

Next-Gen Connectivity for Smart Living





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Unified Smart Living

The average number of connected devices in the home has begun to level off at just over 20 devices. In the early days of IoT and smart home devices, we saw explosive growth as wireless connectivity was added to just about every electronic device. Today, designers and consumers look for ways to optimize a maturing smart home ecosystem. The pieces are in place for intentional smart home design, where each device plays a part in the big picture rather than acting in a vacuum. This eBook covers some of the cutting-edge areas where Qorvo is bridging the gap between a disjointed collection of connected devices and a secure, comprehensive smart solution.

When we think of connected devices, we often think of Wi-Fi®. Wi-Fi does the heavy lifting when it comes to moving large amounts of data between connected devices. The latest standard, Wi-Fi 7, makes leaps in managing traffic between multiple devices. Beyond just giving the channels more bandwidth, Wi-Fi 7 mitigates interfering traffic, so your video doorbell isn't competing for bandwidth against your gaming computer.

Beyond Wi-Fi, exciting developments in other protocols enhance the capabilities of our connected devices. Ultra-wideband (UWB) technology provides centimeter-level location accuracy, opening the door to a home where lights turn off and on as you move between rooms and your keys are never lost. The latest cell phones and car keys already support UWB, and it will continue to grow as a popular protocol for consumer devices because of its accuracy, security, and low power usage.

Wi-Fi, *Bluetooth*®, and Zigbee each serve a unique purpose, and Matter ties all of these protocols together. As a wireless lingua franca, Matter enables communication among devices running on different protocols. Security becomes paramount for such a robust network. Matter's cutting-edge security protocols authenticate every device on the network and encrypt all communications, building a virtual wall that prevents malicious devices from eavesdropping on your home network.

None of these smart home innovations would be possible without antennas providing a communication link between every device. As the number of wireless protocols in use increases, so does the number of RF paths in wireless devices. A 5G mobile phone with support for mmW bands and UWB has more than twice as many RF paths as a typical 4G phone. Accounting for additional RF paths without compromising on device size and battery life creates extremely complex design challenges. You can take advantage of Qorvo's expertise as an industry leader in antenna design to overcome your RF challenges in next-generation smartphones and other wireless devices.



This eBook covers some of the cutting-edge areas where Qorvo is bridging the gap between a disjointed collection of connected devices and a secure, comprehensive smart solution.



Matt Campbell
Mouser Electronics

Bringing Devices with Multiple Standards Together in the Connected Home

By Qorvo

The number of connected devices within our homes continues to rise as consumers increasingly rely on them for convenience, comfort, health, and safety. Some are inside our homes, some are outside. And while these devices are designed to be part of a network, they often communicate using different standards—languages, if you will—depending on the application.

Most of us are familiar with the Wi-Fi standard, which enables content sharing and internet access in the home. But there are several Internet of Things (IoT) technologies other than Wi-Fi, such as *Bluetooth®* Low Energy, Zigbee®, and Thread®. These low-power, low-data-rate wireless standards are commonly used in IoT-connected products such as door locks, LED lighting, and appliances (**Figure 1**).

The challenge that these multiple and different technologies pose is that vendors must decide in advance what kind of technology they are selecting for their devices. For example, in selecting either Zigbee or *Bluetooth®* Low Energy—or both—each choice has its own impact on product design.

Looking forward, even more technologies are coming that target similar smart home use cases, such as the Connected Home Over IP initiative, which combines multiple technologies (802.15.4 and *Bluetooth®* Low Energy) into a single standard. These

developments will make the choice between technologies and future-proof solutions even more challenging.

While today's communications devices have some form of dynamic multi-protocol (DMP) support, this approach requires different tradeoffs. DMP alone is insufficient to realize the connected home's full benefits. Truly seamless connectivity can only be achieved by the ability to listen to and hear *all* devices on the network simultaneously, not just a few.

ConcurrentConnect™ Technology As a Solution

Today, customers have the benefit of *not* having to choose between communication standards or compromise connectivity. The next major leap in multi-standard capabilities—

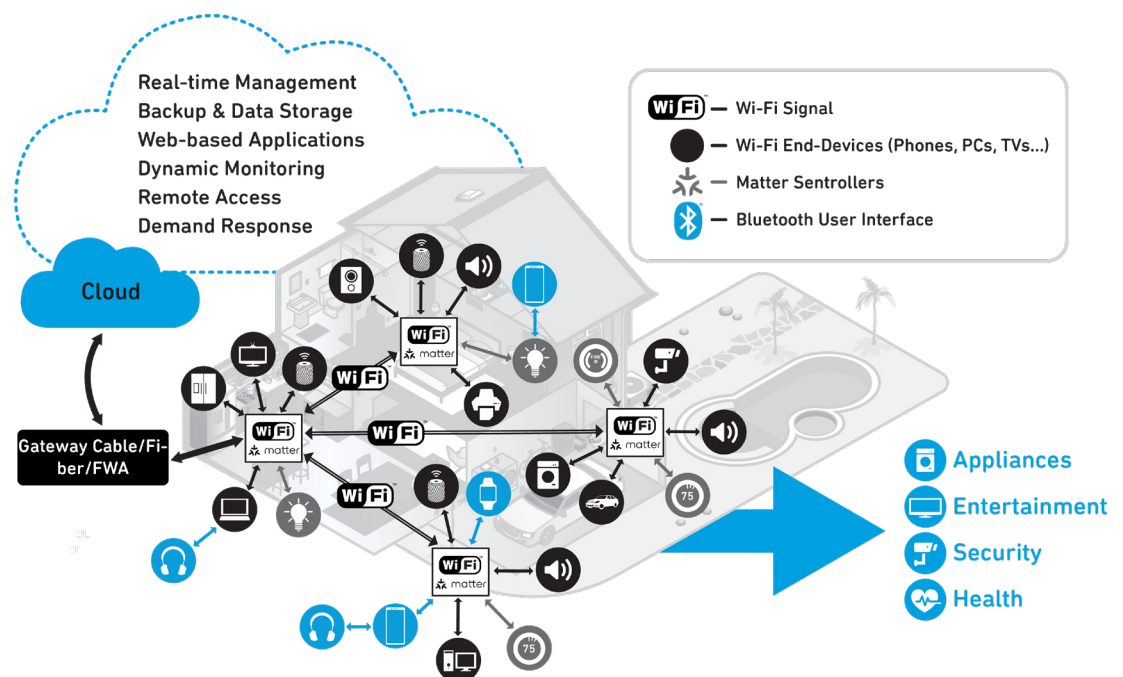


Figure 1: As smart home technology proliferates, so does the challenge of ensuring that devices built on different standards can quickly and effectively communicate. (Source: Qorvo)

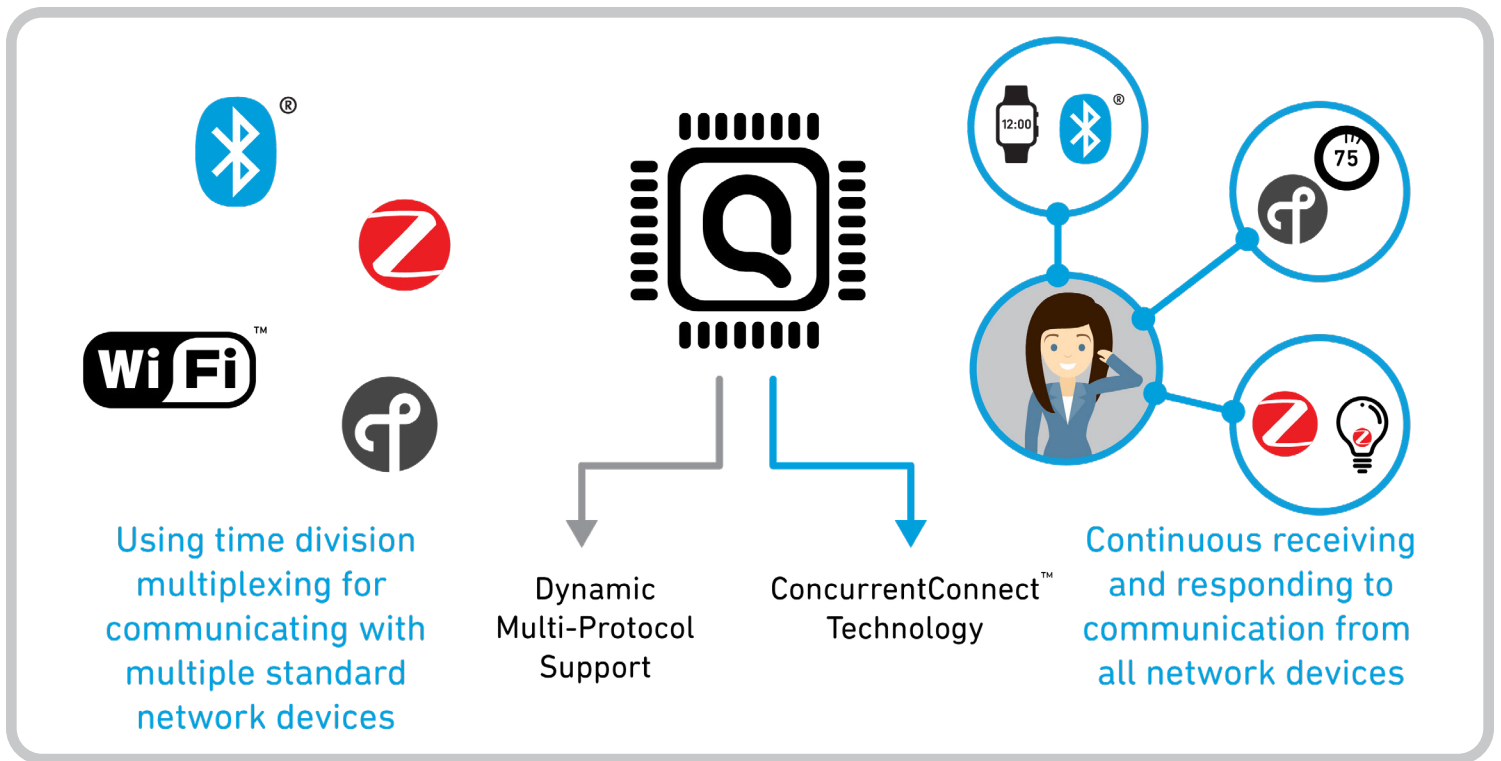


Figure 2: ConcurrentConnect technology, shown to the right, manages communications from different standards and protocols simultaneously with no detectable latency. (Source: Qorvo)

ConcurrentConnect technology from Qorvo—fluently and continuously services two or more networks using different protocols, whether it's Zigbee + Matter (formerly Project CHIP), Zigbee + *Bluetooth*® Low Energy to a smartphone, Matter + *Bluetooth*® Low Energy Mesh, or other multi-network protocol use cases. ConcurrentConnect technology will deliver seamless operation of devices connected in the home via different networks without performance loss.

To illustrate, let's consider a network situation combining Zigbee or Thread and *Bluetooth*® Low Energy devices using a standard node without ConcurrentConnect support. Since the node does not have ConcurrentConnect listening abilities, it switches back and forth between these standards and must communicate with one standard at a time. In addition to the obvious inefficiency, this switching can result in dropped communications and latency, as only one standard is communicated while the other is blocked until the medium becomes free again. Thus, the amount of communication possible in a set time frame becomes a challenge.

With a node that utilizes ConcurrentConnect technology, concurrent listening is achieved, allowing near-instantaneous switching from *Bluetooth*® Low Energy to Zigbee or Thread with little to no dropped communications (**Figure 2**). Thus, the communications between devices are faster, more efficient, more scalable, and able to receive more data packets. This enables unprecedented single-device concurrency capabilities between these protocols.

Qorvo's unique single-chip, single-radio solution, combined with a powerful software development kit, can manage data traffic from multiple standards or protocols simultaneously and with no detectable latency. Plus, designers can reduce part content, resulting in smaller, sleeker form factors and lower product costs. With ConcurrentConnect support, greater flexibility in standards provides customers with virtually unlimited options to develop innovative use cases.

Why Does It Work Better?

There are significant hardware and software challenges when a single radio must support multiple protocols simultaneously. This is because every protocol has its own specifications for how and when devices should listen to incoming data packets and transmit outgoing packets.

Some phases in the protocol may have fixed-time intervals, during which the radio can predict when it should switch to the right frequency (e.g., *Bluetooth*® Low Energy "in connection" phase). However, most of the time, especially while detecting candidates for connection during the listening phase, the radio is required to constantly detect incoming packets *asynchronously* without prior knowledge of specific times in which the radio is required to open its receive window to receive the packet.

Additionally, applications require a simple-to-use interface to operate over multiple protocols seamlessly, such that the application developer becomes immune to protocol dependencies, removing the burden of switching to the corresponding protocol when needed.

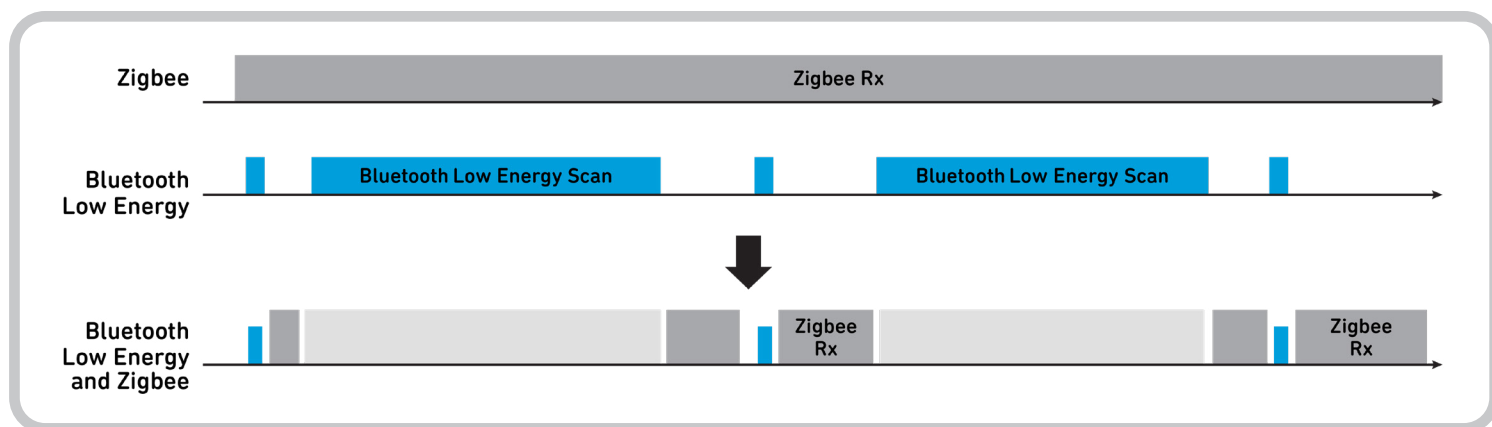


Figure 3: The asynchronous interleaving of packets from different protocols, such as Zigbee and *Bluetooth*® Low Energy, becomes possible with ConcurrentConnect support. (Source: Qorvo)

This is where the Qorvo ConcurrentConnect listening technology shifts the existing paradigm. It enables asynchronous interleaving of packets from different protocols on the hardware level so the device virtually listens to multiple protocols at the same time and no blind spots are observed during the listening phase (**Figure 3**).

ConcurrentConnect technology is abstracted in the software development kit, providing straightforward APIs so the application developer can utilize its capabilities seamlessly in their application. This maximizes the utilization of the medium, as ConcurrentConnect technology maintains a synchronized connection while listening to asynchronous events from multiple protocols.

The key differentiator here with DMP is predictability versus unpredictability. DMP support is based on the predictability of the packets being received and sent; it must know when to switch to *Bluetooth*® Low Energy and then back to Zigbee or Thread, for example. ConcurrentConnect technology supports unpredictability for simultaneous synchronous and asynchronous operation.

ConcurrentConnect technology is based on unique hardware features in Qorvo’s platform that enable packet detection and identification in the most efficient way. Once detected, the packet goes through an identification process in real time on the hardware level and then sends the packet to the appropriate protocol stack, eliminating the need for additional, non-real-time routing logic on the higher software layers (**Figure 4**).

This technology’s accompanying software development kit takes the next step in enabling combinations of the preferred protocols for applications in such a way that the application “thinks” it has its own radio. This simplifies application development and allows the developer to focus on the actual application differentiators.

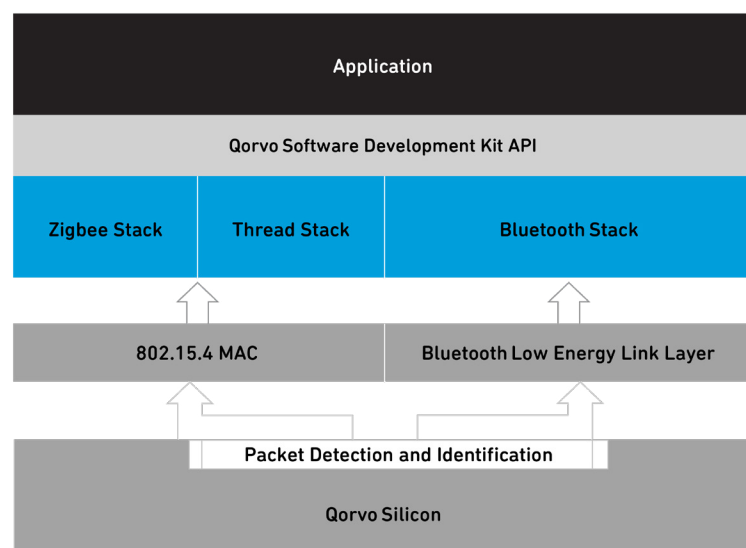


Figure 4: Packet routing on Qorvo hardware is enhanced with ConcurrentConnect support, in which processing is completed on the hardware and software levels. (Source: Qorvo)

As a result, this new connection paradigm opens a wide variety of use cases across the home network, including gateways, hubs, and end devices that require support capabilities for the high frequency of data transfer between multiple devices. With ConcurrentConnect technology, a gateway can seamlessly switch between all the standards and protocols present in the home network, allowing more end devices based on different standards to be connected and controlled. In addition, designers and device owners are not locked into a certain technology as they expand their home connections.

What ConcurrentConnect Technology Enables

With gateway support by ConcurrentConnect technology now able to understand multiple protocols simultaneously, and allowing for a mix of end devices, new use cases in the IoT are possible.

In addition, the end devices themselves will allow for additional use cases. For example, devices can be connected to *Bluetooth*® Low Energy Mesh and Zigbee or Thread networks at the same time. Or a *Bluetooth*® Low Energy-based smartphone can be connected directly to the device while operating on a Zigbee or Thread network.

The ability to listen concurrently also opens up new use cases for combined protocols that were not possible before, like a device based on a Zigbee or Thread network becoming location-aware by continuously scanning for *Bluetooth*® Low Energy beacons from *Bluetooth*® Low Energy trackers.

In the smart home market, connected lighting is one important application that will benefit from ConcurrentConnect technology. For the first time ever, a lightbulb can simultaneously be controlled by Zigbee- or Thread-based switches at the same time as *Bluetooth*® Low Energy switches. Similar benefits can be achieved in motion sensors, thermostats, and other smart home sense and control devices.

Conclusion

Standards are scattered and devices are developing quickly. Qorvo's patented ConcurrentConnect technology is the next step beyond dynamic multi-protocol support. It brings to the IoT market a high degree of efficiency that enables new levels of concurrence while allowing designers and consumers to keep their options open across multiple protocols and standards. It is no longer necessary to choose or compromise as almost any use case becomes possible in the connected home and beyond.



With gateway support by ConcurrentConnect technology now able to understand multiple protocols simultaneously, and allowing for a mix of end devices, new use cases in the IoT are possible.



Reach Farther with Zigbee

Zigbee technology fills the gap between Wi-Fi and Bluetooth. Wi-Fi supports fast data rates over wide bandwidths but uses too much power for battery-powered devices. Bluetooth forms point-to-point connections between only two devices and therefore isn't well suited for networking needs. For low-power networking, Zigbee provides a reliable mesh network that supports many IoT devices, from lighting to sensors.

Each Zigbee device acts as a node in the mesh network, meaning the network can extend beyond the range of a typical Wi-Fi router or Bluetooth receiver. This makes Zigbee technology an excellent option for industrial IoT applications that may have thousands of devices spread across a large area. The mesh capability also builds redundancy into the network, meaning a single end-device failure won't bring the entire network down. If one device fails, the network can "heal" by connecting with other devices. The Zigbee network connects to a Zigbee coordinator, which acts as the interface to the Zigbee network and enables you to manage devices on the network through your phone or computer.

The Zigbee 3.0 standard, ratified in late 2015, consolidated competing protocols. In earlier versions of Zigbee, manufacturers created their own unique ecosystems that were incompatible with other Zigbee devices. Zigbee 3.0 devices share the same ecosystem, giving end users flexibility when adding new devices from multiple manufacturers.

Other protocols, namely Bluetooth Mesh and Thread, follow the example of Zigbee technology to create low-power mesh networks. Bluetooth Mesh relies on Bluetooth Low Energy connections between mesh devices. As the name suggests, *Bluetooth*® Low Energy devices do not require much power because they can go into a low-power sleep mode, similar to Zigbee devices. *Bluetooth*® Low Energy supports faster data transmission rates than Zigbee technology and is well suited for personal devices that have a Bluetooth connection. However, Zigbee technology supports larger networks with more devices, making it more suitable for home and industrial sensor and automation applications.

Thread also builds a mesh network but uses an IP-based connection. This connection simplifies communication between Thread devices and other Wi-Fi-enabled devices like computers and smartphones.

Zigbee technology led the wireless sensor industry for years, but Thread is gaining momentum as the foundation of the new Matter standard. Some modern chipsets support both Zigbee and Thread technologies, enabling support for established Zigbee devices on new Thread and Matter networks. With a deep installed base and years as a leading technology, Zigbee remains a crucial piece of the IoT picture. However, in the coming years, Zigbee devices will coexist with Thread devices under Matter.

Your Roadmap to a Smart Lighting Product Featuring Qorvo's QPG6105

By Qorvo

Introduction

As IoT smart home products continue to evolve and innovate, complexity becomes more prominent. Designers of these products are always looking for ways to invent creative designs that are innovative to support the next generation. To meet these goals, designers need to use state-of-the-art products inside their IoT solutions. Qorvo realizes this and has gone the extra mile to ensure its silicon IoT product solutions are future-proof and innovative, so your IoT end-product design is also state-of-the-art.

How Qorvo Helps Designers

All IoT system designers are hard-pressed to bring their product ideas to market quickly and successfully, while markets, standards, and product ideas are evolving. Without using a simplified development ecosystem that supports all the needs of your design, the process can be challenging. But, by using a partner that puts all the tools and expertise you need at your fingertips, these challenges can be eliminated completely.

This is what Qorvo has done. By providing IoT smart lighting customers with everything they desire to create innovative IoT solutions, your design can be easy and best-in-class. So, what is it that Qorvo provides?

- Software and hardware reference designs for smart lighting solutions
- An IoT gateway development kit for connecting your solution
- A complete set of design tools available through GitHub
- A smartphone app for testing and controlling your lighting solution

These tools and more provide any smart-lighting designer with the necessary instruments to get started, create an innovative design, and get to market fast. Moreover, these tools are simple to use and allow you to concentrate on innovation rather than spending time trying to figure out how things connect or work. This shortens the design phases and provides cost-effective, viable solutions.

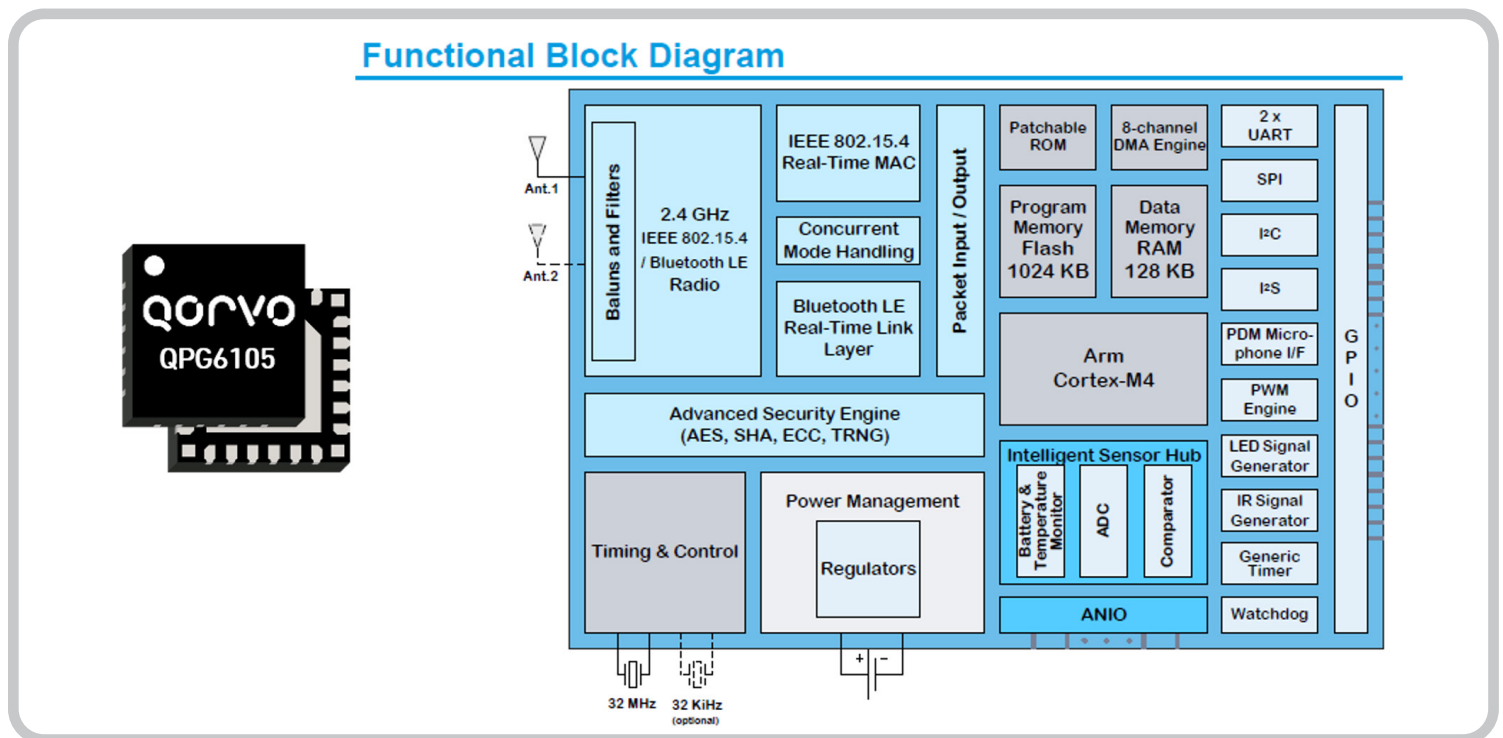


Figure 1: The block diagram of the Qorvo QPG6105 shows many of the SoC's key features. (Source: Qorvo)

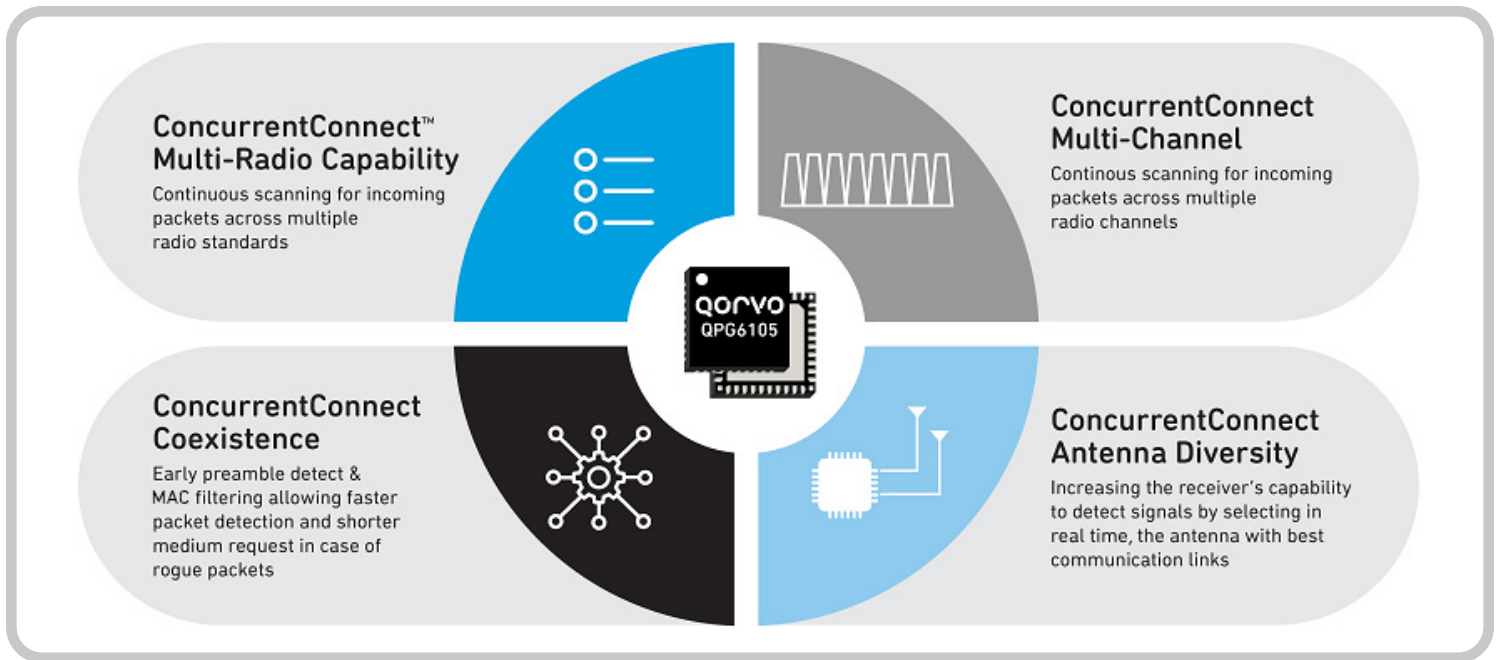


Figure 2: Qorvo's patented ConcurrentConnect technology enables multi-radio, multi-channel, and coexistence functionality with antenna diversity. (Source: Qorvo)

A peek into the Design Tools

The Qorvo QPG6105 smart lighting system-on-chip (SoC) (**Figure 1**), advances the state of smart home networking by supporting different connectivity standards, including IEEE 802.15.4, Zigbee 3.0, Thread, Matter™, and *Bluetooth®* Low Energy 5.2, for sensors and actuators throughout the home. Our design kits enable easy integration of multi-protocol use cases in IoT smart home devices, supporting simultaneous interactions with a Bluetooth-enabled smartphone and the Zigbee or Matter devices in the smart home network. The software and example applications in our development kit are certified, including Bluetooth Low Energy controller, host, service, and profile certification. Moreover, the products are certified to a Zigbee 3.0 platform, and we also have the world's first Matter light bulb product certification.

Other items the QPG6105 provides:

- Best-in-class multi-standard support
- Enhanced security capabilities, including secure key storage, hardware crypto engine, and support for secure boot
- Double the effective range of a connected light design by using Qorvo's unique antenna diversity
- +10dB transmit output power
- Memory: 1MB flash / 128KB RAM/ 256KB ROM – Software leverages the ROM to minimize the flash footprint of the networking stack.
- A large set of peripheral options
- Up to 8 PWM outputs for LED control

QPG6105 IoT Development Kit



[LEARN MORE >](#)

Qorvo's ConcurrentConnect™ Technology

The QPG6105 has Qorvo's patented ConcurrentConnect™ technology (**Figure 2**) in a single chip using a single radio that ensures instantaneous switching from multiple protocols with no latency. With ConcurrentConnect technology, designers can rely on a solution that just works—in every case reducing part content, resulting in smaller, sleeker form factor and lower product costs.

The Qorvo IoT Development Kit Pro

The IoT Development Kit Pro, which includes the QPG6105, has all the software development tools required, including an IoT gateway using our QPG7105M silicon SoC and patented ConcurrentConnect technology (**Figure 3**). This fully functional development kit provides all you need to get started on an IoT design. Moreover, the design kit is Matter ready, meaning you can use this development kit to create next-generation Matter products minutes after opening the box.

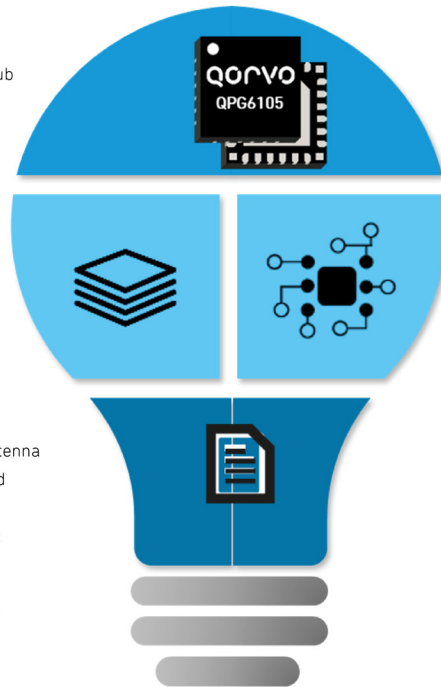
QPG6105 SW Design Tools

Software and documentation publicly available on GitHub

- Matter v1.0 certification-ready door lock and light reference applications
- Several HAL driver examples
- Support for FreeRTOS
- Free tooling (compiler/IDE)

Reference Designs

- Smallest module design in market: 14.3mm × 12mm × 0.8mm
- Easy-to-solder 0.75mm/1.5mm pin width/pitch
- Easy to integrate into many light bulb designs
- Patented small integrated antenna design with no sacrifice on RF performance
- Extra RF port on dedicated pin for customer's own antenna
- Integrated 125°C crystal 32MHz, no calibration needed from customer
- UART/SPI/SWD exposed to user for debugging
- Light bulb and additional sensor control
- 6 PWM
- 1 ADC
- I2C (multiple pins, configurable)



QPG6105 Matter DK

- Includes peripherals for most typical lighting and sensing applications
- Arduino headers allow for future expansion
- Availability of all CAD/EDA source design files for fast integration into customer libraries

Figure 3: The Qorvo IoT Development Kit Pro incorporates the QPG6105 SoC, software development tools, and an IoT gateway. (Source: Qorvo)

Qorvo Support Ladder

Qorvo recognizes their customers are busy and this is why we make certain we provide all the tools to help you design (**Figure 4**). If you cannot locate what you require on our website, then it will surely reside on our GitHub site. Throughout your design, Qorvo will support you. We provide design review support, RF validation services, certification guidelines and assistance, and third-party software tools

like SEGGER J-Link debugging and programming products. Moreover, we provide design considerations (**Figure 5**) or ideas to help springboard your product solution quickly through the development process.

Our ultimate goal is to make your IoT design easy, robust, next generation, and easy to certify. Doing so will ultimately lead to a fast time to market with a fully certified IoT product solution.

Qorvo Hardware and RF Support Flow

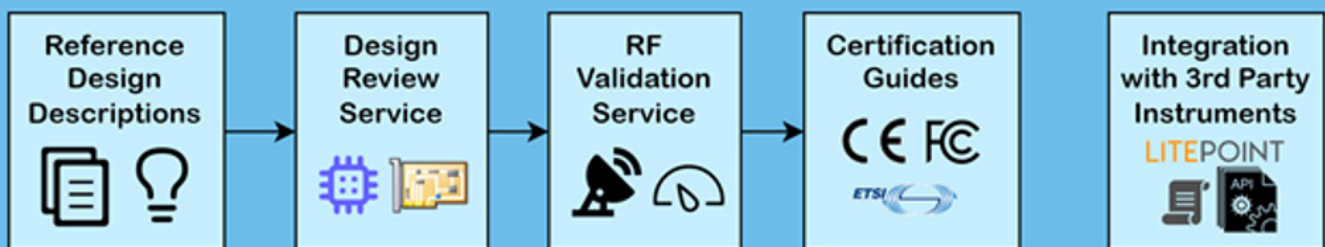


Figure 4: Qorvo offers a variety of support tools throughout the design and development process. (Source: Qorvo)

Design Consideration Example:

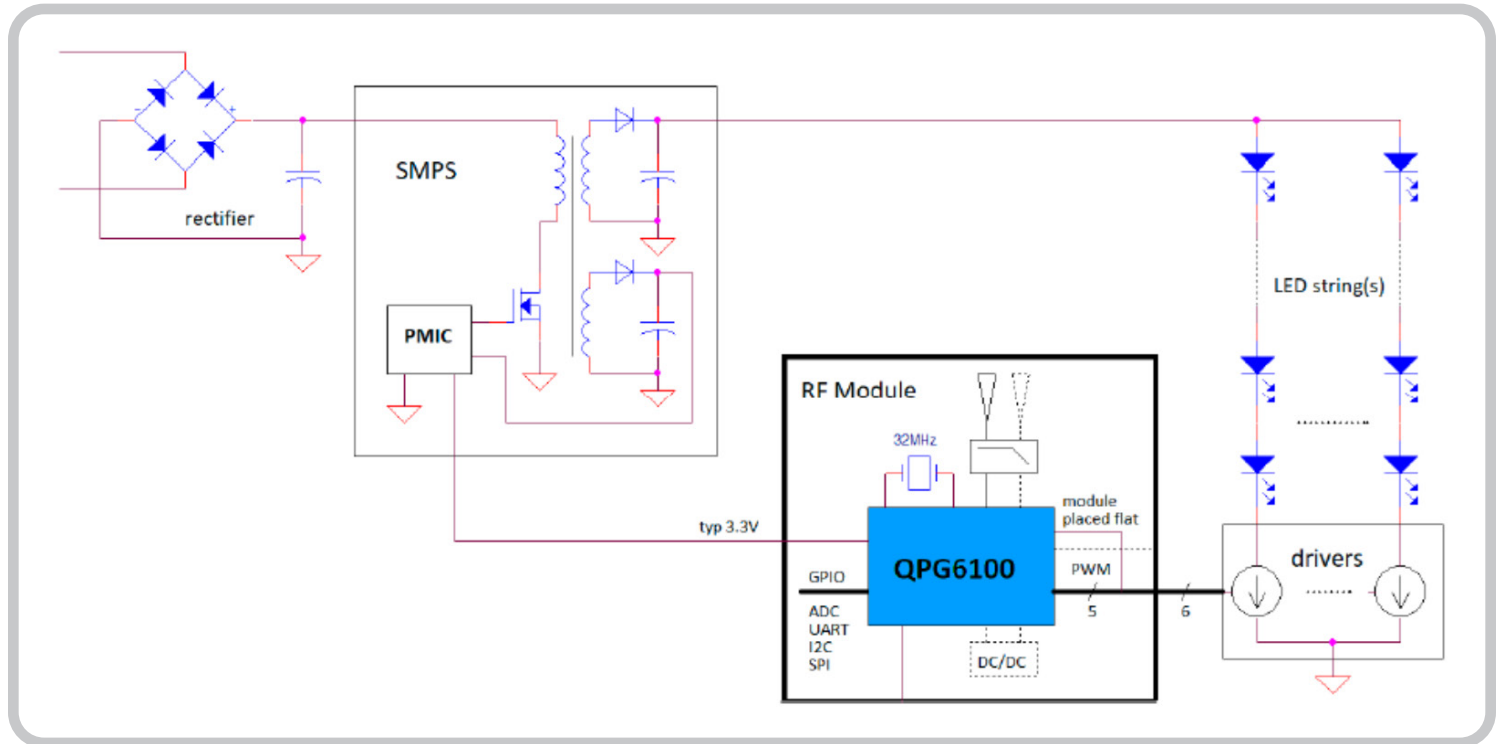


Figure 5: Qorvo's support tools include design considerations to help springboard solution concepts. (Source: Qorvo)

As you can see, Qorvo is a partner that will help you meet your organizations' and customers' goals, creating next-generation, innovative IoT solutions. As a partner with Qorvo, you are provided all the instruments needed to make an IoT product that your customers will find to be sleek, simple to use, "green," and just work with their other IoT product designs in the home.

As you can see, Qorvo is a partner that will help you meet your organizations and customers goals.



Getting Back to Basics with Ultra-Wideband

By Qorvo



Introduction

Ultra-wideband (UWB) is an IEEE 802.15.4a/z standard technology optimized for secure micro-location-based applications. It enables distance and location to be calculated indoors or outdoors with unprecedented accuracy—within a few centimeters—by measuring the time it takes radio signals to travel between devices. Along with centimeter-level ranging accuracy, emphasis was placed on defining a standard that would make UWB robust and immune to various forms of interference, assuring a high level of reliability. The UWB standard was also designed with low power and low cost in mind, and with a focus on meeting requirements to support large numbers of connected devices.

The engineers who created the standard had a vision to make every connected object “location-aware.” UWB is being incorporated into leading smartphones and a wide range of other devices, and ultimately will become a ubiquitous communication standard. It is already being applied to solve problems in many different industries and applications, including keyless car entry, improving efficiency and safety in factories, locating essential supplies in hospitals, and controlling smart devices in homes.

The biggest potential for UWB is in a completely new generation of micro-location-based systems. Just as Wi-Fi® and GPS paved the way for previously inconceivable applications, UWB will enable a wave of applications that use highly accurate location and distance sensing to deliver new experiences and capabilities. Today, people and businesses want to be able to locate pretty much anything in real time, whatever its size.

Let’s say you’re at home and misplaced your car keys, or you’re in a grocery store and can’t find your favorite brand of coffee. Or maybe you’re working in a factory and need a particular tool from a storage bin, or you’re a site manager dealing with an emergency and need to make sure everyone’s exited the building. Indoor positioning at the micro level helps in all these situations because it can locate items and guide you to where they are. To offer enough accuracy, reliability, and real-time capability, the underlying technology needs to be designed for precise location. UWB is changing the game by delivering accurate location information that can be used in a myriad of ways.

UWB Is Best When Precise Location Matters

Unlike other radio frequency (RF) technologies, UWB was specifically designed to enable precise, secure, and real-time measurement of location, distance, and direction, while concurrently supporting two-way communication.

One of UWB's key strengths is that it uses a signal's time of flight (ToF) to calculate the distance between devices. This method is much more accurate than the received signal strength indicator (RSSI) method typically used with other wireless technologies such as Wi-Fi and *Bluetooth*®.

UWB signals also use much greater bandwidth than prevalent narrowband technologies. As a result, UWB signals are extremely short due to the inverse relationship between time and bandwidth. This means that the time resolution of UWB signals is very high, enabling accurate ToF determination. Additionally, the high time resolution and short wavelength of UWB signals make it much more resistant to multipath interference and fading.

These capabilities enable UWB to pinpoint people and things with great accuracy. In fact, UWB is 100 times more accurate than other RF technologies like Wi-Fi for location, delivering accuracy within centimeters instead of meters. This is very important when tracking or locating small objects, or if your application requires you to know if something is on one side of a wall versus the other.

Furthermore, UWB has very low latency, which means that, unlike Wi-Fi and Bluetooth, it can be used for real-time location. It is 50 times faster than GPS, with updates up to 1,000 times per second; that's three thousand times faster than a standard Bluetooth Low Energy beacon. This makes UWB ideal for automation systems and applications involving fast-moving objects, like drones, and it opens the door to many exciting new use cases. The large bandwidth also makes UWB systems suitable for high-speed communications.

Because UWB leverages ToF information combined with distance-bounding communication techniques defined by the IEEE 802.15.4a/z standards, it also provides much greater security than other wireless technologies used for sensing distance and location.

How UWB Measures Location

Unlike other radio technologies, UWB does not use amplitude or frequency modulation to encode the information that its signals carry. Instead, UWB uses short sequences of very narrow pulses (only two nanoseconds) using binary phase-shift keying (BPSK) or burst position modulation (BPM) to encode data. These narrow pulses also have clean edges, allowing precise determination of arrival time and distance in the presence of multipath effects caused by signal reflections.



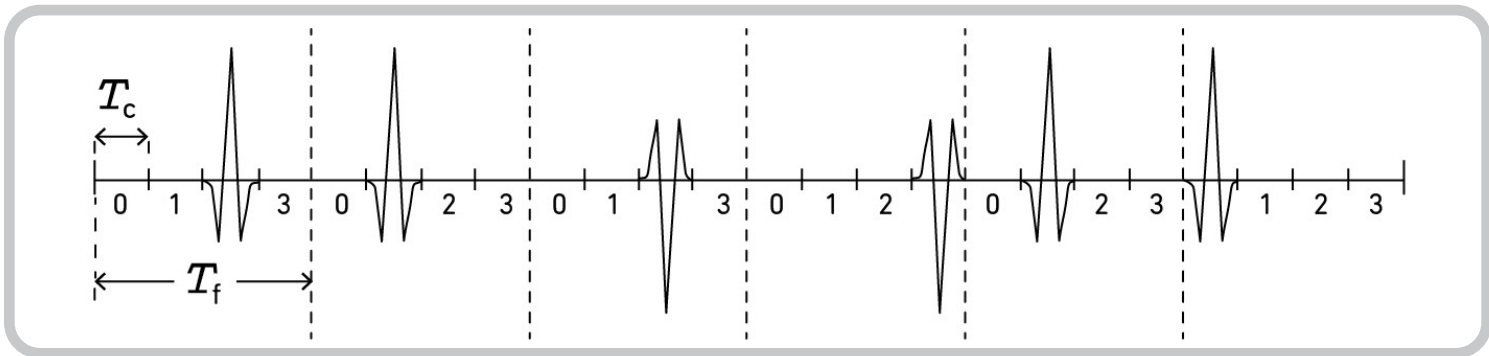


Figure 1: UWB transmits information using short sequences of extremely narrow pulses. (Source: Qorvo)

In the above BPSK example (**Figure 1**), two consecutive impulse radio (IR) signals represent one symbol. The IR signal can occupy one of the chip-intervals (T_c) within a frame (T_f). A time-hopping (T_H) code is used to determine the accurate position of a signal in a dedicated time frame to decrease the chance of interference between UWB systems. In this example, the T_H codes for the symbols are $\{2, 1\}$, $\{2, 3\}$, and $\{1, 0\}$, respectively, so the first and second signals are shifted by two and one chip-intervals and so on. Here, the information corresponds to the polarity of signals, so the IR stream represents the binary data "101."

This BPSK approach, combined with ToF information, enables UWB to calculate precise distance estimates even for indoor environments where multipath reflections are widespread. Using timestamped signals, UWB calculates the time it takes for signals to travel between devices, and then multiplies that time by the signal speed (speed of light) to obtain the distance.

Figure 2 shows the advantage of using ToF to calculate distance in an indoor environment. In the diagram, a UWB signal transmitted by the cube-shaped device reaches the circular device via several different paths. One path reaches the circular device directly through an intervening wall, while the other paths are longer because they involve reflections.

Because the direct path is the shortest, it reaches the circular device first and is used to calculate ToF. The other signals can

be ignored. Think of it like a race: many runners arrive at the finish line, but only the first runner wins. This method works regardless of the signal strength, so it doesn't matter if the direct signal has been attenuated by passing through the intervening wall.

In contrast, technologies that rely on RSSI can produce misleading distance and location measurements in indoor environments. A weak signal strength may lead the receiver to think the transmitting object is farther away when, in fact, the signal has been offset because it passed through a wall. Also note that UWB requires single measurements to determine your position accurately and reliably, while other RF technologies require multiple samples plus filtering to obtain a location result.

UWB Topologies

UWB technology can be implemented in different ways to address a wide range of different needs. The principal topologies are:

- Two-way ranging (TWR)
- Time difference of arrival (TDoA)
- Reverse TDoA
- Phase difference of arrival (PDoA)

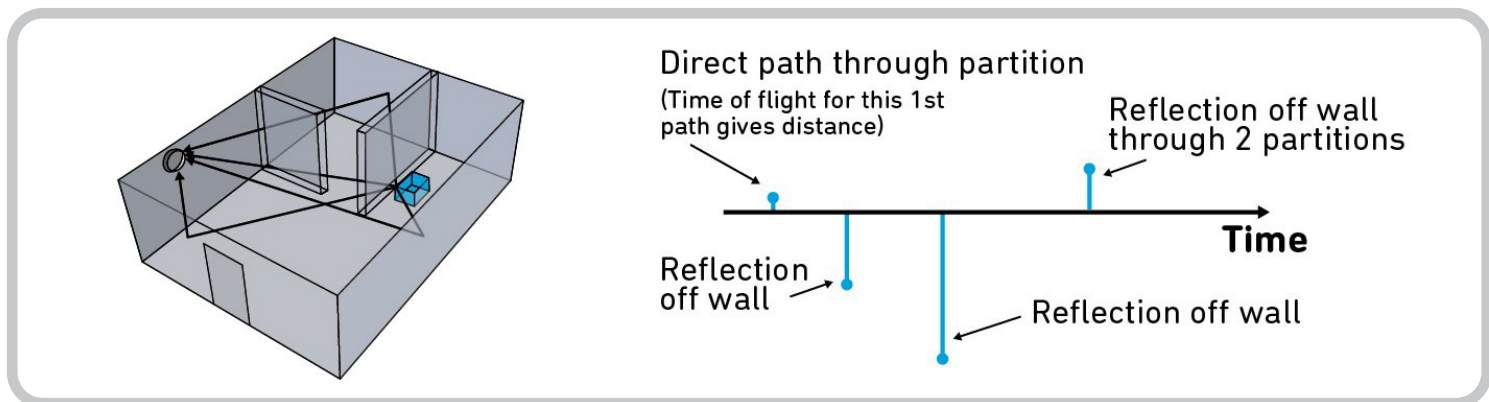


Figure 2: UWB is resistant to multipath effects because it uses ToF to calculate distance. (Source: Qorvo)

To understand distance and location measurement with UWB, it's essential to know the terms "anchor" and "tag." An anchor is generally a fixed UWB device with a known location. 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 as an anchor, tag, or both. 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.

Two-Way Ranging

The TWR method calculates the distance between a tag and an anchor by determining the time it takes for UWB RF signals to pass back and forth between them (ToF) and then multiplying that time by the speed of light. A keyless car entry system is an example of an application that uses TWR for secure and accurate distance determination.

As **Figure 3** shows, the tag initiates TWR by sending a poll message with the known address of an anchor. The anchor records the time that it receives the poll message and sends a response. When the tag receives the response, it calculates the signal ToF based on the signal round-trip time (T_{round}) and the time it took for the anchor to process and reply to the initial poll message (T_{reply}). The distance is calculated by multiplying the ToF by the speed of light. If required, the tag can then pass the calculated distance to the anchor in a final message.

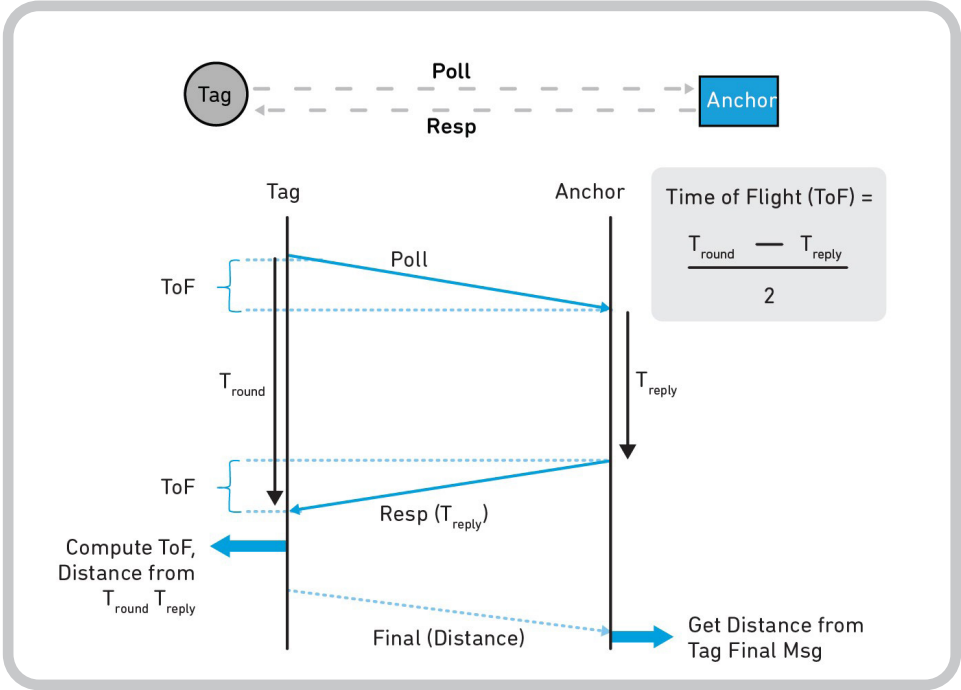


Figure 3: Secure two-way ranging between UWB tag and anchor. (Source: Qorvo)

With multiple anchors each requiring its own antenna, TWR can be used to determine the absolute position of mobile devices or other tags. By determining the distance to three or more anchors in known locations, the device can estimate its location with great accuracy. It can then communicate the distance to location-based applications or gateways using UWB or other wireless technologies, as shown in **Figures 4** and **5**. The disadvantage of using TWR for location measurement in this way is that the tag must carry out a lot of communication, which increases its power consumption and limits scalability.

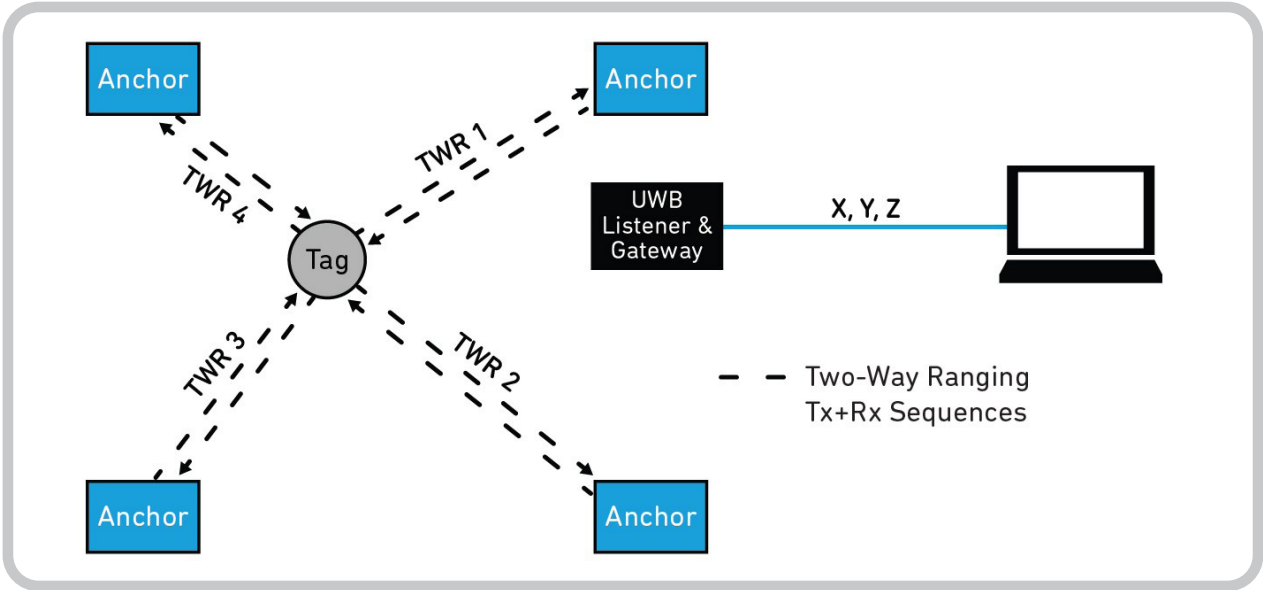


Figure 4: Two-way ranging with 2D/3D assets and listener. (Source: Qorvo)

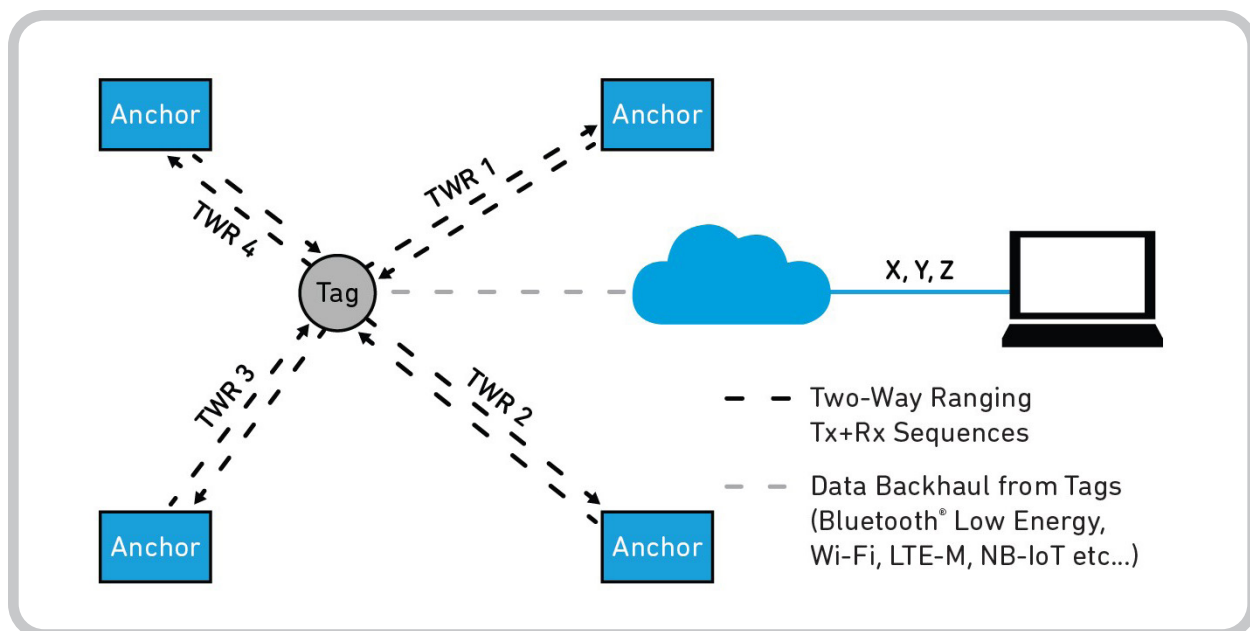


Figure 5: Two-way ranging with 2D/3D assets and data tag backhaul. (Source: Qorvo)

Time Difference of Arrival

The TDoA method is a highly scalable process for determining the location of tags within a venue. Because tags only need to transmit once during the process, they use very little power and, therefore, have a very long battery life.

Multiple anchors are deployed in fixed and known locations and are tightly time-synchronized. When a mobile device sends a “beacon” or “blink” signal, each anchor that receives the signal timestamps its arrival based on the common synchronized time-base. The timestamps from multiple anchors are then forwarded to a central location engine,

which runs multilateration algorithms to determine the device’s location based on the differences in the time that the signal arrived at each anchor. The result is a 2D or 3D position for the mobile device (**Figure 6**).

Reverse Time Difference of Arrival

It is also possible to implement a reverse TDoA system, which works a bit like GPS. Here, the anchors transmit synchronized blinks (with fixed/known offsets to avoid collisions), and the mobile devices use TDoA and multilateration algorithms to compute their location (**Figure 7**).

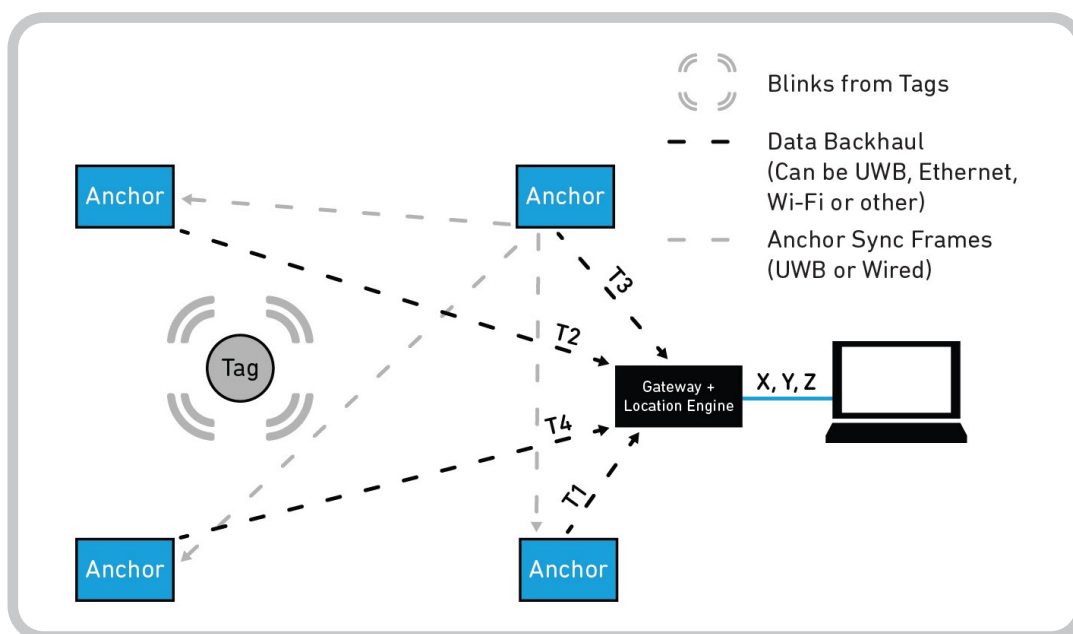


Figure 6: Determining location with multiple anchors using time TDoA. (Source: Qorvo)

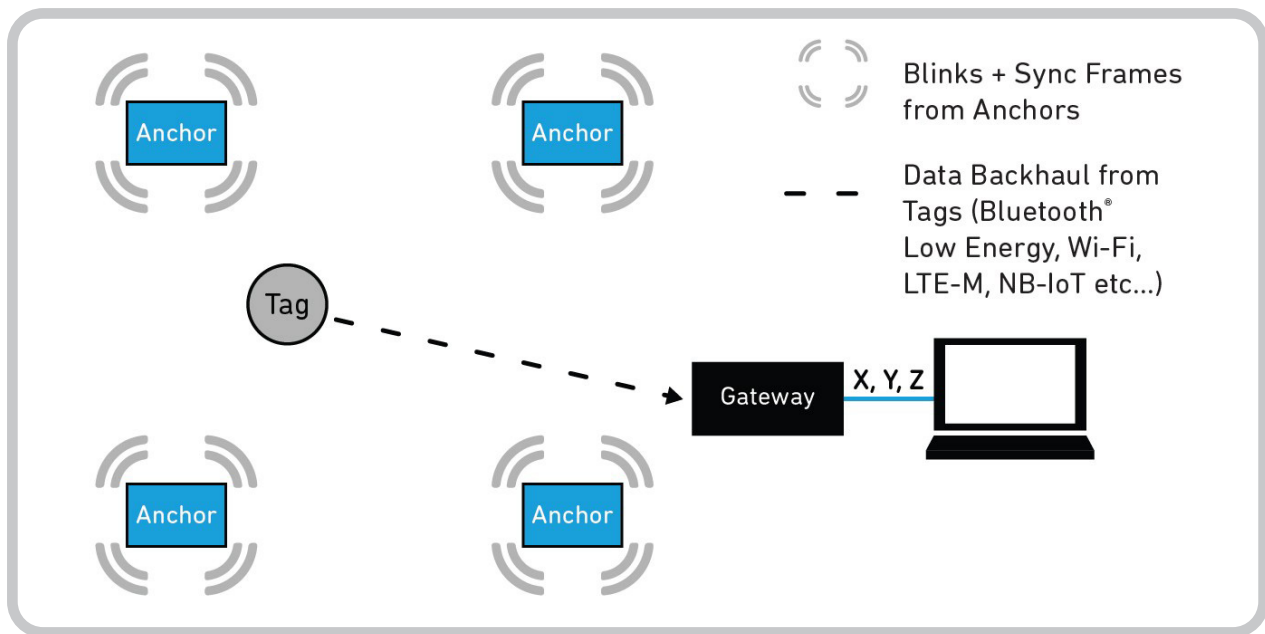


Figure 7: Reverse TDoA uses synchronized blinks to transmit signals from multiple anchors. (Source: Qorvo)

Phase Difference of Arrival

The PDoA method enables two devices to calculate their relative positions using a combination of distance and directional information, thus eliminating the need for any other infrastructure. This simplified method is very important for peer-to-peer applications or when needing to reduce the amount of infrastructure to be deployed.

For PDoA, one of the devices must carry at least two antennae. When this device receives a signal from the other device, it measures the difference in the phase of the arriving

signal at each antenna. Based on this information, it can calculate the angle from which the incoming signal arrived (**Figure 8**). The receiving device now knows the transmitting device's direction and distance.

UWB Regulations

UWB operates in a regulated yet unlicensed spectrum, so anyone can implement UWB communications without a telecommunications license as long as their system operates within the regulated frequency and power range.

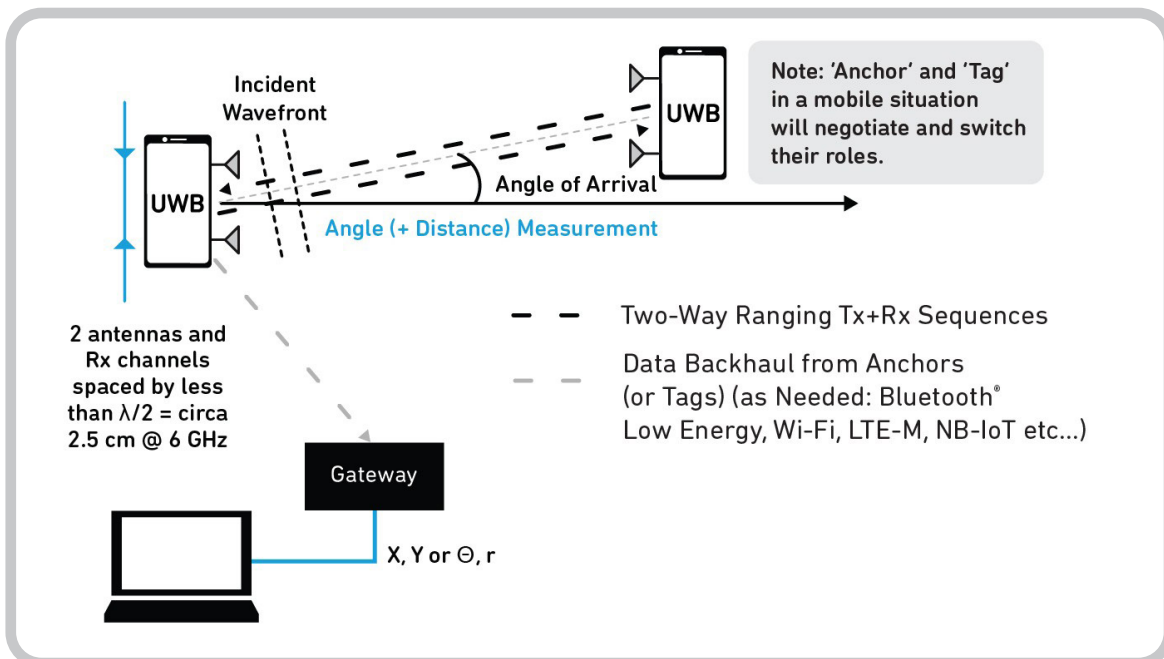


Figure 8: Using PDoA to calculate direction as well as distance. (Source: Qorvo)



The Federal Communication Commission (FCC) has defined UWB systems as those operating with an absolute bandwidth—larger than 500MHz—with maximum power density at a central frequency (f_c) above 2.5GHz, or fractional bandwidth greater than 0.2 with f_c lower than 2.5GHz.

Figure 9 illustrates the calculation of absolute bandwidth (B) and fractional bandwidth. Maximum power density is at the central frequency f_c , and f_H and f_L are the high and low frequencies at which the power spectral density is 10dB below f_c . B_{frac} is defined as B/f_c . In terms of high and low frequencies, we have

$$f_c = \frac{(f_H + f_L)}{2} \text{ so } B_{frac} = 2 \times \frac{(f_H - f_L)}{(f_H + f_L)}$$

The UWB radio frequency range, as defined by the FCC, is between 3.1GHz and 10.6GHz (**Figure 10**).

The FCC and other organizations also limit the power of UWB transmissions to avoid interference with other technologies. Although UWB's large bandwidth is a very useful property, it means that the frequencies used by UWB overlap with those used by other communications technologies (**Figure 11**).

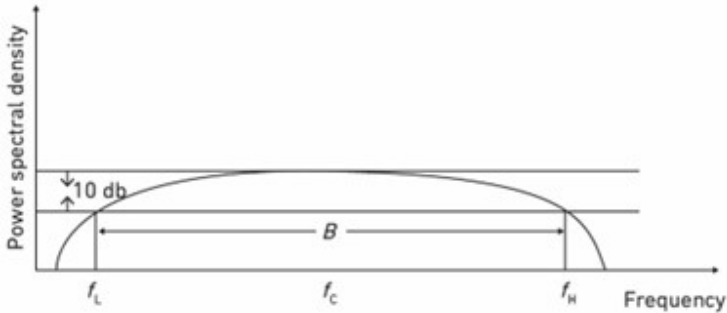


Figure 9: Power spectrum of a UWB system's low, central, and high frequencies. (Source: Qorvo)

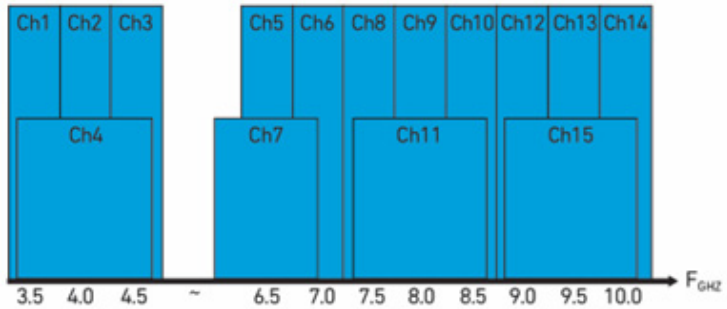


Figure 10: FCC-defined radio frequency ranges for UWB. (Source: Qorvo)

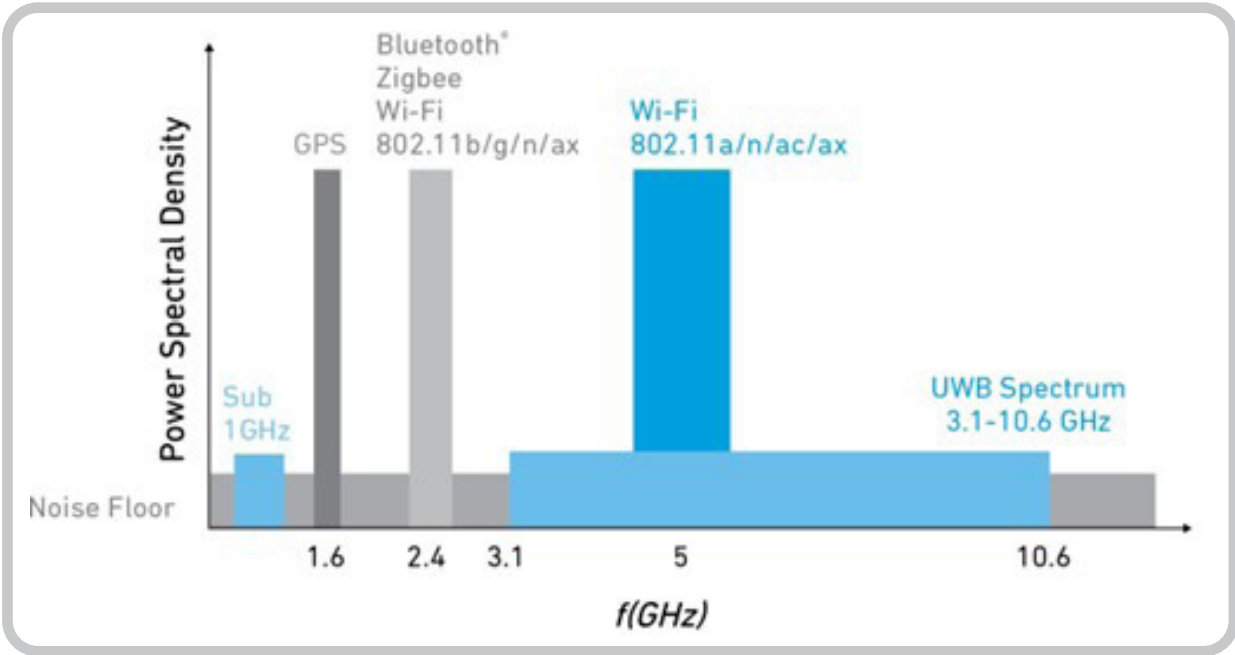
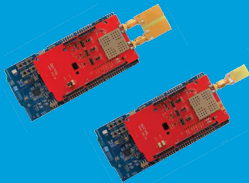


Figure 11: UWB frequencies coexist with other wireless technologies. (Source: Qorvo)



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As seen in **Table 1**, the FCC limits equivalent isotropically radiated power (EIRP) to -41.3dBm in the 3.1GHz - 10.6GHz range, with even tighter restrictions in other frequency ranges.

Table 1: UWB EIRP limits. (Source: Qorvo, 2021)

Frequency (MHz)	EIRP (dBm)
960-1610	-75.3
1610-1990	-53.3
1990-3100	-51.3
3100-10600	-41.3
Above 10600	-51.3

Different players within the UWB industry—from semiconductor suppliers to device manufacturers and test equipment vendors—have already started to address this need for interoperability.

UWB Consortiums and Alliances

Interoperability is critical to ensure mass adoption of UWB. Because every user expects their electronic devices to easily connect and operate with minimal or no effort, it's vital that products, systems, applications, and services from different vendors work together reliably and predictably. Different players within the UWB industry—from semiconductor suppliers to

device manufacturers and test equipment vendors—have already started to address this need for interoperability. Notably, several key consortiums and alliances are collaborating to ensure the interoperability of UWB products. Among their goals is 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.



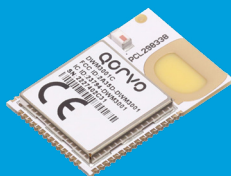
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Here are some of the groups focused on UWB interoperability:

- **FiRa Consortium:** 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. 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. The consortium is developing use cases across many industries, including hands-free access control, indoor location, navigation, and peer-to-peer applications. Their mission involves developing test specifications, certification programs, and events to support interoperability between UWB products.
- **Car Connectivity Consortium® (CCC):** The CCC is a cross-industry organization advancing global technologies for smartphone-to-car connectivity solutions. CCC stakeholders include car manufacturers, Tier 1 automotive 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.
- **UWB Alliance:** 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.

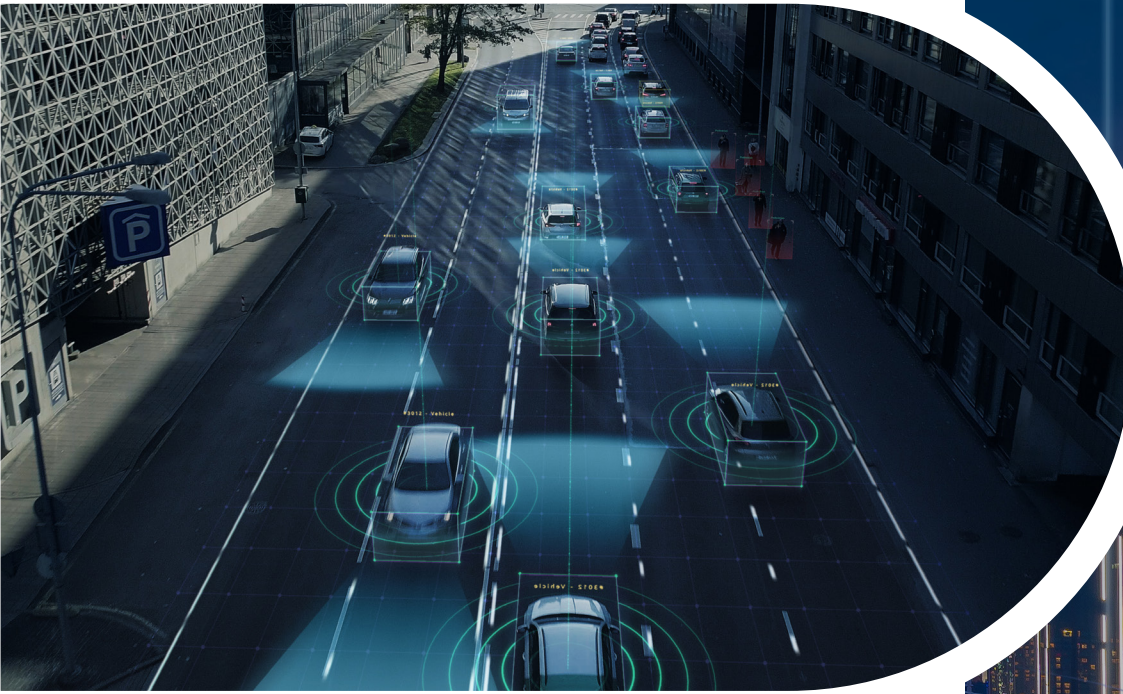
Conclusion

UWB is a technology on the brink of mass adoption. It is already being incorporated into leading smartphones and a wide range of other devices and is geared to become a communication standard seen everywhere. UWB is uniquely capable of calculating location, distance, and direction with unprecedented accuracy—indoors and outdoors—securely and in real time.

These capabilities will unleash a new wave of applications that use this highly accurate location and distance information to deliver new experiences and capabilities, including many applications not previously possible.

The Promise of Ultra-Wideband

Jon Gabay for Mouser Electronics



UWB technology is revolutionizing precise location tracking and data transmission with its high data rates, accurate positioning, and interoperability.

Leveraging high data rates and precise positioning capabilities, ultra-wideband (UWB) technology is increasingly recognized for its superior accuracy in location tracking and data transmission over short distances beyond the scope of Wi-Fi®, Bluetooth®, and GPS. Its capacity for fine-ranging and low-latency communication positions it as an essential tool in applications where centimeter-level precision is critical.

While Wi-Fi and Bluetooth have dominated the handheld and personal data device markets, UWB has been carving out a niche where those technologies (and GPS) can't perform as well, such as with accurate position sensing and tracking. Even RFID can't compare with the features and benefits of UWB (**Figure 1**).



TECHNOLOGY					
WHERE USED					
ACCURACY	 Centimeter	 1-5 meters	 5-15 meters	 Centimeter to 1 meter	 5-20 meters
RELIABILITY	★★★★★ Strong immunity to multi-path and interference	★★★★☆ Very sensitive to multi-path, obstructions and interference	★★★★☆ Very sensitive to multi-path, obstructions and interference	★★★★★	★★★★☆ Very sensitive to obstructions
RANGE / COVERAGE	 Typ. 70m Max 250m Typ. 250m² per anchor	 Typ. 15m Max 100m Typ. 25m² per beacon (for 2m accuracy)	 Typ. 50m Max 150m Typ. 100m² per access point (for 5m accuracy)	 Typ. 1m Max 5m Typ. 25m² per reader	N/A
DATA COMMUNICATIONS	 up to 27Mbps	 up to 2Mbps	 up to 1Gbps		
SECURITY (PHY LAYER)	★★★★★ Distance-Time bounded protocol	★★★★☆ Can be spoofed using relay attack	★★★★☆ Can be spoofed using relay attack	★★★★☆ Can be spoofed using relay attack	N/A
LATENCY	★★★★★ Typ. <1ms to get XYZ	★★★★☆ Typ. >3s to get XYZ	★★★★☆ Typ. >3s to get XYZ	★★★★☆ Typ. 1s to get XYZ	★★★★☆ Typ. 100ms to get XYZ
SCALABILITY DENSITY	★★★★☆ >10's of thousands of tags	★★★★☆ Hundreds to a thousand tags	★★★★☆ Hundreds to a thousand tags	★★★★★ Unlimited	★★★★★ Unlimited
POWER & BATTERY	 5nJ/b TX · 9nJ/b RX Coin Cell	 15nJ/b RX/TX Coin Cell	 50nJ/b RX/TX Lithium Battery	 Passive	 Lithium Battery
TOTAL COST (infrastructure, tag, maintenance)					

Figure 1: UWB is far superior to Wi-Fi, Bluetooth, and RFID in many ways, especially location tracking accuracy and latency. (Source: Qorvo)

As a peer-to-peer network, UWB can hand off signals to adjacent nodes and accurately track movement as tracked objects move into and out of range. This capability enables UWB to be effective in wide-area network applications, utilizing a mesh or baton-passing architecture for expansion. Such an approach covers vast areas, reaching aggregated access points and facilitating optimal node placement. Additionally, it reduces the need for line of sight, enhancing flexibility in various environments.

Based on a hierarchy of anchored initiators and responders, UWB allows multiple devices, sensors, actuators, peripherals, and remote machines to create a personal area network with delineated zones and regions.

It uses a wider bandwidth of the signal spectrum (from 3.1GHz to 10.6GHz), allowing UWB signals to coexist with other RF technologies with minimal interference. It can penetrate walls and ceilings, so it may be used in many indoor applications. But its most significant near-term use will be within the automotive industry.

UWB allows devices to operate within an extensive bandwidth (**Figure 2**). This allows frequency and band selections that are low noise for any specific application. Various modulation schemes can be used to further enhance reliability, including pulse position modulation, bipolar signaling, pulse amplitude modulation, and on/off keying. UWB can also use orthogonal frequency-division multiplexing (OFDM) by subdividing the bandwidth into broadband channels.

Enhancing Advanced Driver Assistance Systems

UWB technology can significantly benefit applications such as autonomous vehicles, drones, robots, asset tracking, and driver assist functions. Perhaps the most lucrative use for UWB is with rapidly advancing modern automobiles, which contain a plethora of sensors and sensor systems. Modern Ethernet-based networking connects sensor zones associated with engine, transmission, multimedia, and entertainment systems inside the vehicle. Still, for lidar, radar, camera systems, and other autonomous driving technologies, automotive systems rely on connected automated vehicle (CAV) sensors. When linked using UWB, CAV sensors become a part of a more comprehensive network.

CAV sensor systems enable important smart automotive technologies such as vehicle-to-vehicle (V2V) and vehicle-to-everything (V2X) connectivity. V2V communications are necessary to help measure distances between vehicles while in motion or performing functions like automated parking, lane alignment, and even pedestrian detection and avoidance. V2X connectivity—which includes V2V, vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and more—enables communication between vehicles and surrounding connected objects and systems, such as traffic signals and emergency vehicles.

Current technologies like GPS assist drivers well enough, and AI-based GPS can even suggest routes that avoid slowdowns. However, the high precision of UWB coupled with GPS can

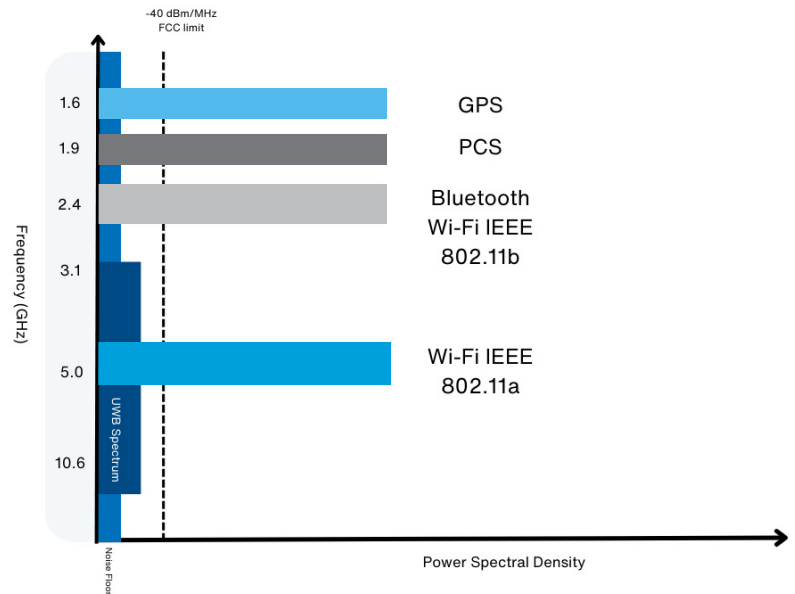


Figure 2: Because UWB utilizes such a wide spectrum, other RF sources do not emit interference. (Source: Mouser Electronics/Jon Gabay)

ensure safety in circumstances where GPS alone will not. For example, if GPS routes a semi-autonomous car through an unfamiliar country road covered in unplowed snow, with no lane markers or indicators of the road edges, the car could easily drive off the road and into danger. In this scenario, the boundaries of the lanes are not visible, and GPS is not accurate enough to relay the exact position to the car's navigation in real time. With UWB and its centimeter-level accuracy, however, the car could navigate the road safely.

Reliability, Speed, and Accuracy

V2X technologies require secure identification and communications, high data rates, and low latencies. This means it must be very hard for any other RF signal to interfere or step on these lines of communication.

UWB is ideal for V2X for two reasons. First, the operating range of 3.1GHz to 10.6GHz keeps it outside the high-traffic RF formats and protocols like Wi-Fi, Bluetooth, Zigbee, HAL, and non-5G cell networks. Second, because UWB is based on pulse radio technology, many devices can be present

CAV sensor systems enable important smart automotive technologies such as vehicle-to-vehicle (V2V) and vehicle-to-everything (V2X) connectivity.





within a volumetric sphere of communication. The quick 2ns bursts can fit between other packets without colliding. This lack of interference allows very accurate time-of-flight measurements to be performed, resulting in high-precision distance-measurement capabilities.

UWB can provide up to 1000 accurate location samples per second for more effective communications, position tracking, and locating, easily 50 times more accurate than GPS. The encompassing standard, IEEE 802.15.4z, incorporates secure ranging and is very immune to spoofed sources. Once synchronized, UWB can measure the time it takes for a signal to travel from transmitter to receiver (time of flight) by multiplying the time by the speed of light. The narrow pulses discriminate against multi-path reflections, and each frame contains a scrambled time code. The 200µs transmit time allows the 1ms round trip measurement, yielding 1000 measurements per second.

With this combined reliability, speed, and accuracy, UWB technology can enhance cooperative driving with precise timing for traffic systems, clear pathways for emergency responders, and more safety measures.

Interoperability

UWB is not limited to automotive safety and autonomous driving technology, offering many uses outside the automotive industry. For example, many pet owners have their veterinarians implant microchips in their pets to provide identification. With UWB's centimeter resolution, future microchips could relay not just identification, but also precise

location should the pet go missing. This same application can work with our mobile devices, laptops, and even wearables.

However, achieving these types of applications will require UWB to work universally across devices and networks. Such interoperability requires cooperation between standards agencies, civic authorities, device makers, and the cellular infrastructure. The IEEE standard is an excellent place to start, and global consortiums are a good way of passing the baton.

One such group, the [FiRa Consortium](#), is dedicated to the “fine ranging” capabilities of modern and future devices. The FiRa Consortium brings together a broad range of companies to devise and promote the interoperability of products and solutions based on UWB technologies.

Fixed-Point Data

While not every application needs location information, fixed-point devices can also benefit from UWB. Arrays of temperature, geological, weather, volcanic, and other scientific data-gathering equipment can use UWB as a means of communicating. An aircraft flyby can read sensor data in some undersea sensors and measurement devices. Even without a flyby, the strategic location of access points could allow a dynamically reconfigurable network to get its data through, even in changing conditions.

Fixed-point devices like door locks can use UWB as a secure near-field means of access and identifying and preparing a house for residents. Already, UWB is integrated into smartphones to unlock homes and automobiles.

UWB Going Forward

Most major device manufacturers have incorporated UWB technology into their devices, meaning there is a large base of knowledge and experience, plus wide availability of parts and development resources. As a result, the design community can tap into a wealth of resources to get to market quickly.

For example, **Qorvo®** is pioneering UWB technology, devices, and modules. Qorvo Impulse Radio UWB technology touts low power and secure, centimeter-level accuracies with low latency and interoperability with industry standards.

Evaluation boards like the **DWM3000EVB** shield support 6.5GHz–8GHz UWB channels for use as UWB transceiver modules or embedded designs. Engineers can also directly design with IC chips that operate as low as 1.5V, like the **DW3000 series transceivers**, which use a simple SPI interface and support up to 6.8 Mbits/sec. in the 5.6 to 8GHz band.

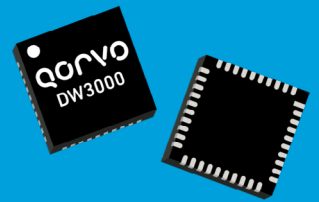
Conclusion

UWB technology is setting a new standard in the realm of wireless communications, delivering unparalleled precision in location tracking and high-speed data transfer. It offers a promising future not only for the automotive sector but also in a broad spectrum of applications, ranging from home security to ecological research. As it continues to integrate seamlessly with existing technologies and standards, UWB paves the way for a more connected and efficient world, pushing the boundaries of what is possible with wireless communication.



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Wi-Fi 7 Offers New and Improved Features

JJ DeLisle For Mouser Electronics



How Wi-Fi 7 Will Reduce Latency, Enhance Determinism, Increase Speeds, & Unleash Wireless Networking's New Potential

Wi-Fi 7, like previous generations, promises support for more connected devices, lower latency, and even faster connections. Several new Wi-Fi 7 features will differentiate this generation from previous generations, such as multi-link operation, preamble puncturing, and wider channel bandwidth.

Introduction

As expected, the latest Wi-Fi Alliance® standard under development, Wi-Fi® 7 (**IEEE 802.11be**), is being designed to unleash a new level of wireless networking performance. Like many previous Wi-Fi generations, this new standard isn't merely a sum of features dedicated to enhancing throughput but also a wider range of wireless innovations that can enable new use cases and enhance capabilities for existing ones. For instance, Wi-Fi 7 is poised to unleash unprecedented low latencies for a wireless network and introduce significant features to enable determinism.

The leading new technologies and enhancements that Wi-Fi 7 will bring are 4K quadrature amplitude modulation (QAM), 320MHz channel bandwidths, Multiple Resource

Units (MRUs), enhanced multi-user multi-input multi-output (MU-MIMO) technology, multi-link operation (MLO), and multiple access points (APs). Many of these new features take some unpacking to understand their benefits and come with various additional technologies and features. This article aims to provide a primer on the new technologies and enhancements introduced in Wi-Fi 7, explaining how these features will enable devices to empower new use cases such as augmented reality/virtual reality (AR/VR), hardline replacement, real-time networking, and many other time-critical and high-performance applications.

Wi-Fi 7 Critical Differentiators

The main enhancements in the new Wi-Fi standard are MLO, physical layer (PHY) enhancements, multi-AP coordination, and enhanced security. This section will provide a brief overview of these categories as well as details of the key features (**Figure 1**) that enable these enhancements. Though these new technologies and enhancements are not guaranteed until the 802.11be amendment is finalized in early 2024, Wi-Fi 7 products have been advertised on the market since early 2023. These products may require software updates to capture the full range of new Wi-Fi 7 features and enhancements after the standard's full release.

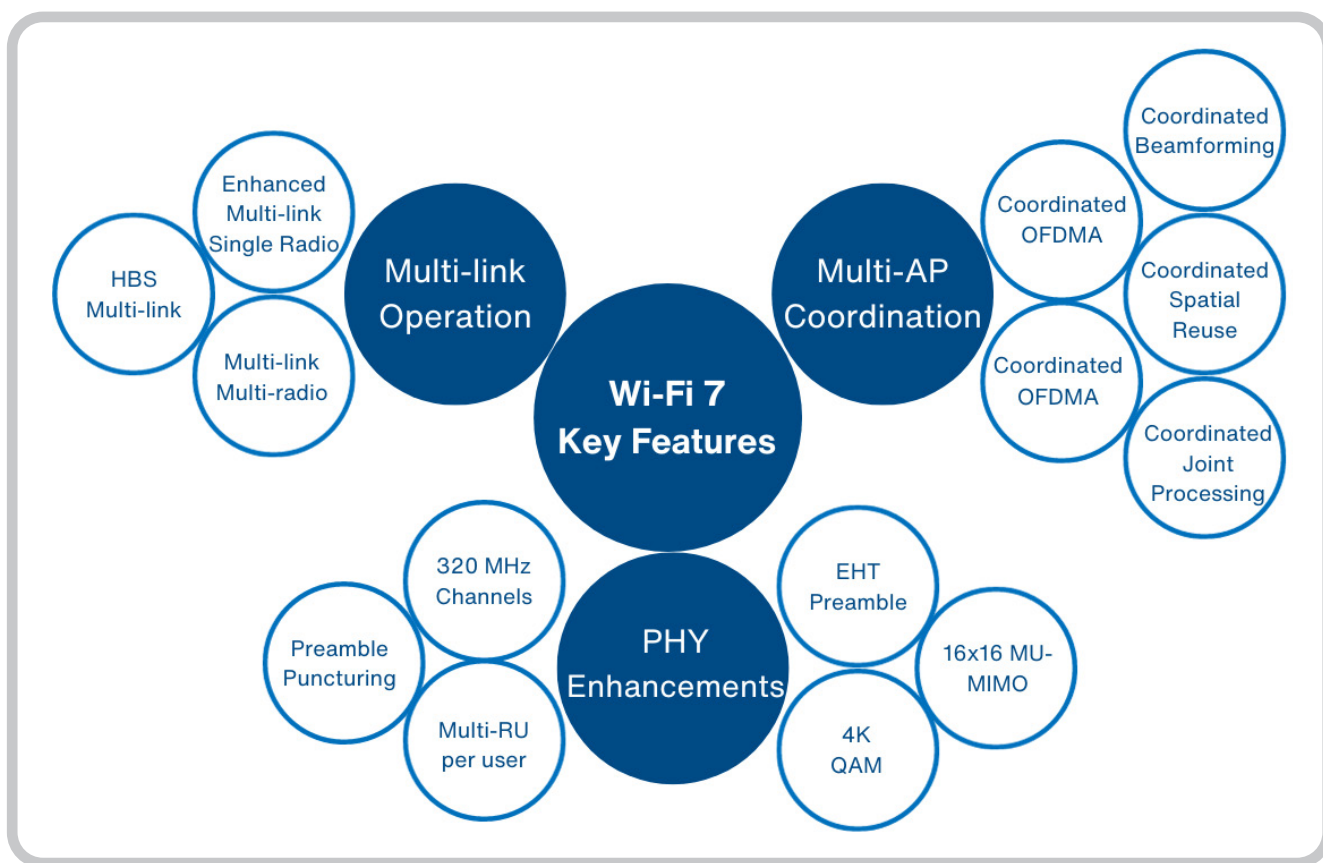


Figure 1: Key features of Wi-Fi 7. (Source: Gaurav Khandelwal. "What to Expect from Wi-Fi 7 (IEEE 802.11be)?" Intricate Research, February 22, 2023. <https://www.intricate.com/post/wi-fi-7-ieee-802-11be>. Redrawn by Mouser Electronics)





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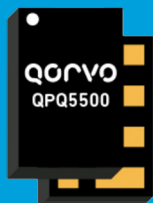
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Multi-Link Operation

MLO technology enables Wi-Fi devices to use multiple channels across different frequency bands simultaneously for transmission and reception over multiple links. This technology enhances speed in congested environments and promises a much more robust wireless link. MLO also has the potential to dramatically reduce latencies by making use of frequency bands that are more responsive in a given environment.

High Band Simultaneous Multi-Link

High Band Simultaneous (HBS) Multi-Link is a feature that allows the simultaneous use of two Wi-Fi radios for four-stream operation in the high-frequency bands of 5GHz and 6GHz. This is especially promising for areas where the 6GHz spectrum is not yet available, as HBS Multi-Link allows for the aggregation of two 160MHz channels in the 5GHz band for a link that can deliver 5Gbps or a combination of a 160MHz and 80MHz channels that can still provide speeds 50 percent faster than Wi-Fi 6/6E.

Enhanced Multi-link Single Radio

Enhanced multi-link single radio (EMLSR) technology is designed to enable efficient dynamic switching among multiple Wi-Fi bands. With EMLSR, a client can listen on two channels, but transmission only occurs on a single channel. To achieve this, the client device performs Clear Channel Assessment (CCA) and receives a control frame, which allows the client to indicate where the next transmission will occur.



The new spectrum opened by Wi-Fi 6E is further employed by Wi-Fi 7 with channel bandwidths extended to 320MHz.



This proposed feature can substantially enhance the use of the secondary channel. EMLSR could lead to between 50 and 70 percent improvements in throughput gain even while subjected to a heavy overlapping basic service set (OBSS) load on single-link (SL) or both primary link (PL) and SL. Hence, this method allows devices with a limited number of transceivers to enhance the latency of a client device without adding significant complexity.

Enhanced Multi-link Multi-radio

EMLMR allows for Wi-Fi devices to operate on multiple links concurrently. There are two EMLMR modes: non-simultaneous transmit and receive (NSTR) and simultaneous transmit and receive (STR). In NSTR EMLMR, no simultaneous transmission and reception is allowed over the pair of links to prevent self-interference. With STR EMLMR, where self-interference isn't a concern due to sufficient frequency separation between the channels or self-interference cancelation capabilities, full simultaneous use of all available channels is possible in multiple bands. STR EMLMR grants an incredibly high level of flexibility and minimal signaling, which is ideal for reducing latency, ensuring communication robustness, and enabling determinism.

PHY Enhancements

Alongside MLO, IEEE 802.11be boasts a wide range of PHY enhancements. These include unique new features to combat interference, such as preamble puncturing and major shifts in spectrum/channel bandwidth availability.

Multiple Resource Units (MRU)

Wi-Fi 7 also allows more than one resource unit (RU) to be assigned to a single station. The result is increased throughput, improved interference immunity, and more

optimal spectrum use. This pairs with orthogonal frequency-division multiple access (OFDMA) and further reduces multi-user latency by a predicted 25 percent.

Preamble Puncturing

Preamble puncturing, or just puncturing, is a feature of MRU that allows for selective puncturing of overlapping spectrum portions. This ensures that the data transmitted is only sent along clear frequency channel portions, which enables enhanced data rates and increased reliability in congested environments.

Wider Channel Bandwidths and New Spectrum

The new spectrum opened by Wi-Fi 6E is further employed by Wi-Fi 7 with channel bandwidths extended to 320MHz. This is double the Wi-Fi 6/6E support of 160MHz channel bandwidths, though Wi-Fi 7 still supports these 160MHz modes.

Higher Order Modulation (4096-QAM)

The modulation complexity for Wi-Fi 7 is dramatically increased over Wi-Fi 6. With Wi-Fi 6, the modulation depth is 1024-QAM (1K QAM). Wi-Fi 7 increases this to 4096-QAM (4K QAM). Though increased modulation complexity can lead to greater susceptibility to noise and phase noise, it also allows for much higher data rates.

Additional Spatial Streams

The maximum spatial stream capability for Wi-Fi 7 is also being increased to sixteen, which is double that of Wi-Fi 6. With up to sixteen spatial streams, 4K QAM, and 320MHz channel bandwidths in the 6GHz spectrum, Wi-Fi 7 could reach maximum client speeds of 46Gbps.





Downlink and Uplink MU-MIMO

Where previous Wi-Fi versions supported only downlink MU-MIMO, Wi-Fi 7 also proposes the ability to support uplink MU-MIMO. This new feature allows for simultaneous transmission and reception among multiple devices across all spatial streams.

Enhanced Quality-of-Service Management

There are many quality-of-service (QoS) enhancements proposed with Wi-Fi 7. This crux is that Wi-Fi 7 should feature a defined QoS provisioning model that includes a dedicated, low-latency, deterministic, and reliable access category.

The following are the main QoS enhancements in Wi-Fi 7:

- Managed QoS and restricted service periods
- Deterministic low latency
- QoS signaling
- Forward-compatible preamble design U-SIG
- Restricted service periods
- National Security and Emergency Preparedness (NSEP) Priority Service
- Triggered peer-to-peer (P2P) Operation
- Four types of physical layer protocol data units (PPDUs)
 - Single user (SU) PPDU
 - Multi-user (MU) PPDU
 - Trigger-based (TB) PPDU
 - Extended range (ER) PPDU

Though Wi-Fi 6 devices can reach latencies as low as single-digit milliseconds, this is often under ideal circumstances, and the worst-case latency can be extremely high in congested environments. With Wi-Fi 7, QoS enhancements and new technologies are being developed to ensure that single-digit millisecond latencies can be sustained for devices in this access category.

Multi-AP Coordination

Multi-access point (MAP) coordination is now a key feature of Wi-Fi 7, designed to improve utilization of limited radio resources. Current Wi-Fi technologies are geared toward fully distributed operations without any significant coordination capability among these APs (with the exception of proprietary Wi-Fi mesh technologies). However, even these solutions are focused on long-term network configurations, and the performance and features of these meshes depend widely on the manufacturers' approach and hardware configurations. Wi-Fi 7 MAP will provide tighter optimization of the PHY and media access control (MAC) layers to achieve better performance in MAP systems.

Several schemes are being considered for MAP:

- Coordinated OFDMA
- Coordinated spatial reuse (SR)
- Coordinated time domain multiple access (TDMA)
- Coordinated beamforming (BF)
- Coordinated joint processing (JP)

Conclusion

To meet user demands for AR/VR, hardline replacement, real-time networking, and many other time-critical and high-performance applications, Wi-Fi latency must be consistently reduced, and determinism is essential. The next evolution of Wi-Fi is being prepared to offer performance enhancements across the board and specific new technologies and features to enable previously underserved or novel use cases.

Though the latest Wi-Fi standard, IEEE 802.11be (Wi-Fi 7), is yet to be set in stone, early 2024 will herald the new Wi-Fi amendment and open the floodgates to fully compliant Wi-Fi 7 technologies ranging from smartphones, laptops, and tablets to smartwatches, access points, AR/VR headsets, and more.

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Reimagining Antenna Design Solutions for Next-Generation Mobile Devices

By Qorvo

Rapid innovation in next-generation mobile devices is creating significant engineering challenges in the form of antenna implementation. A key issue is that 5G handsets typically have more than twice as many RF paths as LTE phones due to new bands and requirements in the cellular, Wi-Fi®, ultra-wideband (UWB), mmWave (mmW), and GPS standards. However, a lack of space limits the ability to add new antennas, and sharing antennas among many bands creates complex problems. Innovations in industrial design, such as foldable or rollable screens and replacing physical buttons with virtual controls, impose significant constraints on antenna design and placement. Additional challenges are created by conflicting targets of increases in carrier power requirements and OEM system efficiency targets and improvements (i.e., battery life). With an extensive track record of helping companies solve the toughest RF problems, Qorvo Antenna Solutions Reimagined (QASR) helps engineers navigate space, design, and performance challenges to harness the true power of antennas in their RF architectures.

The Rapidly Evolving Mobile Industry

The mobile industry's rapid pace of innovation continues unabated as smartphone and wearable manufacturers and mobile operators race to offer increased coverage, higher data rates, new wireless communications capabilities, and revolutionary industrial designs.

Smartphone manufacturers are expanding 5G support across product lines to support the ever-growing demand for data-intensive services such as video streaming, video conferencing, music, and gaming. Accordingly, support for 5G high-bandwidth sub-6GHz bands (n77/n78 and n79) and even wider mmW bands (n257-n261) is spreading from premium to mid-tier and mass-market phones. Adding to the RF complexity, 5G requires not only the addition of new cellular bands but also 4x4 multiple in/multiple out (MIMO) support on higher-frequency bands to deliver faster data speeds.





Figure 1: As manufacturers add more non-cellular bands to provide faster networking and support new location-based services, RF challenges continue to increase. (Source: Qorvo)

Manufacturers are also adding more non-cellular bands into handsets to provide faster networking and support new location-based services (**Figure 1**). For example, Wi-Fi 6E/7 expands Wi-Fi into the 6GHz band and provides extra-wide 160MHz–320MHz channels to offer higher performance for applications such as high-definition streaming, virtual reality, and peer-to-peer gaming while easing congestion of heavily used Wi-Fi spectrum.

UWB technology, first implemented in premium phones, is also increasingly appearing in mid-tier and mass-market phones. UWB enables distance and location to be calculated indoors or outdoors with unprecedented accuracy—within a few centimeters—and is enabling entire new categories of location-based applications and devices. As its name suggests, UWB uses channels that are at least 500MHz wide over a broad 3.1GHz–10.6GHz frequency range with a (current) focus of 6GHz–9GHz in mobile applications. Manufacturers are also adding the new GPS L5 and L2 bands, which offer advantages such as increased positioning accuracy for mission-critical applications.

Meanwhile, smartphones are adding an ever-growing number of complex combinations of multiple cellular bands as mobile operators seek to optimize their existing spectrum to offer higher data rates. Many operators are using E-UTRAN New Radio—Dual Connectivity (EN-DC), which enables them to deploy 5G data speeds much more quickly in certain regions by using a 4G anchor band in combination with 5G data bands. Carrier aggregation (CA), which combines multiple component carriers (CCs) to provide greater bandwidth and faster data rates, is becoming much more complex as more bands are added to combination options. 5G defines hundreds of new combinations of up to

16 CCs, each with contiguous bandwidth up to 100MHz, for a total aggregated bandwidth up to about 1GHz. These include challenging new aggregations of two or more low-frequency bands, such as B20 + B28 combinations in Europe or Asia and B5 + B12, B13, or B14 in North America, which offer the advantage of extended range and greater throughput.

Manufacturers are also implementing higher transmit power to increase coverage with higher-frequency signals, which don't travel as far as those using lower frequencies. Already in widespread use is Power Class 2, which doubles transmit power at the antenna to 26dB, and the industry is currently exploring Power Class 1.5, which specifies a further two-fold power increase to 29dB.

Industrial Design Innovation

Smartphone industrial design is evolving rapidly as manufacturers seek new ways to differentiate their products and offer exciting new consumer experiences. Revolutionary designs include phones with expanding rollable screens and flip phones with foldable displays. Displays that wrap around the edges of phones offer a sleek, cutting-edge appearance while maximizing the screen area available to consumers. Physical buttons are being replaced with virtual controls, typically located on the lower or side edges of these handsets. And manufacturers continue to add other new features that users value, such as better displays, more cameras, multiple biometric authentication methods, higher-quality speakers, and larger batteries. While they are highly attractive to consumers, these features consume space, reducing the area available for the RF front end (RFFE) while also placing new restrictions on where RFFE components and antennas can be located.

Accompanying these trends is the proliferation of small Internet of Things (IoT) devices with cellular and/or non-cellular connectivity, including watches, other wearables, and small tracking devices. Space is at a premium in these devices, and the ability to squeeze RF content into a tiny amount of space is essential.

Antenna Challenges

These innovations in connectivity and industrial design create a broad variety of interrelated antenna challenges for engineers working on next-generation smartphones and other mobile devices.

RF Paths More Than Double

The addition of new cellular and non-cellular bands is massively increasing the total number of RF paths in mobile devices (**Figure 2**). A typical 5G phone with support for mmW bands and UWB has more than twice as many RF paths as a typical 4G phone. Each RF path needs to connect to an antenna, but it's simply impossible to double the number of antennas due to the limited space available in handsets: Increasing the number of antennas means they must be closer to each other, which reduces the isolation between them. This causes coupling-related issues, increasing the potential for non-linear elements in the RFFE, which desensitizes (i.e., desenses) the receiver.

Given the limitation on the total number of antennas that may be implemented in a fixed form factor, the logical approach to handling the growing number of RF paths is to increase each antenna's bandwidth to support a larger number of bands. However, this approach brings its own challenges: Wider-bandwidth antennas tend to be more lossy, and they may require more space because the size of an antenna is determined by the lowest frequency it supports.

Furthermore, using a single antenna to simultaneously transmit and receive multiple bands increases the risk of non-linear spurious emissions generated by mixing signals. Solving these problems is not easy—it requires careful analysis and specialized antenna design techniques combined with appropriate filtering and routing within the RFFE.

UWB

Supporting UWB requires three or four relatively large patch antennas, which consume a considerable amount of the already crowded space within handsets. Accordingly, manufacturers are looking for ways to combine some of these antennas to reduce the overall area required. A further consideration is whether to position one antenna on the edge of the phone for optimal omnidirectional ranging.

Carrier Aggregation and EN-DC

The rapid increase in band combinations for CA and EN-DC exacerbates the antenna challenges. Potential aggregations now include hundreds of different permutations of high-, mid-, and low-frequency bands. They include combinations of multiple bands within each frequency range (such as low-low or mid-mid aggregations) as well as combinations of bands in different regions of the spectrum (such as low-mid and low-mid-high). Furthermore, the maximum bandwidth of each CC has also increased. While 4G limited carrier bandwidth to 20MHz, 5G increases the maximum contiguous bandwidth to 45MHz for bands below 2300MHz and up to 100MHz for bands above 2300MHz.

Because the total number of antennas is limited, each antenna may need to provide high performance for wideband transmit and receive signals over a very wide frequency range, from 600MHz to 5000MHz.

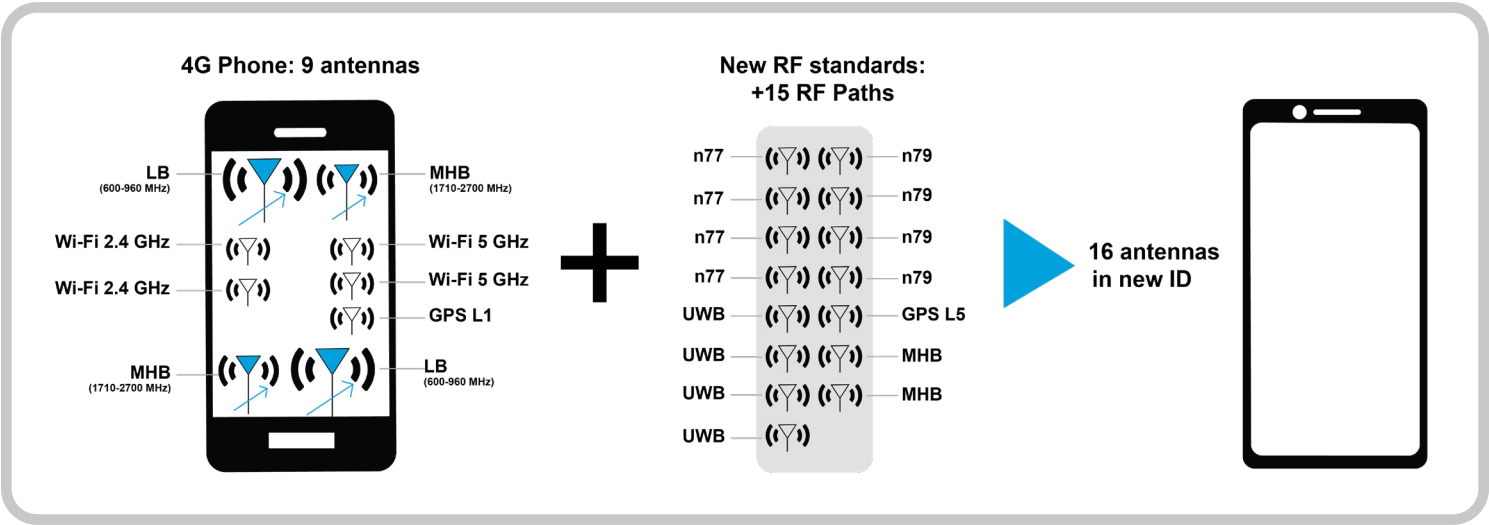


Figure 2: 4G to 5G transition increases constraints on the RF. (Source: Qorvo)



Low-low aggregations create some of the most difficult antenna design problems. Mobile phones typically support low-band frequencies using two primary antennas located at the top and bottom of the phone. These antenna locations minimize the likelihood that user interactions with the phone will impair performance because consumers generally position their hands at the sides of phones, not at the top and bottom. A critical problem is that low-low aggregations may need a third antenna capable of low-band transmissions. That means manufacturers need to find yet more space for this antenna within the handset and ensure that the chosen antenna location provides adequate performance under all use conditions.

Higher Transmit Power

The higher power output defined in the PC 2 and PC 1.5 specifications impacts smartphone battery life. It also means that all post-PA components within the RFFE, including antenna tuners, must handle more power. This generally means that components will need to be larger, which is problematic given the significant space constraints. The increased output power also means RFFE components will generate higher levels of spurious signals, requiring additional attention to mitigating desense and RSE issues.

New Designs Reduce Space for Antennas

New handset designs with foldable and rollable screens create a whole array of antenna challenges. The phone must be able to operate in different physical states—rolled or unrolled, folded, or open—which severely limits the potential locations for antennas, and may also require the use of different antenna materials. Adding to the challenge, the constraints imposed by the design may mean that antennas must be placed in suboptimal locations that make their performance more susceptible to human interaction. Antenna grounding may be affected, impacting radiation efficiency. Careful antenna design and positioning will be needed to ensure efficient operation in all use conditions.

The replacement of mechanical buttons with software-defined virtual buttons creates additional antenna challenges. Locating these buttons along the bottom of the phone maximizes convenience and the screen space available to users. However, this also means that they may interfere with the primary antenna traditionally placed in this location.

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Who Will Solve the Challenges First?

As this article demonstrates, next-generation mobile devices present considerable antenna design and engineering issues. Who will be the first to solve the challenges? The team that wins the innovation race will create a significant competitive advantage in the battle for consumers' minds and wallets, in addition to the well-deserved sense of pride that comes from overcoming challenging obstacles.

How QASR Can Help

QASR is uniquely placed to help smartphone engineers solve the antenna challenges in next-generation smartphones and other devices.

Qorvo is dedicated to investing in the technologies that enable innovation and support the mobile phone's continuing evolution—though innovative technologies alone are not enough to solve tough RF



problems. That's why Qorvo works closely with the mobile industry to help engineers overcome the unique design problems of each mobile device.

Qorvo has an unparalleled track record of helping manufacturers incorporate innovative solutions into smartphones and other devices, including:

- Introducing the industry's first antenna tuners, helping to improve antenna efficiency over a wider range of bands.
- Understanding combinations of antenna-plexers, new paths, and standards to address and simplify complex scenarios that are emerging.
- Driving new and custom technologies to address 5G requirements across antenna tuning, transmit capability, and RF routing.

QASR helps engineers navigate space, design, and performance challenges to harness the true power of antennas in their RF architectures.



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