



THE CONTINUED EVOLUTION OF SHORT-RANGE WIRELESS: NEW TECHNOLOGIES, FUTURE ENHANCEMENTS, AND EMERGING MARKET OPPORTUNITIES

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INTRODUCTION

Over the last 25 years, short-range wireless connectivity technologies, such as Wi-Fi, Bluetooth, Zigbee, and Near-Field Communication (NFC), have revolutionized the world in which we live, enabling an enormous connected device ecosystem that is projected to reach an installed base of 48 billion devices in 2023. In recent years, new connectivity technologies, such as Ultra-Wideband (UWB), have entered the market, promising to enable new use cases and experiences across a wide range of applications. These technologies have all undergone significant transformations since their inception, dramatically increasing performance, efficiency, reliability, security, and scalability, alongside bringing additional feature enhancements that enable them to better service certain targeted applications. Taking Wi-Fi as an example, if we compare single-band 2.4 Gigahertz (GHz) 802.11b and its several Megabits per Second (Mbps) throughput with recent real-world demonstrations of over 5 Gigabits per Second (Gbps) throughput via tri-band 802.11be (Wi-Fi 7), it is hard to believe that the two technologies fall under the same umbrella. In the same vein, Bluetooth's evolution from what was a high-power consumption, audio-centric technology in its Classic form, to a leading low-power wireless technology for Internet of Things (IoT) applications in the form of Bluetooth Low Energy (LE), is a further testament to the continued progress and expansion of the short-range wireless connectivity market over the last couple of decades.

However, continued innovation and growth in the connected device market is dependent upon the further evolution of short-range wireless connectivity technologies. The enormous diversity of consumer and IoT applications are such that a single technology is not able to meet the needs of every market. Meanwhile, future use cases will demand additional improvements from wireless technologies across almost all metrics—this will include throughput, latency, robustness, reliability, power consumption, range, security, scalability, efficiency, size, cost, interoperability, flexibility, and deployment density, to name a few. These enhancements will enable short-range wireless technologies to enable better performance in existing use cases, open new market opportunities, and lead to the development of innovative user experiences across multiple verticals.

Combined, this evolution has led to an extremely competitive short-range wireless technology landscape, with multiple different viable technologies, each with its own strengths and weaknesses, targeting a whole host of consumer and commercial use cases. Table 1 highlights the key features and market opportunities for the major short-range wireless technologies discussed throughout this whitepaper.

Table 1: Key Short-Range Wireless Connectivity Technology Features and Market Opportunity

Wireless Technology	Frequency Bands	Throughput	Range	Power Consumption	Industry Organizations	Market Opportunity
Bluetooth BR/EDR	2.4 GHz	3 Mbps	10 m	Medium	IEEE 802.15, Bluetooth SIG	4.17 billion by 2028 (includes BR/EDR only and dual-mode BR/EDR and Bluetooth LE)
Bluetooth LE	2.4 GHz	2 Mbps	200 m	Low	IEEE 802.15, Bluetooth SIG	7.66 billion by 2028 (includes Bluetooth LE only and dual-mode)
802.11n (Wi-Fi 4)	2.4 GHz & 5 GHz	600 Mbps	Up to 200 m	Medium (dedicated low-power chipsets also available)	IEEE 802.11, Wi-Fi Alliance (WFA)	326 million units by 2028
802.11ac (Wi-Fi 5)	5 GHz	433 Mbps (80 MHz, 1 SS) 6933 Mbps (160 MHz, 8 SS)	Up to 200 m	High	IEEE 802.11, WFA	44 million units by 2028
802.11ax (Wi-Fi 6 & Wi-Fi 6E)	2.4 GHz, 5 GHz & 6 GHz	600.4 Mbps (80 MHz, 1 SS) 9607.8 Mbps (160 MHz, 8 SS)	Up to 200 m	Medium/high (dedicated low-power chipsets also available)	IEEE 802.11, WFA	Nearly 3.5 billion units by 2028
802.11be (Wi-Fi 7)	2.4 GHz, 5 GHz & 6 GHz	5.8 Gbps clients, 46 Gbps capacity	Up to 200 m	High	IEEE 802.11, WFA	1.6 billion by 2028
802.11bn (Wi-Fi 8)	2.4 GHz, 5 GHz & 6 GHz	Targeting 10 Gbps for client devices	Up to 200m	High	IEEE 802.11, WFA	153 million units by 2028
802.11ah (Wi-Fi HaLow)	Sub- 1 GHz	78 Mbps	Up to 200 m	Low	IEEE 802.15, Connectivity Standards Alliance (CSA), Thread Group	1.7 billion units by 2028
Zigbee/Thread (802.15.4)	2.4 GHz & sub-1 GHz	250 Kbps	Up to 200 m	Low	ISO, NFC Forum	1.7 billion units by 2028
NFC	13.56 MHz	106/212/424 Kbps	Up to 1 km	Low	IEEE 802.15, UWB Alliance, FiRa Consortium	1.7 billion units by 2028
UWB (802.15.4a, 802.15.4z)	3.1 GHz to 10.6 GHz	27 Mbps	10-100 m	Low	IEEE 802.15, Connectivity Standards Alliance (CSA), Thread Group	1.3 billion units by 2028

Table 2 maps these technologies across key target market verticals. As it demonstrates, most end markets are being targeted by multiple short-range wireless technologies. Within those verticals, each device type has its own specific requirements, and technology choice will depend on the key metrics listed in Table 1. For some market verticals, technologies will be complementary, in others, directly competitive, and in others, technologies will be chosen based on the specific requirements of diverse end device types. For example, smartphones take advantage of Wi-Fi for video streaming, Bluetooth for audio, UWB for fine-ranging capabilities, and NFC for mobile payments. In Real-Time Location System (RTLS) environments, Wi-Fi, UWB, and Bluetooth often directly compete for market traction. In the smart home, a combination of technologies will be leveraged due to the diverse application requirements, including battery-powered sensors, smart displays, voice-control front ends, smart appliances, video surveillance cameras, and smart door locks, among many others.

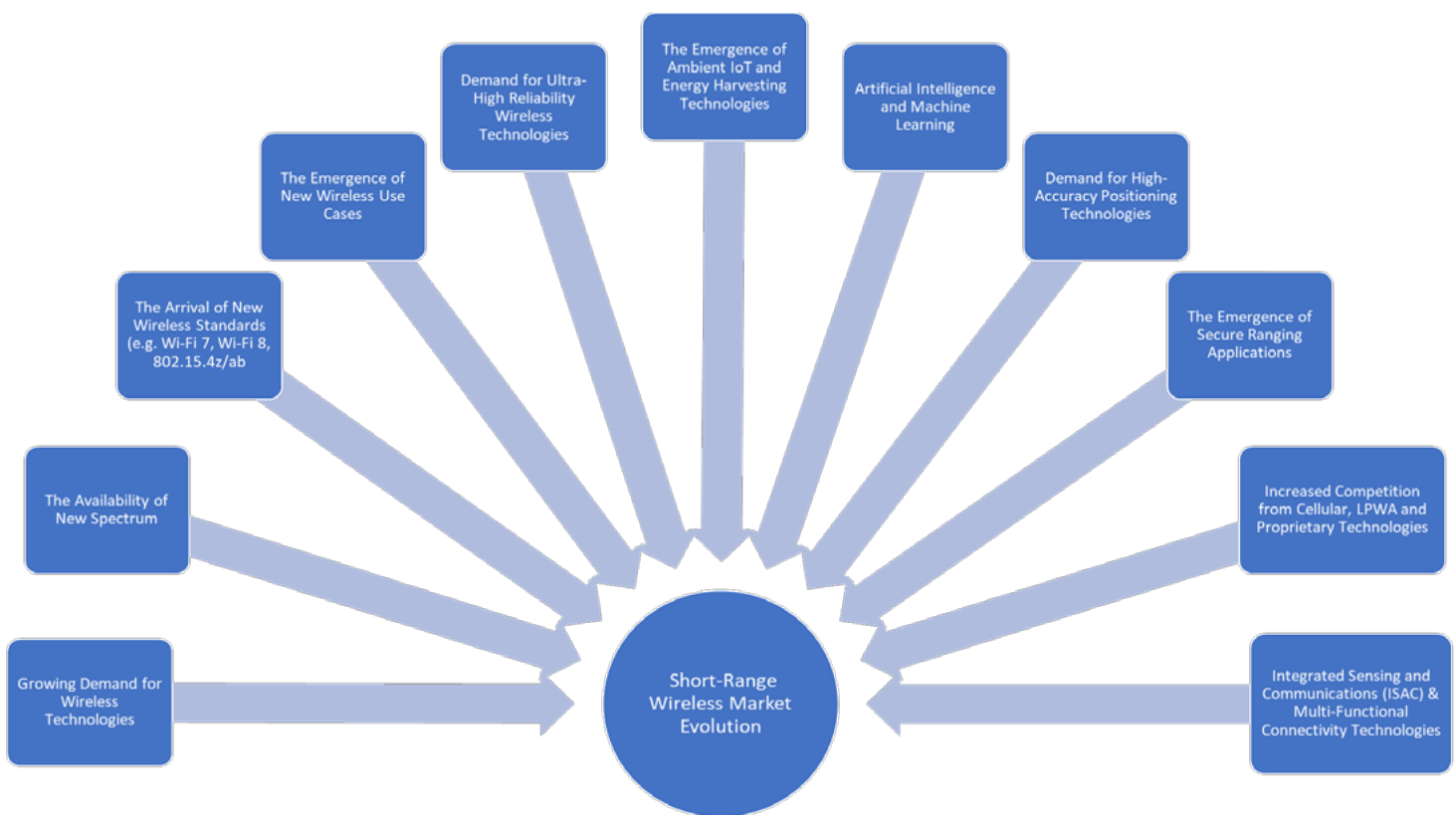
Table 2: Key Short-Range Wireless Connectivity Technologies and Target Markets

Wireless Technology and Target Market	Blue-tooth BR/EDR	Blue-tooth LE	802.11n (Wi-Fi 4)	802.11ac (Wi-Fi 5)	802.11ax (Wi-Fi 6 & Wi-Fi 6E)	802.11be (Wi-Fi 7)	802.11bn (Wi-Fi 8)	802.11ah (Wi-Fi HaLow)	Zigbee / Thread (802.15.4)	NFC	UWB (802.15.4a, 802.15.4z)
Handsets	●	●	●	●	●	●	●			●	●
Mobile & PC Accessories	●	●								●	●
PCs & Tablets	●	●	●	●	●	●	●				●
Home Ent.	●	●		●	●	●	●				●
Wireless Audio	●	●	●	●	●	●	●				●
Other Consumer Electronics		●	●	●	●	●	●			●	●
Smart Home		●	●	●	●	●	●	●	●		●
Smart Appliances		●	●	●	●	●	●	●	●	●	●
Wearables	●	●	●	●	●	●	●			●	●
AR/VR	●	●		●	●	●	●				
Auto	●			●	●	●	●			●	●
Smart Health		●	●		●	●	●	●	●		
Smart Cities		●	●	●	●	●	●	●	●	●	●
Building Automation		●	●	●	●	●	●	●	●		●
RTLS & Asset Tracking		●	●		●						●
Personal Trackers		●									●
Condition Monitoring		●	●		●	●	●	●	●		●
Electronic Shelf Labels		●						●	●	●	
POS Terminals		●	●		●			●		●	●
Video Surveillance			●	●	●	●	●	●			

At the same time, short-range wireless technologies are becoming increasingly multifunctional. Technologies that once just supported data transfer between devices are now incorporating advanced positioning, ranging, radar and sensing, and wireless charging capabilities. This is enabling multiple unique use cases, such as precise device positioning, Simultaneous Location and Mapping (SLAM), human presence detection, gesture recognition, and other new non-connectivity related usage scenarios, all while using the same underlying wireless technologies. These advanced features are fundamental to future Integrated Sensing and Communication (ISAC) concepts, whereby ubiquitous wireless technologies will combine communications with precise positioning and sensing to enable truly intelligent environments built upon interconnected digital twins. Combined with Artificial Intelligence (AI) and Machine Learning (ML), this has the potential to lead to real-time perceptive networks capable of mapping, analyzing, reacting to, and predicting changes in the physical world, leading to the creation of highly valuable transformative services across home, commercial, automotive, industrial, and smart city environments.

Several trends are converging to enable these next-generation short-range wireless applications. These can be summarized in Figure 1:

Figure 1: Key Drivers for Next-Generation Short-Range Wireless Technologies



This whitepaper seeks to highlight how the short-range wireless market will evolve to enable valuable new use cases and services over the next decade. First, it will discuss the evolving competitive landscape, key target use cases, and differentiators between each technology. It will then discuss the continued evolution of each technology through the arrival of new standards, new sensing and positioning features, and other enhancements. Finally, it will highlight challenges facing the connectivity market, and provide strategic recommendations on what the short-range wireless connectivity market needs to do to reach its full potential over the next decade and beyond.

SHORT-RANGE WIRELESS TECHNOLOGY OVERVIEW

Table 1 provided a top-level summary of the major short-range wireless connectivity technologies. This section will provide a more in-depth look at the features, target use cases, market opportunities, competitive landscape, and future innovation roadmap for Wi-Fi, UWB, Bluetooth, ZigBee/Thread, and NFC technologies.

WI-FI TECHNOLOGY OVERVIEW

WI-FI KEY FEATURES AND DIFFERENTIATORS

Based on the IEEE 802.11 standards, Wi-Fi technology provides high-throughput, low latency, and short- to medium-range connectivity for a wide range of applications. In contrast to alternative short-range wireless technologies, which provide between 250 Kilobits per Second (Kbps) to 27 Mbps data rates, Wi-Fi's throughput is order of magnitudes higher, offering between hundreds of Mbps to multi-Gbps depending on the specific IEEE 802.11 standard and frequency band in which it operates. Wi-Fi devices can benefit from the ability to connect to an enormous installed base of Wi-Fi Access Points (APs) within home, commercial, and industrial environments, enabling direct cloud connectivity without the need for intermediary gateways or bridging devices. This not only simplifies installation, but also reduces the overall cost, design complexity, and time to market when compared to alternative technologies. However, power consumption is typically much higher when compared with other short-range wireless solutions.

Wi-Fi technology is backward compatible and encompasses multiple technologies operating in a combination of the 2.4 GHz, 5 GHz, and newly available 6 GHz bands. This includes 802.11b, 802.11a, 802.11g, 802.11n (Wi-Fi 4), 802.11ac (Wi-Fi 5), 802.11ax (Wi-Fi 6), 802.11be (Wi-Fi 7), and 802.11bn (Wi-Fi 8), each with its own specific features and performance metrics. Most IEEE 802.11 enhancements up until Wi-Fi 5 (802.11ac) focused on increasing the throughput of the technology. However, in 2021, the most recent Wi-Fi standard, 802.11ax (Wi-Fi 6) was published, placing greater emphasis on improving overall system performance and per user throughput. Key enhancements, such as Orthogonal Frequency Division Multiple Access (OFDMA), Basic Service Set (BSS) Coloring, Target Wake Time (TWT), and beamforming, were all implemented to improve the overall efficiency of the technology, bringing up to a 4X increase in throughput per user, up to 67% reduction in power consumption for Wi-Fi clients, and up to a 4X increase in range, as well as reduced latency and greater reliability in dense deployment scenarios. Wi-Fi 6 also supports a maximum theoretical throughput of up to 9.6 Gbps.

Alongside these, additional sub-1 GHz 802.11ah (Wi-Fi HaLow) and 60 GHz Millimeter Wave (mmWave) 802.11ad/802.11ay (WiGig) technologies also fall under the Wi-Fi banner, providing extended range (HaLow) and high-speed point-to-point connectivity (WiGig), respectively. However, opportunities for these technologies have remained limited to more niche applications, and will likely remain so for the foreseeable future. Beyond the IEEE 802.11 Working Group, which continually develops these Wi-Fi standards, the Wi-Fi Alliance (WFA) is a nonprofit organization made up of hundreds of members active in the Wi-Fi ecosystem that seek to drive global Wi-Fi adoption through spectrum advocacy, interoperability, and certification programs, as well as developing new security, deployment, and usability features.

WI-FI KEY TARGET USE CASES AND COMPETITIVE LANDSCAPE

Historically, Wi-Fi has mainly targeted devices requiring the maximum possible throughput alongside low-latency performance. In addition to APs and Wireless Local Area Network (WLAN) infrastructure, Wi-Fi's largest historical markets have been smartphones, notebooks, tablets, home entertainment devices, such as smart Televisions (TVs) and game consoles, and a whole host of other connected consumer electronics products for which high-speed Internet access and video streaming capabilities are paramount. As these devices are typically line powered or have large batteries, Wi-Fi's high-power consumption has been a worthy trade-off in providing up to hundreds of Mbps to several Gbps of throughput. Only cellular technologies, such as 5G, have been able to offer similar capabilities, and the two technologies are often deployed together to provide ubiquitous indoor and outdoor connectivity.

However, as Table 2 demonstrated, Wi-Fi is addressing an ever-diversifying set of client devices and is increasingly being adopted within a growing number of IoT use cases. This includes smart home automation and smart appliances, RTLSs, commercial building automation, robotics, smart retail, healthcare, and Industrial IoT (IIoT) applications, alongside providing connectivity for numerous consumer electronics devices that require low-cost, streamlined cloud connectivity. These devices typically have lower throughput requirements, but are also much more limited in terms of form factor, cost, computing resources, antennas, and battery sizes. For many IoT applications, Wi-Fi 4, particularly single-band 2.4 GHz solutions, have been the go-to standard for basic, low-cost Wi-Fi connectivity for these applications.

Wi-Fi has traditionally struggled to serve battery-powered IoT markets due to inherently higher power consumption. Alternative technologies, such as Bluetooth, 802.15.4, Z-Wave, and proprietary 2.4 GHz and sub-1 GHz wireless, have, therefore, had greater success in these IoT markets. However, thanks to continued innovations in low-cost, low-power Wi-Fi 4 chipsets and the arrival of Wi-Fi 6, Wi-Fi can increasingly target resource constrained battery-powered IoT devices. Recent innovations in low-power Wi-Fi are enabling enormous improvements in battery life spans for these Wi-Fi-enabled IoT devices, enabling multi-year battery life, while taking advantage of seamless direct-to-cloud connectivity via existing Wi-Fi infrastructure in the home, enterprise, and industrial environments. At the same time, alternative technologies with more limited throughput are incapable of supporting a growing number of video-related applications across both consumer and enterprise environments. Wi-Fi-enabled devices, such as video doorbells, home security cameras, and commercial video surveillance solutions, are projected to grow significantly in the coming years, many of which will be battery-powered. Low-power Wi-Fi can enable greater flexibility in deploying these solutions and open up a much larger addressable market.

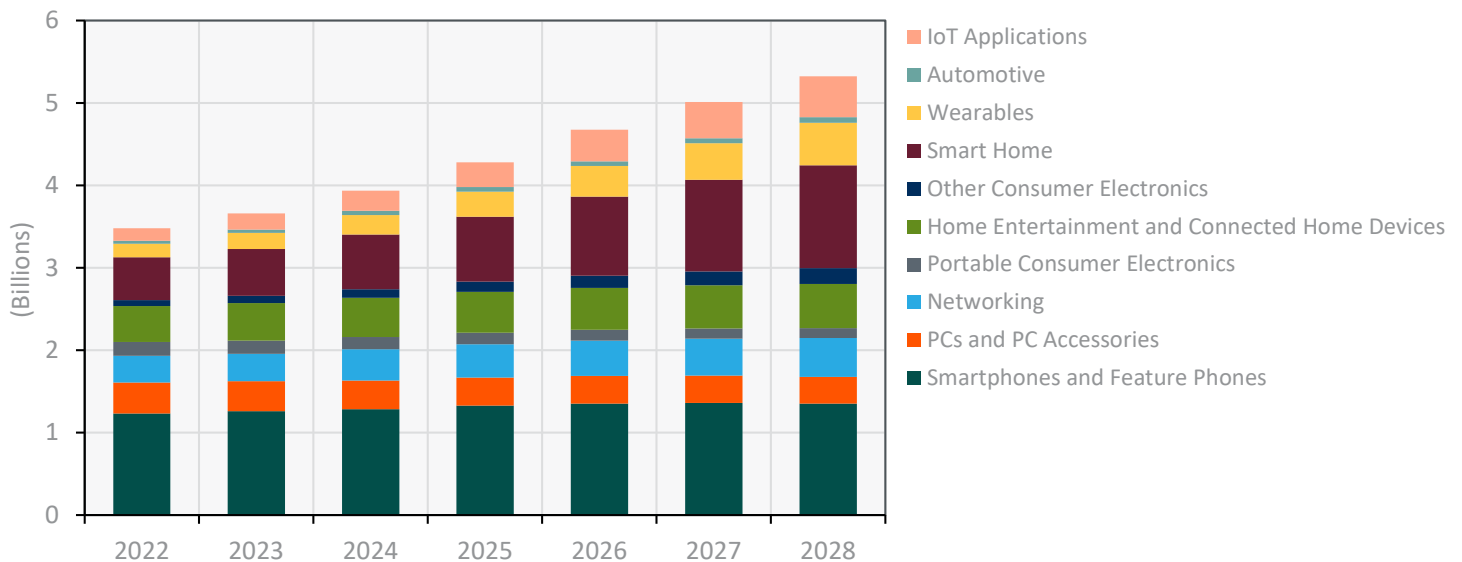
Despite its many inherent advantages, Wi-Fi faces strong competition from alternative technologies that are available at lower cost and can provide significantly lower power consumption. To capture a growing portion of the battery-powered IoT market, continued innovation at both the standards level, alongside chipset and Radio Frequency (RF) design, will all be required if Wi-Fi is to remain a technology of choice for battery-powered IoT applications. However, for the majority of devices with limited throughput requirements and the need for low-power consumption, Bluetooth LE and 802.15.4 (Zigbee/Thread)-based solutions will have a clear advantage.

WI-FI MARKET OPPORTUNITIES

Over the last 25 years, the Wi-Fi market has witnessed enormous growth. By the end of 2022, Wi-Fi-enabled devices reached nearly 34 billion cumulative shipments. As Chart 1 demonstrates, by 2028, annual device shipments are expected to reach more than 5.3 billion units, a 53% increase compared with 3.5 billion in 2022. When looking more closely at the growth sectors, traditional areas of success for Wi-Fi, such as smartphones, PCs, home entertainment, and networking infrastructure, will still see steady growth; however, broadly speaking, it will be areas like the smart home, wearables, and IoT applications that will grow more rapidly over the next 5 years. These markets represent a growing portion of the overall Wi-Fi market. In 2022, IoT applications already accounted for 24% of the total Wi-Fi device shipments. By 2028, this is expected to grow to 44%, equating to 2.4 billion Wi-Fi-enabled IoT devices at this time.

Chart 1: Wi-Fi-Enabled Device Shipments
World Markets: 2022 to 2028

(Source: ABI Research)



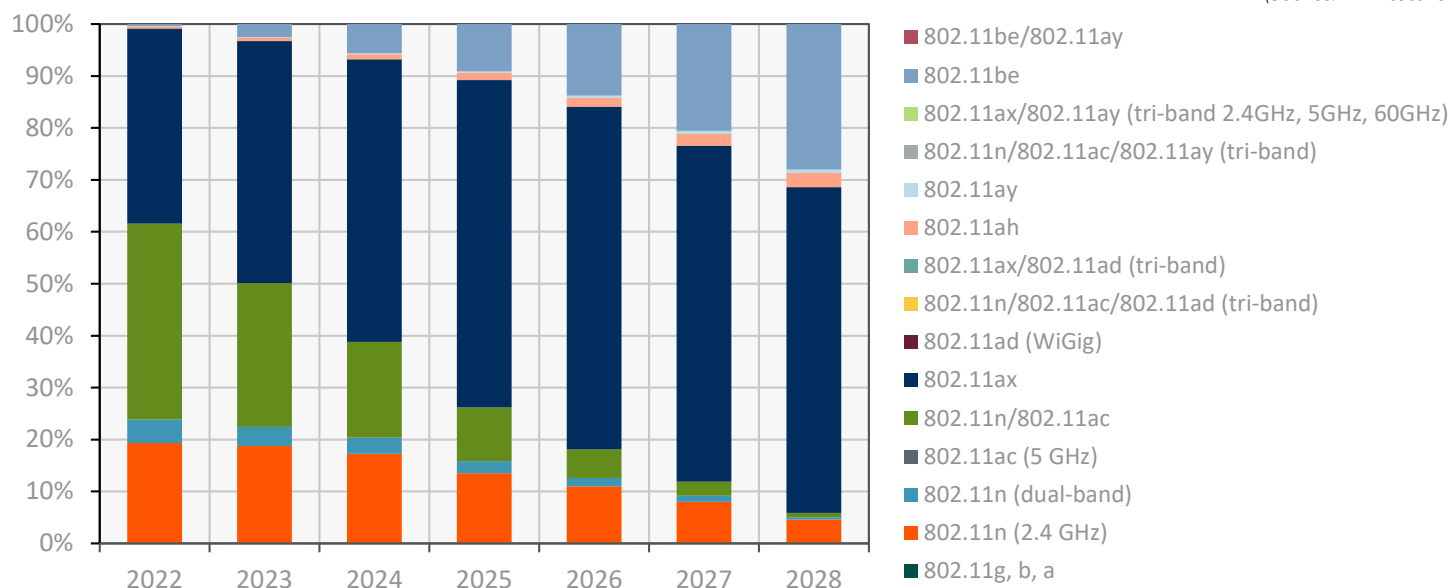
These sectors will require a combination of Wi-Fi technologies depending on the specific device type and performance requirements. For example, within the smart home, Wi-Fi technology can be leveraged to connect smart display voice-control front ends, always-on smart thermostats, battery-powered smart blinds, wireless security cameras, and smart doorbells and door locks, alongside powered devices, such as smart lighting and smart plugs. For wearables, this encompasses battery-sensitive smartwatches, as well as high performance Virtual Reality (VR) headsets. In industrial applications, this could require high-throughput, low-latency Augmented Reality (AR) headsets, alongside battery-powered Wi-Fi sensors for industrial machine monitoring. In home entertainment, this will require ultra-low latency connectivity to game consoles and 8K streaming capabilities for smart TVs. These use cases require Wi-Fi technology to improve at both ends of the performance spectrum and ensure it can effectively address both high-performance, low-latency clients and cost-, size-, and power-sensitive IoT devices.

As Chart 2 shows, the Wi-Fi market is currently rapidly transitioning to Wi-Fi 6 technology, accounting for 47% of all Wi-Fi chipset shipments in 2023. By 2026, this is expected to reach nearly 2/3 of the total market. Wi-Fi 4 will continue to address low-cost and battery-sensitive applica-

tions, but will eventually be supplanted by IoT-centric Wi-Fi 6 chipsets that can offer additional improvements on power consumption and better performance in crowded environments. In high-performance applications, the market will increasingly shift toward Wi-Fi 7, discussed in more detail below.

**Chart 2: Wi-Fi Chipset Shipment Share by Protocol
World Markets: 2022 to 2028**

(Source: ABI Research)



WI-FI MARKET EVOLUTION

WI-FI 6E AND THE 6 GHZ BAND

The recent opening up of the 6 GHz spectrum for unlicensed use across different regions is arguably one of the most significant events in the history of Wi-Fi. In certain regions, such as the United States, this means an additional 1.2 GHz of spectrum, while others, such as the United Kingdom, have adopted 500 MHz. In extending Wi-Fi 6's benefits to the 6 GHz band via Wi-Fi 6E, devices can take advantage of more widely available 160 MHz channels and avoid competition with slower legacy devices. This brings numerous benefits, including higher throughput, much more capacity, greater reliability, lower latency, and better Quality of Service (QoS) than ever before, helping to solve some of the key challenges that Wi-Fi is increasingly facing.

IEEE 802.11BE/WI-FI 7 (EXTREMELY HIGH THROUGHPUT)

However, given that Wi-Fi 6E is an extension of Wi-Fi 6 into the 6 GHz band, it will need additional work to take full advantage of the additional spectrum. As a result, development of IEEE 802.11be, also known as Wi-Fi 7, started in 2019 with the goal of bringing additional features to better use all three frequency bands to deliver further improvements in throughput and latency. Known as Extremely High Throughput (EHT), IEEE 802.11be aims to support a maximum throughput of at least 30 Gbps, while providing latencies potentially lower than 5 Milliseconds (ms). Key features like 320 MHz channel bandwidths, 4K Quadrature Amplitude Modulation (QAM), Multi-Link Operation (MLO), Multi-Resource Units (MRUs) and Restricted Target Wake Time (r-TWT) will enable this, with mainstream 2x2 smartphone, PC, and tablet client devices capable of achieving

a device maximum peak throughput of up to 5.8 Gbps. This represents a 2.4X increase over the 2.4 Gbps achieved via Wi-Fi 6/Wi-Fi 6E. With even single stream devices capable of supporting up to 2.9 Gbps, this can enable multi-gigabit throughput on more basic Wi-Fi clients, while enormous reductions in latency versus Wi-Fi 6 can be achieved. In terms of overall capacity, while Wi-Fi 6 can deliver a maximum aggregated throughput of 9.6 Gbps, Wi-Fi 7 has the potential to extend this to over 40 Gbps depending on the specific feature set. This will enable significant increases in the capacity of Wi-Fi networks. These throughput, capacity, and latency enhancements will be critical in enabling Wi-Fi to better address growing demands across a number of consumer and enterprise applications, including remote working and learning, home entertainment, gaming, AR/VR and metaverse applications, automotive, and IIoT.

IEEE 802.11BN/WI-FI 8 (ULTRA-HIGH RELIABILITY)

While Wi-Fi 7 will bring tremendous benefits, IEEE 802.11 is already beginning work on the next generation of Wi-Fi, IEEE 802.11bn, also known as Wi-Fi 8. In July 2022, the Ultra High Reliability (UHR) Study Group was formed, serving as the initial steps toward defining Wi-Fi 8. Building on Wi-Fi 7, the major goals of the new standard are to address some of the more demanding and stringent applications for wireless technologies that will emerge toward the end of this decade and beyond. This will help enable new market opportunities across consumer and enterprise sectors, leading to the potential creation of valuable new Wi-Fi deployments based on more mission-critical applications. This will also enable the technology to better compete with and complement 5G and 6G, which are currently perceived as having much greater reliability within enterprise applications.

Of course, reliability is a broad metric, and as the formal task group is not expected to be formed until November 2023, it is difficult to know exactly what the performance targets will be, as well as how they are intended to be achieved. However, broadly speaking, Wi-Fi 8 targets the 2.4 GHz, 5 GHz, and 6 GHz bands, and aims to bring the following improvements when compared with Wi-Fi 7:

- Higher throughput, network capacity, and throughput over longer ranges. The current target is 10 Gbps on 2x2 clients, growing from 5.8 Gbps in Wi-Fi 7.
- Improvements to worst-case latency and jitter, even within high mobility deployments and areas of overlapping networks. This is to provide better manageability and greater determinism.
- More efficient use of the spectrum, including better performance in congested environments.
- Improvements in power-saving mechanisms for both traditional AP-to-station deployments and within peer-to-peer operations. The idea is to improve device battery life, while optimizing energy efficiency and reducing the carbon footprint of Wi-Fi technology.

Several techniques have initially been proposed to achieve these goals, including multi-AP coordination and distributed MLO to name but a few. However, these are still preliminary and a more concrete roadmap for Wi-Fi 8 will likely emerge in the coming months.

While Wi-Fi 7 will undoubtedly bring vast improvements to QoS and help to deliver on more reliability-centric applications, Wi-Fi 8 is specifically designed to bring further improvements over what Wi-Fi 7 can deliver. Many of the target use cases will also overlap with Wi-Fi 7. However,

some of the initial use case discussions for Wi-Fi 8 have centered on expanding Wi-Fi to new areas, alongside enhancing existing deployments within home, enterprise, and industrial environments. These could help deliver more cost-effective, high-reliability deployments when compared with alternative solutions, such as private cellular network deployments. For example, some preliminary proposals for target use cases include industrial machine control, collaborative and mobile robotics in warehouse and manufacturing environments, remote telesurgery, agricultural machinery control, high-density Wi-Fi in public venues, and improved AR/VR performance. These use cases will require high throughput, low latency, and stable and speedy handover, alongside ultra-high reliability.

ULTRA-WIDEBAND TECHNOLOGY OVERVIEW

UWB KEY FEATURES AND DIFFERENTIATORS

UWB has recently re-emerged as a secure, fine-ranging technology capable of enabling a wide range of innovative location-based user applications and services. UWB is a short-range impulse radio technology that can securely and accurately calculate the relative position of other UWB-enabled devices at a distance of up to 100 Meters (m) with up to 10 Centimeters (cm) of accuracy. As the name suggests, UWB uses a wide channel bandwidth (500 MHz) between 3.1 GHz and 10.6 GHz, and short 2 Nanosecond (ns) pulses to accurately measure the Time-of-Flight (ToF) between two devices, such as smartphones, wearables, keys, tags, door locks, and anchor points. When in proximity, these devices begin ranging using ToF measurements that calculate the roundtrip time of the communication. One device can, therefore, calculate the relative location of the other instantly (with refresh rates at 100X per second) continuously, with movements being monitored in real time. Meanwhile, Angle of Arrival (AoA) techniques ensure that the system knows the precise location and direction of a device, ensuring that devices like door locks can determine on which side of the door a user is standing, and fully understand user intent. As UWB operates in the 3.1 GHz to 10.6 GHz part of the spectrum, it remains distanced from the crowded 2.4 GHz band that other unlicensed wireless technologies operate in, and allows it to work alongside Wi-Fi, Bluetooth, NFC, and IEEE 802.15.4 with little interference. UWB is also capable of data communication, supporting throughput of up to 27 Mbps at relatively low-power consumption, enabling unique secure positioning and communication use cases.

In August 2019, the Fine Ranging Consortium (FiRa) was founded. This organization seeks to aid with the promotion, development, and adoption of fine ranging and positioning use cases associated with UWB. It also defines standards and certifications for interoperability among chipsets, devices, and solutions to provide seamless and safe experiences without restrictions. The UWB Alliance is another UWB organization aiming to create a favorable regulatory and spectrum landscape for UWB technology, working on securing rulesets to expand new use cases, enabling spectrum sharing with low interference, making additional spectrum available, and influencing regional regulatory bodies for global expansion of UWB spectrum.

UWB KEY TARGET USE CASES AND COMPETITIVE LANDSCAPE

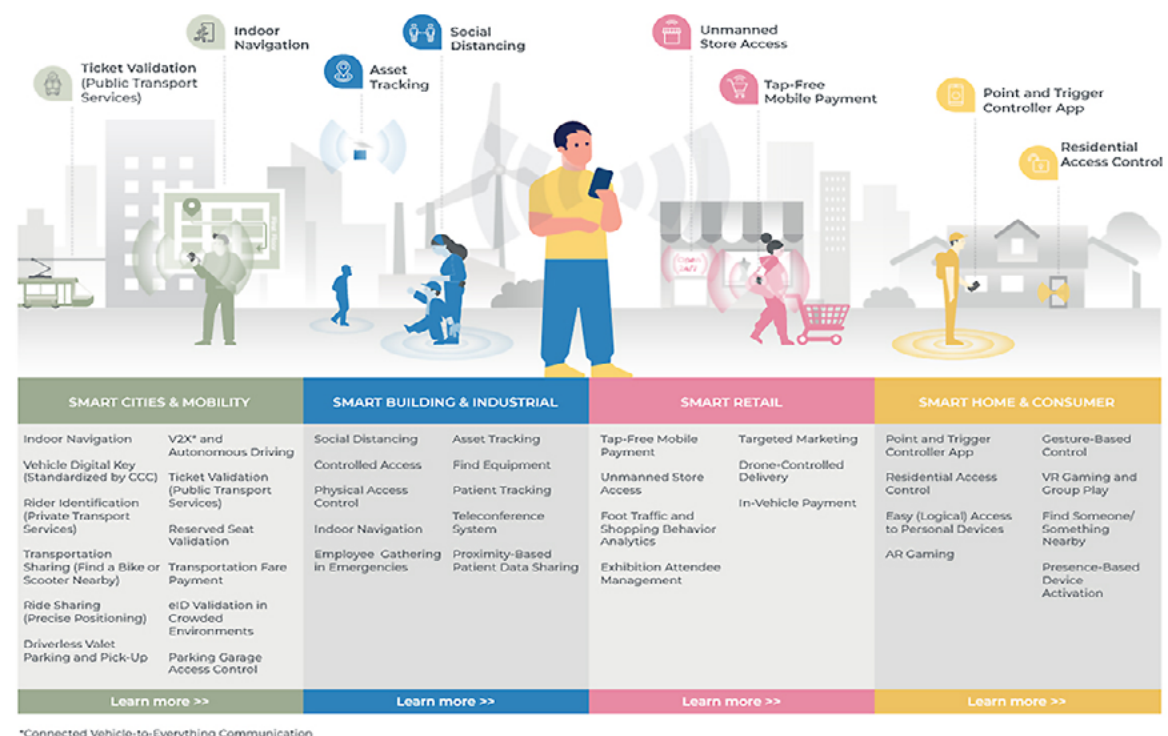
Over the last decade, IEEE 802.15.4a-based UWB solutions have increasingly been adopted within high-accuracy indoor RTLS applications. It has faced strong competition from alternative Wi-Fi and Bluetooth-based RTLSs that, despite lower accuracy, can typically be deployed at lower cost. In the last few years, development of the new IEEE 802.15.4z UWB standard has led to addi-

tional security extensions being added to the technology. This has provided UWB with the ability to provide secure, authentic, and centimeter-level accurate distance and location measurement, enabling a number of secure fine-ranging and positioning applications demanded by automotive, mobile, smart home, smart building, and other IoT solution providers. These unique secure ranging abilities have incentivized many smartphone, wearable, automotive, and smart home vendors to incorporate the technology. However, Bluetooth and Wi-Fi's upcoming ranging capabilities combined with their already ubiquitous presence in mobile devices and infrastructure may dissuade some in investing in UWB technology.

Figure 2 demonstrates the leading fine-ranging UWB use cases as defined by the FiRa Consortium. This includes a combination of device-to-device and device-to-infrastructure applications, including hands-free secure vehicle and building access, indoor localization, asset tracking, hands-free payments, seamless smart home interaction and automation, AR, gaming, and a whole range of emerging smart building, smart city, industrial, and other IoT applications.

Figure 2: UWB Fine-Ranging Use Cases

(Source: FiRa Consortium)

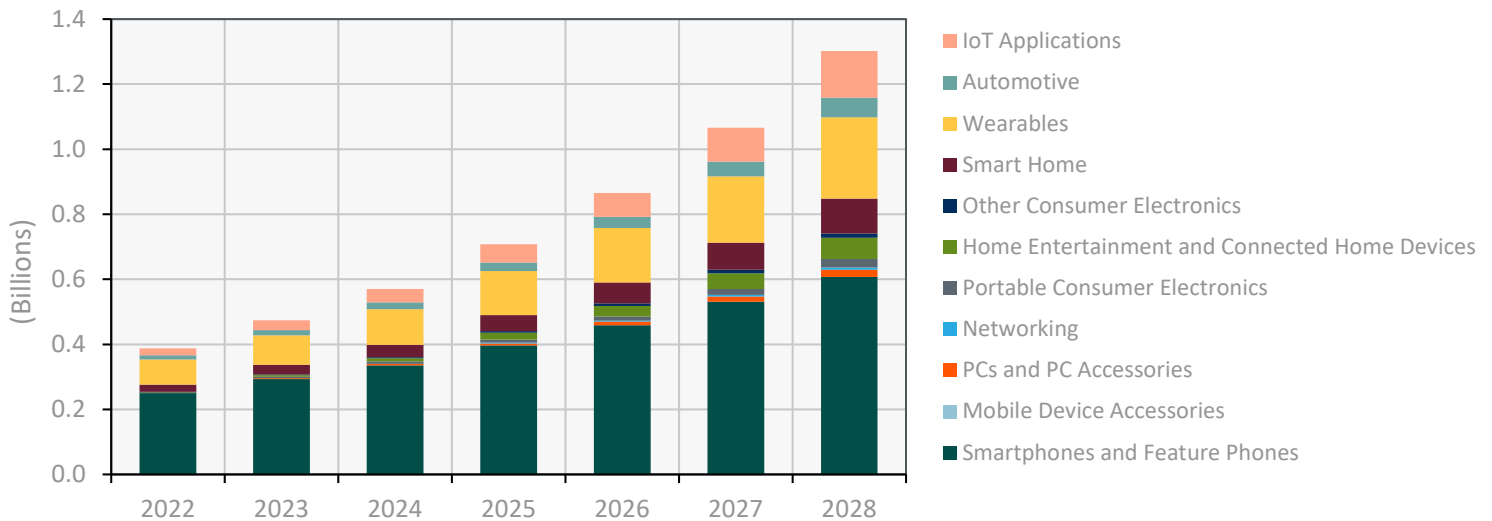


UWB MARKET OPPORTUNITIES

Chart 3 shows UWB-enabled device shipment forecasts. While we are undoubtedly still very much in the early stages of UWB adoption, over the next 5 years, UWB adoption is expected to be rapid, growing from 386 million units in 2023 to more than 1.3 billion by 2028.

Chart 3: UWB-Enabled Device Shipments
World Markets: 2022 to 2028

(Source: ABI Research)



UWB's ecosystem growth will depend significantly on the rollout of UWB technology within smartphone devices. In 2022, 21% of smartphone shipments included UWB technology, including Apple's iPhone 11 to 14 series of devices, Samsung's Galaxy S21, S22, S23 Ultra, Z Fold 2, 3, and 4 devices, Google's Pixel 6 Pro, 7 Pro, and Fold, and Xiaomi's Mi MIX 4. In 2023, this has already expanded to new vendors, including the HONOR Magic 5 Ultimate and Meizu 20 Infinity. By 2028, ABI Research expects nearly half of smartphones shipped to include UWB technology as penetration extends beyond flagship devices. Adoption in Apple Watches from the Series 6 onward has also propelled the smartwatch market to become one of the biggest markets for UWB adoption to date. Integration of UWB in smartphone and wearable platforms will be vital in driving further UWB adoption in a range of accessory items, alongside automotive keyless entry applications, smart home, smart building access, and payment applications.

Secure car access will act as a catalyst for the first adoption wave within the automotive and mobile device industry. Strong backing from the Car Connectivity Consortium (CCC) and its various members, including car Original Equipment Manufacturers (OEMs), automotive Tier One suppliers, phone manufacturers, chipset vendors, security product suppliers, and app developers, has led to the creation of the Digital Key Release 3 specification, released in July 2021, an open standard that combines UWB, NFC, and Bluetooth LE to enable devices like mobile phones to function as a key that will seamlessly lock, unlock, and start vehicles from the pocket. A number of new vehicles have already been equipped with UWB technology. This includes the BMW 7, iX and iX1, X1, XM, i4, and i7 series, Genesis GV60, the Kia EV9, the Mercedes-Benz E-Class, and Volvo EX30. Meanwhile, iOS and Android smartphones equipped with UWB support these digital car keys from various vendors. There are a number of potential future applications for UWB within vehicles, including paying for valet parking automatically, and car-as-a-key where a UWB-enabled garage door lock would unlock as the vehicle approaches it. By 2028, nearly 1/3 of vehicles shipped are expected to be equipped with UWB as secure access technology.

Smartphones with UWB are capable of locating items, such as keys, wallets, backpacks, luggage, and other personal items, with a UWB personal tracker tag attached to them. In April 2021, Apple unveiled its AirTag solution, enabling users to more accurately locate their lost items through its

UWB Precision Finding technology, guiding them to their AirTag using sound, haptics, and visual feedback. In April 2021, Samsung also officially launched its Galaxy SmartTag+ tracker. In the longer term, as the cost of UWB solutions continues to fall, UWB has the potential to be embedded directly within consumer goods to enable precise tracking of valuable personal items.

UWB has the potential to enable more seamless, automated, and personalized experiences within the home, thanks to its ability to precisely pinpoint the distance and direction between different UWB-enabled objects within the home environment. This will allow for better end-user interaction experiences and more intelligent automated homes that rely less on manual interaction and can adapt in real time to the specific needs for end users. For example, UWB-enabled smartphones can interact with other UWB-enabled connected home devices, such as speakers, TVs, light bulbs, thermostats, or other smart appliances like fans. Thanks to UWB's high accuracy and direction capabilities, the smartphone can detect exactly what device is being pointed at and automatically open up a relevant control panel on the smartphone display.

Commercial and residential access control is perhaps the most natural extension of UWB's initial activities within the automotive secure access realm. Embedding UWB within residential and commercial door locks and access control readers has the potential to improve security, enable better user experiences, and provide innovative advanced capabilities, such as flexible digital key, provisioning that can adapt to specific needs and requirements of the end user or enterprise. Much like in the automotive realm, IoT access control enables UWB-enabled end user devices, such as smartphones, wearables, key fobs, or badges, to act as digital keys. In November 2022, Samsung partnered with Zigbang to create the first UWB-enabled smart home door lock. Meanwhile, key members of the FiRa Consortium include key access control market vendors like Allegion, Bosch, HID Global, Thales, dormakaba, Kastle Systems, LEGIC, and Elatec, among others. The FiRa Consortium also has a dedicated working group working toward the standardization of access control use cases. This will help ensure that mobile devices from various OEMs will be able to open locks and readers from different OEMs, and that different devices will be able to seamlessly transfer access control keys between them.

UWB MARKET EVOLUTION

While a number of use cases and devices have already been investigated and developed, UWB is still a new technology, and as its adoption continues to grow, so will its potential and innovation. A growing ecosystem of solution providers, including Apple, Samsung, NXP, Qorvo, STMicroelectronics, Infineon, and SPARK Microsystems, among others, will all help drive further development of the UWB market. Beyond 2030, ABI Research expects UWB technology to proliferate far more significantly in other environments. This will be driven not only by fine-ranging applications, but also data transfer-centric and radar-based use cases, as discussed below.

UWB as a High-Throughput, Low-Latency Networking Technology

Various UWB chipset vendors have also demonstrated the potential of the technology as a high-throughput, low-latency data transfer technology. This could help enable next-generation audio experiences, improvements in wearable devices, innovation in personal area networks, better AR/VR devices, and potential medical use cases like miniaturized wireless telemetry modules. For example, imec has developed a UWB chip capable of providing data rates of 1.66 Gbps using less than 10 Milliwatt (mW) of power; UWB chipsets from SPARK Microsystems provide data rates of up to 10 Mbps @ 1.5 nJ/bit energy efficiency, and in March 2023, PSB Speakers, Sonical, and MQA

announced a partnership to create high-resolution audio headphones based on Qorvo's UWB technology. These efforts, along with future enhancements to UWB technology, could place UWB in growing competition with Wi-Fi and Bluetooth technology for high-speed point-to-point applications, lossless audio, low-latency PC and gaming accessories like keyboards and mice, and a number of IoT applications, including smart home appliances and sensors, door locks, Electronic Shelf Labels (ESLs), and medical devices, such as diagnostic devices, surgical instruments, and patient monitoring solutions.

IEEE 802.15.4ab—Next-Generation UWB

While it seems like 802.15.4z has barely arrived on the market, the IEEE is already hard at work in developing the next generation of UWB technology. IEEE 802.15 Task Group 4ab, also known as the UWB Next Generation, was formed in 2021 and is building on 802.15.4-2020 and 802.15.4z-2020 to bring several PHY/MAC-related ranging enhancements to the technology. The intention is to expand the standard and enable it to target a wider range of applications, while maintaining backward compatibility. It also takes advantage of UWB's growing presence across a number of fine-ranging applications, as well as the use of UWB in sensing and data-related applications. Completion of the extension is expected in 2024, and major enhancements targeting peer-to-peer, peer-to-multi-peer, and station-to-infrastructure applications include:

- Additional coding, preamble, and modulation schemes to support improved link budget and/or reduced air-time relative to IEEE Std 802.15.4 UWB
- Additional channels and operating frequencies
- Interference mitigation techniques to support greater device density and higher traffic use cases relative to the IEEE Std 802.15.4 UWB
- Improvements to accuracy, precision, reliability, and interoperability for high-integrity ranging, alongside schemes to reduce complexity and power consumption
- Definitions for tightly coupled hybrid operation with narrowband signaling to assist UWB
- Enhanced native discovery and connection setup mechanisms
- Sensing capabilities to support presence detection and environment mapping
- Mechanisms supporting low-power low-latency streaming, as well as high data-rate streaming allowing at least 50 Mbps of throughput

These enhancements will be vital in helping to ensure that the UWB ecosystem does not fully fragment across the different use cases and ensure that UWB chipsets remain fully interoperable while able to support more diverse applications.

BLUETOOTH TECHNOLOGY OVERVIEW

BLUETOOTH KEY FEATURES AND DIFFERENTIATORS

There are two main types of Bluetooth technology, Bluetooth Basic Rate/Enhanced Data Rate (BR/EDR), also known as Bluetooth Classic, and Bluetooth Low Energy (LE), both of which operate in the 2.4 GHz unlicensed Industrial, Scientific, and Medical (ISM) band. Bluetooth Classic is a point-to-point technology that supports a maximum data rate of 3 Mbps when using the EDR PHY, and has primarily been used as an audio streaming technology to enable wireless headphones and speakers, automotive infotainment systems, and file transfer between devices.

Power consumption is relatively high at approximately 1 Watt (W). In contrast, Bluetooth LE, first arriving in 2010, is a continually evolving low-power (between 0.01 W and 0.5 W) Bluetooth technology that supports multiple topologies and additional features, such as positioning capabilities. Depending on the specific operation mode, Bluetooth LE can support data rates of up to 2 Mbps. Bluetooth technology is available at very low cost, with standalone Bluetooth LE Systems-on-Chip (SoCs) typically available for well under US\$1.

Over time, Bluetooth LE has continued to improve performance and add new features to better target new markets. New topologies, such as broadcast functionality, have enabled the technology to target beacon and RTLS applications, while the arrival of Bluetooth mesh in 2017 enabled the technology to increasingly target commercial lighting applications, bringing it in direct competition with 802.15.4-based solutions like Zigbee. Bluetooth 5.0, introduced in 2016, brought support for 2 Mbps throughput to Bluetooth LE, alongside a 4X range increase and an 8X increase in data broadcasting capacity. Bluetooth 5.1 in 2019 brought Direction Finding, enabling support for AoA and Angle of Departure (AoD) positioning techniques to provide much higher accuracy location services versus previous Received Signal Strength Indicator (RSSI) methods. This made it more competitive with technologies like UWB within RTLS applications.

Bluetooth 5.2, in December 2019, laid the foundations for Bluetooth LE Audio, leading to improved audio quality, reduced power consumption, lower latency, improved interoperability, easier development of hearing aids and true-wireless devices, new audio device types, and the emergence of new public and private audio sharing and broadcast use cases for both consumer and assistive listening applications, known as Auracast broadcast audio. Most recently, in early 2023, the Bluetooth Special Interest Group (SIG) announced the release of a new wireless standard for the ESL market. The intention is to create a scalable, low-power, secure ESL standard that can enable the ESL market to reach its full potential. The Bluetooth ESL standard will leverage key new feature enhancements introduced in Bluetooth Core Specification Version 5.4, including Periodic Advertising with Responses (PAWR) and Encrypted Advertising Data, to deliver secure and scalable connectionless ESL deployments required by the ESL market.

The Bluetooth SIG is a global organization of more than 38,000 companies responsible for the development of Bluetooth technology through creating new Bluetooth specifications, delivering an extensive certification program, and raising awareness and the adoption of Bluetooth technology across many verticals.

BLUETOOTH KEY TARGET USE CASES AND COMPETITIVE LANDSCAPE

Of all the short-range wireless technologies discussed in this whitepaper, Bluetooth arguably has the most diverse range of target markets and applications. Bluetooth has built a ubiquitous presence in smartphones, tablets, and PCs via dual-mode solutions that support both Bluetooth Classic and Bluetooth LE technology, enabling wireless audio, peripheral, and accessory connectivity. This enormous presence in source devices like, combined with the inherent low power and low cost of the technology, availability from a wide selection of chipset vendors, integration with

Wi-Fi in combo Integrated Circuits (ICs), and continual technical evolution, have meant that the technology has almost become the default choice for device-to-device connectivity across a wide range of consumer and IoT applications. As a result, Bluetooth LE has propelled itself into an enormous range of markets, including wearables, connected toys, mobile and PC accessories,

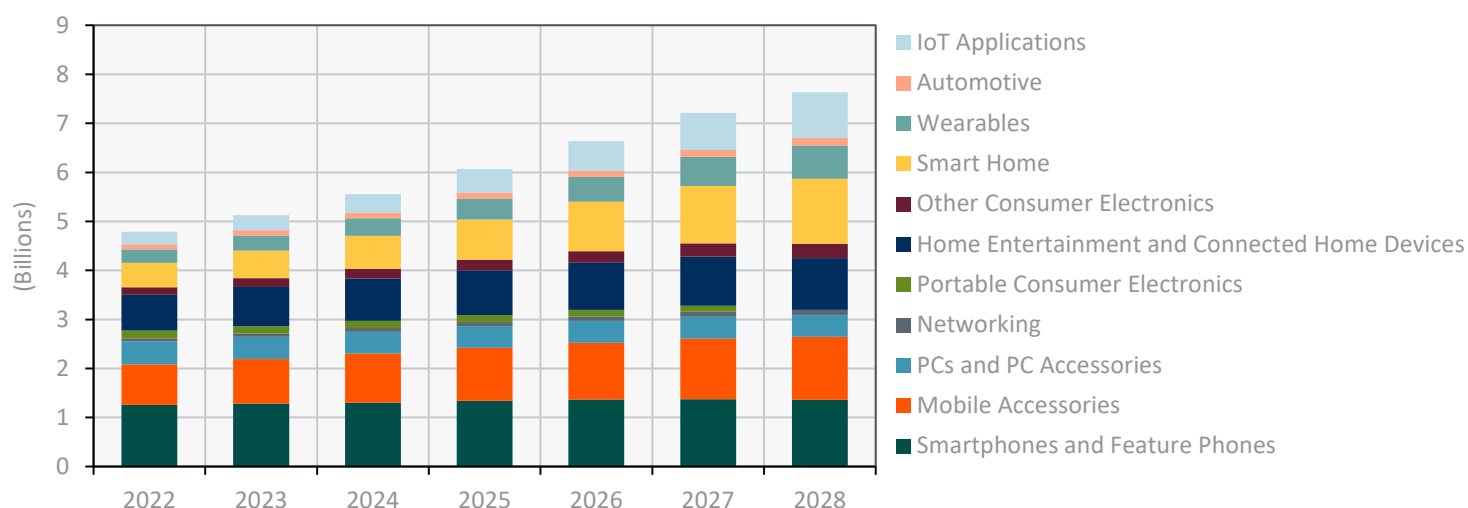
personal trackers, hearing aids, automotive key fobs, smart home automation devices, and smart appliances. It has also built traction across a wide range of IoT applications spanning low-power sensors, beacons and tags, commercial building automation and lighting control, smart health-care devices, ESLs, and industrial equipment monitoring. Given this diversity, Bluetooth also faces strong competition from alternative technologies, such as low-power Wi-Fi, UWB, Zigbee and Thread, as well as proprietary 2.4 GHz technologies, from connectivity, positioning, and ranging perspectives. However, in many use cases, such as wearables, smart appliances, and automotive key fobs, among others, Bluetooth is deployed alongside competitive technologies via combo and multiprotocol ICs to enable streamlined device provisioning or low-power mobile device interaction.

BLUETOOTH MARKET OPPORTUNITIES

Chart 4 shows forecasts for all Bluetooth technologies between 2022 and 2028. Since the arrival of Bluetooth LE, annual Bluetooth shipments have accelerated dramatically, growing from 1.4 billion devices in 2010 to 4.8 billion in 2022. By 2028, this will reach approach 8 billion. While dual-mode platform devices, such as smartphones, PCs, and tablets, will see steady growth over the next 5 years, the biggest future opportunities in the Bluetooth market will come from Bluetooth LE devices across a number of diverse sectors. This is expected to grow to nearly 3.7 billion annual device shipments by 2028. Meanwhile, legacy Bluetooth Classic is expected to decline considerably, from 10% of the market in 2022 to less than 3% in 2028, as LE Audio increasingly gains market share and as additional Bluetooth LE enhancements to throughput and latency emerge. In addition to nearly 1.3 billion mobile accessories, most notably headsets and true-wireless earbuds, growth in several IoT applications is expected to propel the Bluetooth market forward. Bluetooth smart home devices are expected to reach more than 1.3 billion annual unit shipments in 2028, while nearly 700 million wearables, over 500 million beacons, tags, and personal trackers, 135 million building automation devices, 108 million healthcare devices, and 100 million ESLs will account for the largest portions of this growth.

Chart 4: Bluetooth-Enabled Device Shipments
World Markets: 2022 to 2028

(Source: ABI Research)



BLUETOOTH MARKET EVOLUTION

These enhancements clearly demonstrate the successful history of Bluetooth's technology evolution and the ability to adapt itself to support new market sectors. Over the next 5 to 10 years, there are several additional enhancements that the Bluetooth SIG and its members have identified as key priorities for future innovation and to fend off any competitive threats.

Higher Data Throughput

As discussed, Bluetooth 5.0 enabled Bluetooth LE to support double its existing throughput via the LE 2M PHY. The intention was to enable enhanced data transfer performance for a wide range of devices increasingly supporting Bluetooth LE connectivity. However, with alternative technologies like UWB being able to support higher data rates, Bluetooth's more limited throughput may pose problems in the longer term as UWB is increasingly embedded within smart-phones. This could include audio applications where lossless audio is increasingly desired, but limited to proprietary codecs and implementations, such as from Qualcomm via its aptX lossless codec. As a result, the Higher Data Throughput project was established, with the intention of supporting data rates of up to 8 Mbps. This could not only enable lossless audio, but potentially video applications, creating new product categories for Bluetooth and ensuring it remains competitive in traditional stronghold areas like audio and IoT applications.

Bluetooth LE in Higher Frequency Bands

Bluetooth has remained a technology that has operated in the 2.4 GHz band since its inception. However, growing congestion and inherent limitations of the band itself make it difficult to bring further innovation. As a result, development is underway within a subgroup of the Bluetooth Core Specification Working Group to enable Bluetooth LE to operate in higher RF bands like 5 GHz and 6 GHz. In November 2022, the Bluetooth SIG announced that it was targeting these additional bands in order to allow the technology to continue to develop on key areas, such as increasing throughput, bringing lower latency, and enhancing positioning accuracy, for the next couple of decades. Along with UWB and Wi-Fi, this also helps make a stronger case for 6 GHz spectrum to be designated for unlicensed use.

Ultra-Low Latency HID

Bluetooth is increasingly being leveraged within controlling devices across many market sectors, including PC accessories, gaming, and AR/VR headsets. These markets are increasingly desiring greater sensitivity, higher accuracy, and lower latency. However, Bluetooth is not currently ideal for gaming controllers and mice due to lower polling rates, resulting in worse latency than wired or proprietary wireless alternatives. For example, Bluetooth typically has a polling rate of 125 Hz, resulting in delays of up to 8 ms. In contrast, 1,000 Hz polling rates, which is being targeted by the enhancement, typically supported by gaming mice, reduce this to around 1 ms. This could allow Bluetooth to better compete against proprietary wireless and, increasingly, UWB technologies, while taking advantage of new controller applications brought about by growth in the AR/VR space.

Of course, this list is by no means exhaustive, and numerous other enhancements will also depend on future support for Bluetooth in the 5 GHz and 6 GHz spectrum. However, Bluetooth will continue to innovate, while the strong ecosystem of vendors and low-cost solutions will drive the market forward over the next decade.

IEEE 802.15.4 (ZIGBEE/THREAD/MATTER)

MARKET OVERVIEW

KEY FEATURES AND DIFFERENTIATORS

Developed by the IEEE 802.15 Working Group for Wireless Specialty Networks (WSN), IEEE 802.15.4 is another important wireless radio standard. First released in 2003, the IEEE 802.15.4 radio forms the foundation for multiple standard and proprietary network layer protocols, such as Zigbee, Thread, ISA100.11a, and WirelessHART, among others, and targets a wide range of low throughput, low-power, and low-cost use cases. IEEE 802.15.4's range is typically limited to 10s of meters, though this can be extended with mesh implementations, while the maximum supported data rate is around 250 Kbps. While this data rate is limited, it ensures that resource-constrained devices like wireless sensors can support years of battery life, ideal in environments where replacing batteries on a regular basis could lead to costly maintenance cycles. IEEE 802.15.4 radios can operate in either sub-1 GHz or 2.4 GHz bands depending on the deployment requirements. Support for mesh capabilities allow for the building of scalable, long-range, dense network deployments, ideal for commercial lighting, Industry 4.0, or smart city environments.

KEY TARGET USE CASES AND COMPETITIVE LANDSCAPE

Depending on the specific network layer protocol, IEEE 802.15.4 radios target a number of different applications. For example, Zigbee, historically the most popular 802.15.4 technology, has targeted a range of applications across smart home, commercial building, smart utility, and Industry 4.0 environments. Popular Zigbee smart home automation devices include smart lighting, door locks, thermostats, smoke detectors, and other battery-powered wireless sensor devices. In smart buildings, Zigbee technology is typically leveraged within networked lighting control applications, wireless sensors, and Heating, Ventilation, and Air Conditioning (HVAC) control. Zigbee has also been widely deployed within a number of smart metering rollouts around the world, including a simultaneous 2.4 GHz and sub-1 GHz rollout in the United Kingdom.

Another IEEE 802.15.4-based technology targeting the smart home is Thread. Operating in the 2.4 GHz band, Thread is an alternative low-power IPv6-based network layer protocol that supports mesh and comes with enhanced security and lower latency. Its support for IP enables interoperability at the application layer via cross-industry initiatives, such as Matter. This is a protocol designed by the Connectivity Standards Alliance (CSA) to run over technologies like Wi-Fi and Thread, in order to make it easier for device manufacturers to build smart home devices that can work together effectively and enable valuable new smart home services. While the transition from Zigbee to Thread will not be total and will not be immediate, Matter and its support for Thread will make significant inroads into the demand and the future of Zigbee within the residential market. Zigbee will remain a strategic choice among vendors and service providers for if and how they transition their existing Zigbee support over to Thread, but as existing devices age and are replaced with greater functionality and interoperability, it will increasingly be a case of when, not if Zigbee is replaced by Thread. Zigbee and Thread's main competition has historically been Z-Wave and Bluetooth LE, particularly within sensor and lighting applications. For industrial environments, technologies like ISA 100.11a and WirelessHART leverage IEEE 802.15.4 to deliver mesh networks for process automation and other industrial use cases.

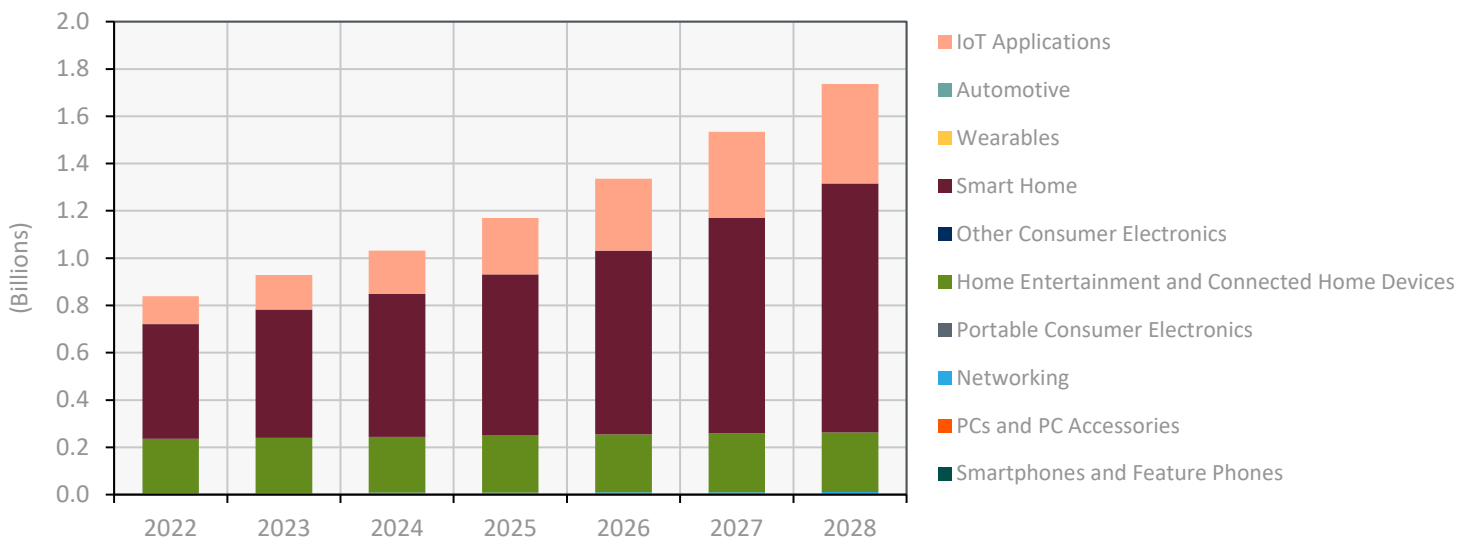
Several IEEE 802.15.4-based technologies are managed by the CSA, formerly the Zigbee Alliance, an organization with over 600 members that is responsible for developing the Zigbee and Matter standards, alongside Smart Energy, Green Power, RF4CE, and JupiterMesh. Thread is developed by the Thread Group.

MARKET OPPORTUNITIES

Chart 5 shows total IEEE 802.15.4-enabled device shipment forecasts. Driven by continued adoption of Zigbee and Thread, the smart home market will represent the largest portion of IEEE 802.15.4 shipments for the foreseeable future. By 2028, over 60% of the IEEE 802.15.4 market will come from the smart home, accounting for well over 1 billion units. Within this segment, low-power home automation devices will dominate growth, followed by residential smart lighting, smart appliances, and voice-control front end and controller devices, many of which have begun to embed Zigbee and Thread technology. Over time, growth in other key IoT sectors, such as commercial building automation and smart meters, will lead to over 420 million annual IoT shipments by 2028, accounting for nearly 1/4 of the IEEE 802.15.4 market by 2028.

Chart 5: 802.15.4-Enabled Device Shipments
World Markets: 2022 to 2028

(Source: ABI Research)



FUTURE EVOLUTION

Thanks to the activities of the CSA, Zigbee technology continues to evolve. In January 2023, the CSA introduced Zigbee Direct, which seeks to leverage Bluetooth LE technology to help simplify the onboarding and control process of Zigbee devices. Essentially, this allows a Bluetooth-enabled device, such as a smartphone or voice-control front end, to establish a connection with a Zigbee Direct device, which can then be used to control or onboard devices to the Zigbee mesh network. Considering that smartphones, many smart home controllers, and wireless APs still do not support Zigbee technology, this helps avoid the need to develop additional gateways or bridging devices that have traditionally added to the cost and complexity of deploying Zigbee-enabled devices. In April 2023, the CSA announced the release of Zigbee Pro 2023. This will bring new standardized security features to authenticate devices before joining the network, added support for sub-1 GHz frequencies in Europe and North America, and improved operations within hub-centric networks. These enhancements will bring significant improvements to Zigbee's security, range, power consumption, and reliability, potentially opening up new opportunities within smart home, commercial building, smart energy, and smart city applications.

NEAR-FIELD COMMUNICATION

KEY FEATURES AND DIFFERENTIATORS

NFC is an ultra-short-range wireless connectivity technology that uses the 13.56 MHz frequency band to support data rates of up to 424 Kbps over typical ranges of 2 cm via magnetic field induction. The two main types of NFC devices are known as active and passive. Active refers to devices like smartphones or other powered devices that can send and receive data to and from passive, battery-less devices and objects, such as cards and NFC tags. These active devices transmit power over the connection to enable communication with the passive objects. This enables highly secure, low-cost, and proximity-based communications between a wide range of devices. NFC technology is managed by the NFC Forum, which is responsible for defining various specifications for NFC technology across different use cases.

KEY TARGET USE CASES AND COMPETITIVE LANDSCAPE

NFC technology has a number of operating modes depending on the specific target use cases. This can include Card Emulation Mode, enabling devices like smartphones or smartwatches to emulate a contactless card and communicate with a contactless reader device. This can be leveraged for contactless payments and ticketing applications and is the largest use case for NFC technology today. NFC technology is also increasingly being leveraged as an access control technology for home, commercial, and automotive access control via key fobs, smart cards, or phone-as-key implementations, and is being deployed alongside Bluetooth LE and UWB solutions for backup purposes. Alongside this, the Reader/Writer mode enables devices like smartphones to read information from NFC tags that can be embedded in almost any product. This enables better consumer engagement, enhanced supply chain monitoring, greater brand protection, and new product authentication use cases. This can include embedding tags in luxury items, food and pharmaceutical products, and product accessories and refills, among many other applications. For example, smart appliances like toothbrushes or power tools are now embedding NFC readers to ensure they are connected to authentic attachments or refills equipped with NFC tags. These can also be used to automatically configure the accessories to the optimal parameters.

In addition to this, in October 2021 the NFC Forum released its Wireless Charging Specification (WLC) 2.0. Building on the 1.0 specification released in 2020, this enables devices like smartphones to be able to charge small, battery-powered consumer and IoT devices, such as true-wireless earbuds, smartwatches, and mobile accessories, at a rate of up to 1 W. This could open significant new opportunities for embedding NFC technology within compact device categories. Alongside this, NFC is also leveraged as a provisioning technology for a wide range of headless IoT devices thanks to its strong smartphone presence.

MARKET OPPORTUNITIES

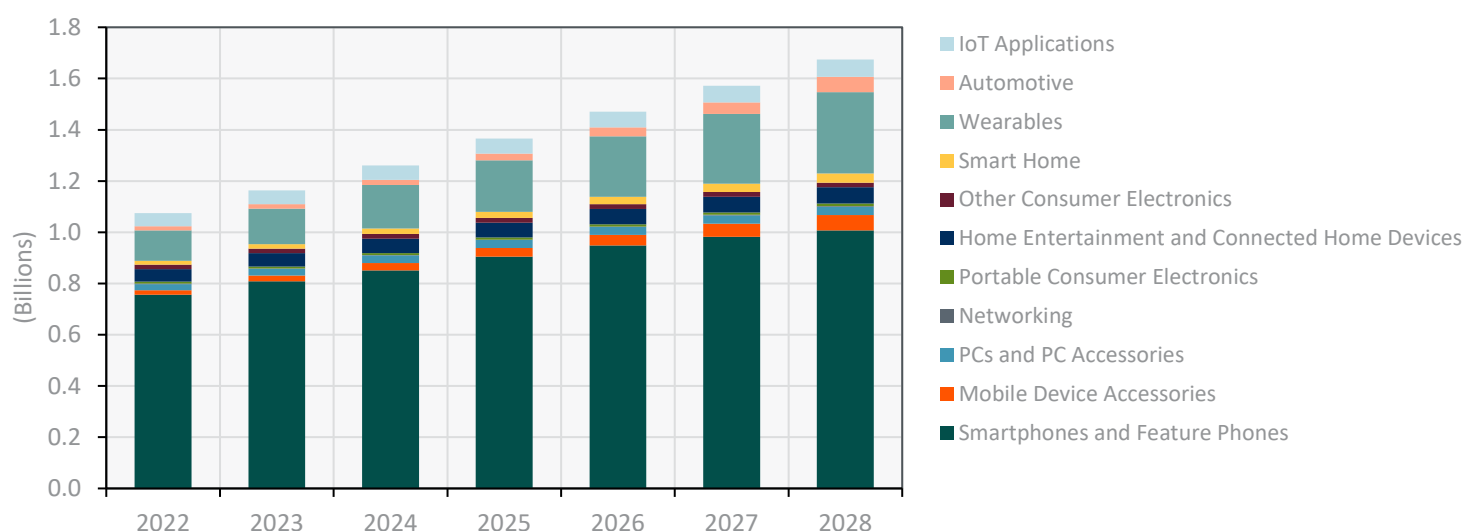
Chart 6 shows forecasts for NFC technology. Perhaps unsurprisingly, the two largest market opportunities for NFC technology will continue to be within smartphones and smartwatches, primarily for mobile payment-related applications. By 2028, ABI Research expects NFC technology to be present within 75% of smartphones and 94% of smartwatches as contactless payment technology continues to be accepted around the world. Related to this, more than 56 million Point-of-Sale (POS) terminals equipped with NFC technology are expected to ship annually by 2028. Other notable market opportunities include the automotive sector. In-car use cases for NFC include driver authentication for engine start, seamless pairing of personal devices to the automotive Bluetooth or Wi-Fi, and a simplified way of recognizing the driver and personalizing the air conditioning, seat, and mirror settings to their preferred settings. NFC is also likely to be increasingly leveraged in automotive access key fobs, alongside UWB and Bluetooth LE, with

NFC being used as a backup technology for battery-drained fobs or mobile devices. This can also be applied to smart door locks within the home, or commercial access control readers in smart building applications. Within the smart home, a growing number of smart appliances are expected to support NFC reader technology for authentication and automated configuration of accessories equipped with NFC tags. Finally, as NFC wireless charging builds momentum over time, it is possible that NFC could see a significant expansion in areas like true-wireless earbuds, mobile and PC accessories, and other battery-powered mass market consumer products with small antenna sizes that can benefit from wireless charging capabilities.

ABI Research forecasts that NFC tag shipments will grow from 1 billion annual shipments in 2022 to over 3.8 billion by 2028 as the penetration of NFC readers increases across key market segments, awareness of NFC tag use cases increases, and tag prices continue to fall. However, these tags are likely to face new competition from alternative passive Bluetooth LE and UWB ambient IoT solutions that are starting to be deployed in scalable volumes, as discussed later.

Chart 6: NFC-Enabled Device Shipments
World Markets: 2022 to 2028

(Source: ABI Research)



FUTURE EVOLUTION

As with other short-range wireless connectivity technologies, NFC continues to evolve to add new features and enhancements. In June 2023, the NFC Forum unveiled its new 5-year technology roadmap, encompassing the following five key initiatives:

- Increasing the wireless charging capabilities from 1 W to 3 W
- Increasing the range by 4X to 6X from the current maximum of 5 cm
- Expanding the capabilities of a single tap to support several actions, such as receipt delivery or loyalty card recognition
- Enabling smartphones to become POS terminals to allow users to receive payments anywhere
- Enabling NFC to share data formats needed to improve sustainability, such as how and where to recycle a product, regulatory requirements, and information on the product composition

Combined, these efforts have the potential to improve the overall utility and usability of NFC technology, accelerate payment rollouts, encourage further NFC adoption in devices, and open up new market opportunities within wireless charging applications where previous limitations may have prevented adoption.

FUTURE SHORT-RANGE WIRELESS INNOVATIONS: SENSING, POSITIONING, AND AMBIENT IoT SENSING

RADAR AND THE ROAD TO INTEGRATED SENSING AND COMMUNICATION

WI-FI SENSING AND IEEE 802.11BF

Wi-Fi sensing is an emerging technology that leverages RF signals from Wi-Fi infrastructure to detect presence and motion. The technology is fast becoming one of the most competitive sensing solutions on the market, and with the final standardization of IEEE 802.11bf, also known as Wi-Fi sensing, on track for March 2025, this will enable Wi-Fi to evolve from a communication-only standard to a dual-function technology that forms a fundamental component of the future of ISAC visions. By combining communication and sensing, the overall value of Wi-Fi deployments and devices over the coming decade will increase, thanks to the creation of valuable new services across both consumer and enterprise environments. IEEE 802.11bf is targeting operation across the 2.4 GHz, 5 GHz, 6 GHz, and mmWave bands, including 45 GHz and 60 GHz, each with its own unique advantages.

The IEEE 802.11bf task group has defined a number of different use cases for Wi-Fi sensing. These can be broadly categorized in five major areas, including:

- **Room Sensing:** Including presence detection, motion detection, intrusion detection, directional audio, and people counting.
- **Gesture Recognition:** Including finger, hand, and full body gesture identification, aliveness detection, face and body recognition, proximity detection, and home appliance control.
- **Healthcare:** Including fall detection, remote diagnostics (e.g., breath and heart rate monitoring), elderly and infant presence detection and monitoring, and sneeze sensing.
- **In-Car Sensing:** Including in-vehicle presence detection and driver sleepiness/condition detection.
- **3D Vision:** Including mapping of 3D environments.

In the longer term, Wi-Fi sensing is set to evolve from a relatively low-precision technology to one with increased granularity and more advanced sensing algorithms, enabling more precise use cases to be developed. Alongside other next-generation wireless technologies like 6G, Wi-Fi sensing could enable combined ISAC functionality to unlock new use valuable cases, including:

- **Vehicle-to-Everything:** Including secure hands-free access, high-precision location, SLAM, and vehicle platooning.
- **Remote Sensing:** Including Drone Synthetic Aperture Radar (SAR) imaging, satellite imaging, and broadcasting.
- **Smart Manufacturing and IIoT:** Including high-accuracy robotics localization and tracking, Automated Guided Vehicle (AGV) navigation, remote facility monitoring, employee health oversight, employee localization and authorization, and predictive maintenance.
- **Sensing-as-a-Service:** Including mobile crowd sensing, cooperative localization and imaging, channel knowledge map construction, and drone monitoring and management.

- **Environmental Monitoring:** Including rain, pollution, or insect monitoring.

Wi-Fi sensing is still in the early stages of maturity, and the ecosystem has barely scratched the surface of what is possible. IEEE 802.11bf will help provide the necessary framework for Wi-Fi sensing to realize its true potential, enabling the technology to scale to new applications and environments. However, much work needs to be done to ensure the successful rollout of Wi-Fi sensing technologies. This includes vendor interoperability, greater ecosystem collaboration, wider access to Channel State Information (CSI), regulatory and privacy compliance, certification and quality assurance, the proliferation of compatible chipsets and devices, continued improvements in accuracy and reliability, and education on the value of Wi-Fi sensing for consumers and enterprises alike.

UWB AS RADAR/SENSING TECHNOLOGY

A number of companies are also beginning to leverage UWB as a radar/sensing technology across a number of different applications. The ability for UWB radar to provide fine motion detection has the potential to enable use cases, such as automotive child and pet presence detection, gesture recognition and control, consumer electronics proximity and presence detection, cot infant monitoring, and motion sensing in smart buildings, among many others. For example, NXP's UWB Trimension portfolio was recently expanded to include a single-chip solution combining UWB and fine-ranging capabilities. Meanwhile, CEVA announced that its RivieraWaves UWB IP has been extended to support UWB radar for Child Presence Detection (CPD) as specified by The European New Car Assessment Programme (Euro NCAP) and similar specifications in other regions. As UWB is increasingly deployed in vehicles for keyless entry, automotive OEMs could potentially enable the same radios as a radar technology, reducing the need or complementing alternative in-vehicle radar/sensing technologies, such as 60 GHz. Other companies like NOVELDA offer a UWB radar solution for both proximity and occupancy solutions. The company has partnered with Lenovo to enable auto-wake-up and auto-lock functionality via an embedded UWB sensor in ThinkPad notebooks, while the company also launched a UWB occupancy sensor for lighting applications.

POSITIONING AND RANGING ENHANCEMENTS

IEEE 802.11AZ-BASED WI-FI NEXT-GENERATION POSITIONING AND IEEE 802.11BK 320 MHz SUPPORT

A common thread between Wi-Fi and other short-range wireless innovations are continual improvements to positioning capabilities. Wi-Fi's enormous presence across home, commercial, and industrial environments also make it uniquely suited to deliver valuable location services with minimal infrastructure rollouts.

The IEEE 802.11-2016 standard, also known as IEEE 802.11mc, introduced Fine Time Measurement (FTM), enabling Wi-Fi equipment to providing ranging estimates between two Wi-Fi-enabled devices, such as a Wi-Fi AP and a smartphone. This enhancement enabled the potential to track devices within 1 m to 2 m. However, to date, it has been unable to build a strong presence compared with alternatives, such as Bluetooth LE and UWB.

IEEE 802.11 recently finalized its next evolutionary step in Wi-Fi location technology, with the arrival of IEEE 802.11az in March 2023, also known as Next Generation Positioning (NGP). This will enable sub-1 meter accuracy with the potential to enable much higher quality location services,

including indoor navigation, proximity services, traffic analytics, geo-authentication, asset and personnel tracking, access control, improved Wi-Fi handover, enhanced AR, and contextual services within home and commercial environments. With the arrival of 6 GHz, IEEE 802.11az could also be leveraged to self-locate 6 GHz APs, enabling standard power 6 GHz via Automated Frequency Coordination (AFC), thanks to the higher accuracy it can bring.

A key addition in IEEE 802.11az is the introduction of enhanced security and anti-spoofing mechanisms. This will help prevent man-in-the-middle and other attacks to enable secure ranging applications. This could overlap with many UWB and Bluetooth High Accuracy Distance Measurement (HADM) use case ranges from automotive and commercial building keyless entry to device unlocking. IEEE 802.11az can also use Multiple Input, Multiple Output (MIMO) technology to take advantage of multiple transmitters to enhance performance in environments with multiple obstacles/Non-Line-of-Sight (NLOS), which are typical challenges within warehouse or industrial environments. Improved accuracy is also enabled through the use of wider 160 MHz channels introduced in Wi-Fi 6.

IEEE 802.11az also brings scalability improvements, enabling highly accurate location services, even within dense deployment scenarios, such as stadiums, transportation terminals, and retail environments. Improvements in range acquisition time and dynamic scheduling also means client devices will use less energy and that location services will not detrimentally impact battery life. Some existing chipsets on the market from Intel and NXP are already forward compatible with the IEEE 802.11az standard; however, ABI Research expects this to become much more commonplace over the next few years.

With the availability of the 6 GHz spectrum, the IEEE 802.11 is also working on bringing further enhancements that take advantage of potential 320 MHz channels in Wi-Fi 7 and Wi-Fi 8. IEEE 802.11bk, set to be completed in 2024, could bring even higher accuracy when using 320 MHz channels, and will extend the capabilities of IEEE 802.11az to support these channel widths.

BLUETOOTH HIGH ACCURACY DISTANCE MEASUREMENT

Bluetooth is also continuing to build upon its existing positioning capabilities to allow it to enable additional use cases and better compete with alternative technologies, such as UWB. Enhancements to the Bluetooth Core Specification are being made to incorporate Channel Sounding capabilities. This will use phase-based ranging to enable HADM between two Bluetooth LE devices, bringing significant enhancements for positioning applications, improving the accuracy, latency, and security over existing systems, and it is expected to be widely supported by the chipset ecosystem without the need for a new chip or advanced antenna designs. This means that Bluetooth technology's ranging capabilities will be included as standard and could potentially require a lower investment than UWB with its own dedicated chip.

Use cases like automotive keyless entry are an obvious target, thanks to the ability to prevent relay attacks, a key challenge facing existing RSSI implementations and a big reason behind the switch to UWB. In November 2022, Alps Alpine Co., Ltd. and Broadcom Inc. announced the introduction of an automotive Phone as a Key (PaaK) system based on Bluetooth LE HADM. Other notable targeted applications include residential and commercial access control, and smartphone and other device-to-device item location. Leading Bluetooth LE vendors, such as Silicon Labs and Nordic Semiconductor, have also recently demonstrated two-way ranging via HADM for a variety of applications. Similarly, Synaptics recently launched a tri-band SoC with support for Bluetooth HADM.

As a result of Bluetooth's upcoming support for secure ranging and an almost ubiquitous presence of Bluetooth within mobile devices, some vendors may decide not to invest in UWB, but

instead offer unique positioning experiences via Bluetooth technology. This could help reduce the cost and design complexity of ranging-capable devices.

AMBIENT IOT

Over the last few years, a new class of wireless connectivity solutions has emerged. Known as ambient IoT, this encompasses embedding connectivity into virtually any “thing” and enables those things to be able to share vital information about their location or condition without the device requiring a battery. These ultra-small, ultra-thin, low cost, and battery-free tags have the potential to revolutionize the way in which we monitor food, medical, and manufacturing supply chains, as well as enable a number of different use cases across automotive, clothing, smart home, commercial buildings, and consumer goods tracking. For example, in the food supply chain, ambient IoT tags can be leveraged at the item level to help authenticate products, ensure the integrity of products, optimize logistics and inventory management, automate compliance, prevent losses, and reduce waste, among others.

Based on Bluetooth LE technology, Wiliot has developed battery-free or battery-assisted tags that are the size of a postage stamp. These tags, known as IoT Pixels, can be attached to items and can measure temperature, location, proximity, and tamper detection, with future support coming for surface occupancy, proximity, and humidity. The solutions have a range of 10 m, while future versions of its tags will continue to innovate on size, cost, and enable energy harvesting from devices like phones or other appliances. In April 2023, Paragon ID also introduced a battery-less Bluetooth LE and UWB sensor tag targeting similar applications. The solution is currently capable of a 20-m range, with a roadmap to extend this to 30 m in the next few years.

The opportunity for ambient IoT will also be enabled by alternative technologies, including 6G, with Release 18 and Release 19 set to study ambient IoT and develop Key Performance Indicators (KPIs) for this segment. Meanwhile, in March 2023, the IEEE 802.11 Working Group formed a new Study Group dedicated to “Ambient IoT Devices.” The objective here is to enable Wi-Fi to embed itself within new product categories that can be maintenance free, offer ultra-low complexity, lower cost, and more form factors, and offer battery-free communication. This could solve some key challenges of the IoT, including battery replacement, maintenance costs, and the ability to operate in constrained form factors or challenging deployment environments.

The group has defined a number of use cases, including inventory and asset tracking, environmental and facility monitoring, indoor positioning, and condition-based monitoring across smart manufacturing, smart home, logistics and warehouse, smart agriculture, smart energy, and supply chain applications. While development is very much in its early stages, these devices are intended to be extremely low complexity with simplified RF and limited memory, alongside Millimeter (mm)-level thickness. The targeted coverage area is 30 m indoors and 200 m outdoors, putting it well above Bluetooth technology, alongside peak data rates of 20 Kbps or 100 Kbps. The goal is to also be capable of providing 1 m to 3 m of horizontal positioning accuracy, all the while maintaining less than 1 mW of peak power consumption.

According to ABI Research, ambient IoT has enormous market potential, with a Total Addressable Market (TAM) of more than 10 trillion devices across different market verticals. However, various industry organizations, such as the IEEE, Bluetooth SIG, and The 3rd Generation Partnership Project (3GPP) need to do a lot of work in standardizing these technologies if the market is to reach its true potential over the next decade. This will include working on areas like compatibility and coexistence with existing technologies, security, energy harvesting capabilities, and positioning capabilities, among several other metrics.

CHALLENGES AND STRATEGIC RECOMMENDATIONS FOR NEXT-GENERATION WIRELESS CONNECTIVITY TECHNOLOGIES

As has been demonstrated, the wireless connectivity market is rapidly evolving, opening enormous potential new use cases and services across a wide range of end markets. However, several challenges have impacted and will continue to impact opportunities for short-range wireless connectivity technologies, as well as new ones that will emerge over the next 5 to 10 years. Some of the key barriers are described below.

THE NEED FOR ADDITIONAL SPECTRUM

To mitigate growing congestion alongside supporting new use cases and features requires additional spectrum. Technologies like Wi-Fi, UWB, and Bluetooth are all targeting additional spectrum in different bands to achieve this, including 6 GHz, mmWave, and 7 – 10 GHz and above.

Fundamental to the future of Wi-Fi 7, and in the future Wi-Fi 8, is 6 GHz. However, the world has fractured into three blocs: those that have released the entire 1200 Megahertz (MHz) of the spectrum (5925 – 7125 MHz) for unlicensed use, those that allocated only the lower portion (5925 – 6425 MHz), and the undecided. This has resulted in divergent 6 GHz global policies. Ultimately, however, the global 6 GHz band will remain fragmented for the near future, and regional policy makers should finalize their decisions on 6 GHz as soon as possible to provide clarity and a path forward for chipset and device manufacturers to maximize their spectrum allocation. Given this inevitable regional disparity, vendors should take advantage of Wi-Fi 7 and Wi-Fi 8, which can bring performance enhancements in dual-band implementations via MLO, and help fully use the available 6 GHz spectrum within each region. These enhancements will be necessary in enabling higher capacity networks, but will also play an important role in delivering the throughput and latency advancements required for next-generation consumer and enterprise applications, such as 8K streaming and Extended Reality (XR).

Bluetooth is also banking on 6 GHz unlicensed availability for future innovations over the next decade. Regional variations in unlicensed 6 GHz spectrum allocation could constrain certain future Bluetooth use cases to certain regions and add complexity to a technology that has historically built its success on global operations and shared features.

Beyond what is happening today, as wireless networks become increasingly congested, the need for additional spectrum is only likely to grow over the next decade. As competition intensifies, the short-range wireless ecosystem will need to investigate additional frequency bands and effectively promote the potential economic benefits that unlicensed spectrum can bring when compared to alternative technologies.

REGULATORY RESTRICTIONS

Short-range wireless technologies are subjected to a number of regulatory restrictions. If workarounds can be provided, it could enhance performance. For technologies like UWB, which was initially positioned as a data transfer technology, various regulations were developed over 20 years ago to ensure minimizing interference with incumbents. As a result, strict power, frequency, and location-specific limitations were placed on the technology. However, these are no longer

aligned with current innovations and use cases in UWB technology, particularly ranging and positioning applications. While regulatory waivers can be obtained, these are often very specific and can take up to several years to progress. As a result, the FiRa Consortium has proposed a number of regulatory changes to help UWB reach its potential. This includes fixed outdoor operation for location and control applications, explicit authorization for internal and external automotive use cases, higher power indoor use for better coverage, additional spectrum above 10 GHz, and the creation of a safe harbor band for critical UWB use cases, among others.

In a similar vein, Wi-Fi in the 6 GHz band also has a number of restrictions. To combat this, in November 2022, the Federal Communications Commission (FCC) approved the use of AFC database systems to enable standard power operations in the 6 GHz band, bringing significant range and performance enhancements for 6 GHz Wi-Fi devices. For example, standard power 6 GHz Wi-Fi 7 has the potential to deliver 63X higher transmission power compared to Low Power Indoor (LPI) Wi-Fi 6E. These will help Wi-Fi bring a more compelling value proposition compared to cellular technologies, with the greatest potential within large-scale indoor/outdoor Wi-Fi networks deployed within large public venues, campus networks, warehouses, and manufacturing sites.

COEXISTENCE

As the installed base of short-range wireless devices grows, this will naturally bring increased interference and congestion, resulting in exacerbated coexistence challenges. This will grow over time as demands on the network increase, density of deployments grow, and a mixture of device types need to be supported. As a result, there is a need to ensure coexistence between different short-range wireless technologies and to ensure that one technology does not detrimentally impact another. This has the potential to become a significant issue in the 6 GHz band as new licensed-exempt Wi-Fi, Bluetooth, and UWB services compete for spectrum across myriad use cases, while also avoiding harmful interference to incumbent licensed wireless systems. For example, there have already been some UWB services that have had to relocate to an alternative frequency band due to the arrival of 6 GHz Wi-Fi, and with UWB's existing power restrictions, there is potential the technology could be increasingly drowned out by alternatives. With QoS being such a vital metric for various applications, the importance of this coexistence will only grow into the next decade. In order to enable high throughput, low latency, improved QoS, and greater coverage, questions also need to be asked around how to more efficiently allocate spectrum, time, and space resources to each technology.

MULTI-FUNCTION TECHNOLOGIES

Adding to this complexity is the fact that each wireless technology is evolving to support multiple different implementations, including data transfer, secure ranging, high-accuracy positioning, sensing capabilities, ambient IoT support, or new topologies, such as broadcast or mesh. These multi-functional abilities will undoubtedly increase the value proposition of wireless technologies and allow them to better compete with alternatives. However, it will become increasingly important to ensure that one capability does not significantly impact another; for example, sensing capabilities impacting Wi-Fi network performance and reliability, or a radar implementation of one technology impacting another. Alongside this, proprietary implementations or enhancements to standards-based technologies may also cause additional coexistence issues. Therefore, work needs to be done to ensure that technologies can support these additional functions without diminishing other solutions operating in close proximity.

However, while improvements can be made to increase interoperability, fundamentally, existing short-range wireless technologies are not designed for optimal resource sharing and effective coordination among them, making it very difficult to guarantee performance, QoS, and latency requirements, with a knock-on impact on power consumption, robustness, and reliability of many short-range wireless deployments. The presence of multiple competing technologies in the same environments all vying for the same resources makes this a very difficult challenge to solve.

SUPPORT FOR HETEROGENEOUS APPLICATIONS

Thanks to their flexibility, short-range wireless technologies have expanded to support an enormous variety of use cases and applications. However, this diversity often requires technologies to prioritize different metrics; for example, throughput versus power consumption. As the requirements at both ends of the performance spectrum become even more stringent, this may require additional work in the standards development process to ensure that all of the diverse demands can be met and that certain target areas do not fall behind.

GROWING COMPETITION

Short-range wireless technologies face increasing competition each other and also from other wireless technologies, such as cellular, Low-Power Wide Area (LPWA), proprietary 2.4 and sub-1 GHz, or market specific wireless technologies that are also evolving. Meanwhile, new technologies continue to emerge, such as NearLink and DECT-2020 New Radio (NR), which could also capture opportunities across many environments. However, the relationship between each technology is dependent on the market in which they operate. In certain markets, such as smartphones, these technologies have traditionally had clearly-defined use cases, with Wi-Fi and 5G for high-throughput connectivity, Bluetooth for audio and accessory connectivity, NFC for payments, and UWB for ranging applications. However, as Wi-Fi and Bluetooth both support ranging capabilities, and UWB supports lossless audio, the landscape may change over time. Similarly, in the mobile and PC accessory market, there is potential growing competition between UWB and Bluetooth for high-performance/low-latency peripherals, while the emergence of new technologies, such as NearLink, could also disrupt the low latency peripheral and audio markets.

In the smart home market, technologies both compete, collaborate, and coexist, depending on the specific applications. For example, Wi-Fi, Bluetooth, ZigBee/Thread, Z-Wave and other short-range wireless lighting, sensor, thermostats, and appliances exist today, often in direct competition. In the automotive and smart building space, Bluetooth may increasingly encroach upon UWB's market opportunity in keyless entry applications as it incorporates enhanced ranging functionality. In industrial IoT applications, Wi-Fi, Bluetooth, and 802.15.4-based condition monitoring solutions all compete for market share. Meanwhile, technologies like 5G-Advanced and 6G will bring further improvements to key metrics, including throughput, latency, reliability, determinism, scalability, and power consumption, alongside incorporating better support for IoT devices, integrated sensing and communications, and precise positioning, and leveraging ML capabilities for optimized network management and other features. Short-range wireless technologies will need to continue their evolution with similar performance and QoS in order to not risk losing ground.

IMPROVED USER INTERFACES

Clearly, no single technology can address all wireless use cases, so IoT deployments will need to take advantage of the unique strengths of each technology, while creating intelligent applications that can effectively solve the specific requirements of each use case. Additional work needs to be undertaken to ensure that disparate devices that leverage different technologies come from different vendors or leverage different IoT platforms that are able to effectively communicate to generate intelligent use cases and bring valuable insights. Industry organizations, such as the CSA, are developing open-source connectivity standards to better enable unified user interfaces that are simple and easy to use to onboard, configure, control, and maintain IoT devices from different vendors across single or multiple different lower layer technologies.

WIDER SYSTEM INNOVATION

The evolution of the short-range wireless market landscape will also depend on continued innovation in other elements of system design. This will include improvements in computing capabilities, sensor technologies, batteries, RF and filters, antenna size and performance, energy harvesting capabilities, ML algorithms, and many other features. These enhancements will be critical in helping short-range wireless technologies meet their future objectives and enhancements to key metrics.

GROWING DESIGN COMPLEXITY

The expansion of short-range wireless capabilities could cause further complexity and cost to be added to IC and device design. For example, support for additional radios, MLO, and combined communications and sensing, among other enhancements, all have the potential to drive up costs. The industry must continue to strike the right balance between support for new features and enhancements, while also ensuring that the market can scale effectively without losing out to the competition. This could include leveraging ML tools to reduce the complexity of devices.

THE ROLE OF CONNECTIVITY INDUSTRY ORGANIZATIONS

Beyond the connectivity standards themselves, there lies an extremely complex landscape of industry organizations, consortia, and alliances, often with their own divergent interests and focal points, making it even more difficult to ensure coexistence between different technologies and within applications and end markets. There is a growing need for these various organizations to come together and more effectively communicate in order to enable improved coexistence, and identify potential avenues of cooperation.

These organizations also have a vital role in ensuring interoperability between different vendors, creating standardized profiles to help accelerate adoption, identifying new use cases via their membership and working groups, or to deliver additional certification programs to ensure conforming to guidelines and standards.

CONCLUSION

The short-range wireless connectivity market is currently undergoing an enormous transformation. Growing demand for wireless devices across numerous consumer and enterprise markets has led to continued growth in recent years, with most short-range wireless technologies now expected to reach billions of annual unit shipments by the end of the decade.

Thanks to their unique abilities and performance metrics, technologies like Wi-Fi, Bluetooth, UWB, 802.15.4, and NFC have been able to target a wide variety of markets. Wi-Fi has traditionally focused on high-throughput applications, Bluetooth on audio and increasingly low power IoT devices, UWB on secure fine-ranging applications, 802.15.4 on smart home and wireless sensor networks, and NFC on mobile payments. At the same time, new wireless use cases continue to emerge on a daily basis, each with its own unique requirements. Backed by organizations like the IEEE, the WFA, the Bluetooth SIG, the FiRa Consortium, the CSA, and the NFC Forum, next-generation use cases that stretch beyond this decade have been identified, and each technology is continuing to evolve in order to target a much wider variety of applications.

This will be achieved through the arrival of new standards, such as Wi-Fi 7, Wi-Fi 8, next-generation UWB, and continued enhancements to Bluetooth, 802.15.4, and NFC, enabled by the availability of new spectrum, greater use of existing resources, and support for new features and topologies. These enhancements will help these technologies support next-generation wireless use cases that require improvements across key metrics encompassing throughput, range, latency, reliability, power consumption, and scalability, among many others. At the same time, these technologies are increasingly innovating within overlapping areas. This includes not only enhancements to throughput and reliability, but also the ability to provide high-accuracy positioning, support for secure ranging, joint communications, and sensing, alongside growing support for the emerging ambient IoT market. This competition has the potential to create valuable new services and scale these technologies to new heights.



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