag: A small electronic device that is attached to an object that needs to be tracked.

time difference of arrival (TDoA): An electronic technique used in direction finding and navigation, in which the time of arrival of a specific signal, at physically separate receiving stations with precisely synchronized time references, is calculated.

time of arrival (ToA): The absolute time instant when a radio signal emanating from a transmitter reaches a remote receiver.

time of flight (ToF): The measurement of the time taken by an object, particle, or wave to travel a distance through a medium.

two-way ranging (TWR): A method used to determine the time of flight (ToF) of a UWB RF signal and then calculate the distance between the nodes by multiplying the time by the speed of light.

ultra-wideband (UWB): An IEEE 802.15.4a/z standard technology optimized for secure micro-location-based applications that enables unprecedented accuracy (within a few centimeters) by calculating the time it takes radio signals to travel between devices.

UWB Alliance: An alliance to promote interoperable ultra-wideband (UWB) wireless computer networking products from multiple vendors.

virtual reality (VR): A computer-generated three-dimensional (3D) image representation of an object or objects, which a user can interact with in a similar manner to real-world objects.

wireless fidelity (Wi-Fi): A generic term that refers to the communication standard for the wireless network that works as a local area network (LAN) to operate without using the cable and any type of wiring. Known as WLAN.

To learn more, watch our UWB video at www.qorvo.com/go/uwb-video.

Your Complete UWB Solution at Qorvo®

SEMICONDUCTORS: Our UWB-based ICs deliver centimeter accuracy and highly reliable measurements while operating from coin cell batteries, making this an affordable solution for any type of application.

SOFTWARE: We deliver comprehensive software packages – from embedded networking stacks and location engines to reference designs for Android/Linux app and sensor integration.

MODULES: From prototyping to manufacturing, our modules can help you reduce the complexity and cost of your design as well as your time to market.

REFERENCE DESIGNS: We provide hardware, software and RF reference designs for various applications and platforms so that you can focus on your own area of expertise and reduce your time to market.

TECHNICAL COMMUNITY: Qorvo partners and engages with many technical community members and organizations to help enable and play a fundamental role in next-generation wireless solutions.

Discover new possibilities with ultra-wideband

Ultra-wideband (UWB) delivers the "where" to enable contextual decision making. It reduces manufacturing operating costs, increases safety, and provides greater security for data communication. UWB's technology capabilities open the door to a broad range of new applications, like secure keyless entry, secure payments, enhanced navigation, and precise asset location. It enhances the connected home by controlling smart devices based on the location of people and provides buildings with turn-by-turn navigation services. It also improves automotive secure communications between the key fob and the car and improves factory efficiencies and personnel safety. UWB is on the path to becoming the next ubiquitous wireless connectivity used in our everyday lives, making our dreams a reality.

Inside…

- Understand the history and future of UWB
- Learn how UWB works
- Review key UWB technology features
- Discover the aspects of UWB driving new location-based use cases
- Learn the best topology for your UWB application
- Understand how UWB determines location

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