HOW MULTI-PROTOCOL WIRELESS PLATFORMS ARE ENABLING THE NEXT WAVE OF WIRELESS INNOVATION

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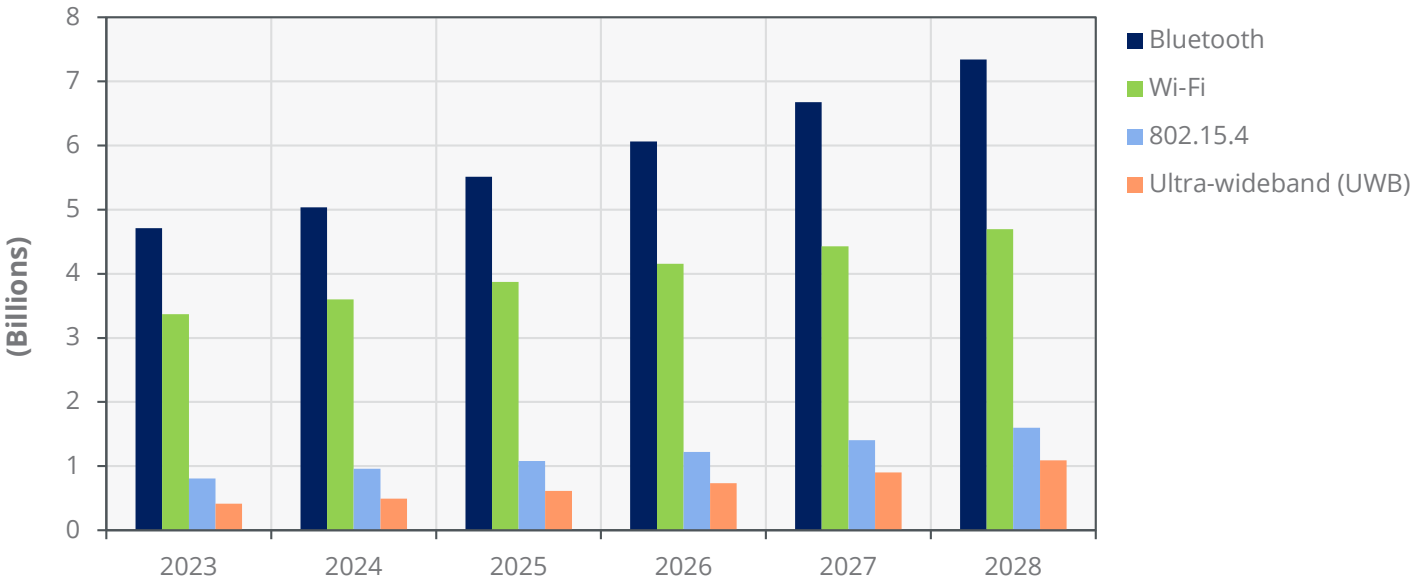
INTRODUCTION

Over the last couple of decades, the connectivity market has transformed the way we live. Not a single day goes by with most of us not spending hours using or, at the very least, interacting with a wide variety of connected devices. By the end of 2024, ABI Research forecasts that the installed base of connected devices will reach over 55 billion units, spanning a wide array of end markets, including mobile devices, Personal Computers (PCs), wearables, home entertainment, smart home, automotive, commercial building, industrial, and other consumer and Internet of Things (IoT) applications. Fundamental to this growth has been the rapid expansion of short-range wireless connectivity technologies such as Wi-Fi, Bluetooth®, and 802.15.4 (most notably Zigbee and Thread). Meanwhile, the comparatively nascent Ultra-Wideband (UWB) technology, equipped with its own unique feature set, is also expected to grow considerably over the next few years, as it enables several new use cases and innovative user experiences.

As Chart 1 demonstrates, the opportunities for each of these technologies are forecast to increase markedly over the next 5 years. By 2028, annual Bluetooth®-enabled device shipments are expected to reach over 7.3 billion units, Wi-Fi is expected to reach 4.7 billion units, 802.15.4 is expected to reach 1.6 billion units, and UWB is expected to reach nearly 1.1 billion units. This will equate to Compound Annual Growth Rates (CAGRs) of 9%, 7%, 15%, and 21%, respectively, between 2023 and 2028.

Chart 1: Device Shipments by Wireless Connectivity Technology World Markets: 2023 to 2028

(Source: ABI Research)



Much of this growth will be built upon a significant expansion in the number of applications and device types that these technologies will be addressing. Given the diversity of the IoT, as well as continued technology innovation, new wireless use cases are emerging on a regular basis, and these will account for a growing portion of the connected device market over the next decade. In addition, devices themselves are growing in complexity, supporting more and more different use cases and features, often with wildly divergent needs. This is resulting in an extremely heterogeneous set of requirements that enabling wireless connectivity technologies need to be able to address effectively, including:

- High throughput (up to multiple-Gigabits per Second (Gbps))
- Low latency operation
- Ultra-low power consumption for multi-year battery life, energy harvesting, or ambient IoT integration
- High security
- Support for multiple topologies, e.g., point-to-point, star, mesh, broadcast, and connectionless one-to many
- High scalability, interoperability, and support for unified application layer protocols, e.g., Matter
- Support for multiple features, profiles, and software stacks
- Operation in multiple frequency bands, including concurrent operation
- Support for high accuracy integration of secure ranging and radar and sensing capabilities
- Support for high accuracy, centimeter-level positioning using Angle of Arrival (AoA), Channel Sounding, Time of Flight and other localization techniques
- Support for always-on connectivity

- Direct-to-cloud connectivity
- Streamlined device provisioning
- The ability to communicate with mobile devices, wearables, and existing infrastructure
- Ultra-high reliability
- Robust Radio Frequency (RF) performance and strong coexistence between different technologies
- Deployment in harsh RF, high density, crowded, or congested environments
- Support for operation in extended temperature ranges
- The ability to operate within indoor and outdoor environments
- Future-proof connectivity and long device life spans (10 years or more)
- The ability to support low-cost and resource-constrained devices
- Support for small form factors and reduced device footprints

THE UNIQUE BENEFITS OF WI-FI, BLUETOOTH®, 802.15.4, AND UWB TECHNOLOGY

Given this varied list of requirements, it is clearer than ever before that a single connectivity technology will be incapable of addressing this diversity effectively, while each wireless technology has its own unique benefits and limitations.

Wi-Fi Market Evolution and Future Opportunities

Wi-Fi, based on the IEEE 802.11 standards, typically provides high-throughput, low latency, and short to medium-range Internet Protocol (IP)-based connectivity across a wide range of applications, including mobile devices, PCs, video cameras, Access Points (APs), smart Televisions (TVs), games consoles, Extended Reality (XR) headsets, and other devices where high-speed Internet access and video streaming capabilities are key priorities. With typical throughput between hundreds of Megabits per Second (Mbps) to multi-Gbps depending on the specific IEEE 802.11 standard and which of the 2.4 Gigahertz (GH)z, 5 GHz, or 6 GHz frequency band on which it operates, Wi-Fi has historically targeted line-powered or devices with large batteries that require the maximum possible throughput, alongside low-latency performance, with relatively high-power consumption as a result.

However, thanks to continued innovation through low-cost, low-power Wi-Fi 4 and Wi-Fi 6 chipsets, Wi-Fi technology is now capable of addressing an ever-growing number of client devices across the consumer, commercial, and Industrial IoT (IIoT), including resource-constrained and battery-powered IoT devices. These devices, including wearables, sensors, thermostats, and door locks, typically have lower throughput requirements, but are also much more limited in terms of form factor, cost, computing resources, antennas, and battery sizes. Meanwhile, these low-power innovations are also enabling Wi-Fi to create new opportunities in battery-powered video applications, such as within smart doorbells and home security cameras, while enabling multi-year life spans on more basic devices. Other key benefits of Wi-Fi technology include the ability to connect to the huge installed base of Wi-Fi-enabled APs across different environments, enabling always-on, direct-to-cloud connectivity, reducing design complexity and accelerating time to market.

Wi-Fi technology is continuing to evolve to support new features such as Wi-Fi sensing, enhanced positioning, higher throughput, Multi-Link Operation (MLO), and ultra-high reliability through new standards such as Wi-Fi 7 and, in the future, Wi-Fi 8.

Bluetooth® Market Evolution and Future Opportunities

Bluetooth® arguably has the most diverse range of target markets and applications of all technologies discussed in this whitepaper. Having built a ubiquitous presence in smartphones, tablets, and PCs via dual-mode solutions that support both Bluetooth® Basic Rate(BR)/Enhanced Data Rate (EDR) (Bluetooth® Classic) and Bluetooth® Low Energy (LE) technology, Bluetooth® has become the primary enabler of wireless audio, peripheral, and accessory connectivity. Meanwhile, the enormous presence in these platform devices, combined with the inherent low power and low cost of the technology, availability from a wide selection of chipset vendors, 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, 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 healthcare devices, Electronic Shelf Labels (ESLs), and industrial equipment monitoring, among others.

Meanwhile, Bluetooth® LE technology continues to evolve at a rapid pace. Over the last decade, the technology has added support for new features such as Bluetooth® mesh, extended range capabilities, improved positioning via Angle of Arrival (AoA)/Angle of Departure (AoD), and most recently Channel Sounding, enhanced audio capabilities with LE Audio and Auracast™ broadcast audio, and Periodic Advertising with Response (PAwR) to enable more scalable, connectionless bidirectional communications for applications such as ESLs and newly release of Channel Sounding for enhanced accurate positioning. This evolution is set to continue, with more exciting features on the horizon like high data throughput (7.5 Mbps, for High-Definition (HD) audio streams and more), and ultra-low latency (for gaming peripherals).

802.15.4 Market Evolution and Future Opportunities

IEEE 802.15.4 is another low-power wireless connectivity technology targeting a wide range of consumer, commercial, and IIoT applications. Zigbee, historically the most popular 802.15.4 technology, is a mesh networking technology that has been deployed across a wide range of applications within smart home, commercial building, smart utility, and Industry 4.0 environments. While offering a maximum throughput of 250 Kilobits per Second (Kbps), its low cost, low power consumption, and efficient mesh capabilities make it well suited for a range of home automation devices, including 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. Meanwhile, another key 802.15.4-based technology with strong adoption in 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. Matter is a relatively new initiative from the Connectivity Standards Alliance (CSA) to abstract and encompass multiple connectivity technologies below a common protocol, natively supporting link technologies like Wi-Fi and Thread. With strong support from the tech giants, Matter is enjoying rapid, wide-spread success, solving real-world consumer concerns around the complexity of installing heterogenous smart home systems and unlocking the potential of this market.

UWB Market Evolution and Future Opportunities

UWB is a short-range impulse radio technology capable of securely and accurately calculating the relative position of other UWB-enabled devices at a distance of up to 100 Meters (m) and down to centimeters of accuracy. Over the last decade, IEEE 802.15.4a-based UWB solutions have increasingly been adopted to provide centimeter-level tracking within indoor Real-Time Location System (RTLS) applications. However, in the last 5 years, the arrival of the new IEEE 802.15.4z standard, which incorporated additional security extensions to the technology, has enabled UWB to emerge as a secure, fine-ranging technology capable of enabling a much wider range of innovative location-based user applications and services.

UWB uses a wide channel bandwidth (500 MHz) between the 3.1 GHz and 10.6 GHz frequency bands and short 2 Nanosecond (ns) pulses to accurately measure the Time-of-Flight (ToF) between two devices, such as smartphones, wearables, keys fobs, tags, door locks, and anchor points. When in proximity, these devices begin ranging using ToF measurements to calculate the round trip time of the communication. One device can, therefore, calculate the relative location of the other instantly (with refresh rates at 100X per second) and continuously, with movements being monitored in real time. Meanwhile, 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.

These features have provided UWB with the ability to provide highly secure and accurate distance and location measurement, enabling several 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 connected home Original Equipment Manufacturers (OEMs) to incorporate the technology for automotive keyless entry, personal tracking, audio handover, and other emerging use cases. Organizations such as the Car Connectivity Consortium (CCC) and its Digital Key 3.0 specification, the FiRa Consortium, and the Connectivity Standards Alliance's (CSA) Aliro are all helping to standardize various UWB use cases with the help of Bluetooth® LE and Near Field Communication (NFC) technology.

A number of companies are also beginning to leverage UWB as a radar and sensing technology across a number of different applications. The ability for UWB radar to provide fine motion detection is enabling several innovative 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 and car parks, among many others.

UWB technology is still very much in its early phase of maturity and the number of use cases it will be able to support or enhance is expected to grow enormously over the next decade. Key organizations backing the technology, including the FiRa Consortium continue to develop new specifications for UWB technology, including the recently published FiRa 2.0 Specifications, which identified untracked indoor navigation, find someone/something, and point-and-trigger use cases as key emerging use cases for the technology.

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 over time.

THE GROWING NEED FOR MULTI-PROTOCOL CONNECTIVITY SOLUTIONS

The diversity of applications and feature requirements mean that several technology combinations will be required enable new innovative use cases and features.

Some devices will require multi-Gbps throughput, others will require years of operation on coin cell batteries, others will need to embed secure ranging capabilities, and some will increasingly add sensing and radar functionality. Many will require a combination of all these different metrics. Meanwhile, even within the same technology, this diversity continues to increase. A Wi-Fi device targeting smartphones will have very different needs compared to a battery-powered sensor, while a Wi-Fi device deployed in the home may have very different connectivity requirements compared to one in an industrial setting. Each connectivity technology must, therefore, prioritize different metrics depending on the application. This requires increasingly flexible connectivity portfolios with the ability to address multiple use cases.

Devices will also increasingly rely on the features of multiple technologies in order to help them scale effectively. For example, the successful rollout of Matter-enabled Thread devices will be closely tied to the partnership with Bluetooth® LE for seamless commissioning. Similarly, UWB technology used within digital key, access control, and FiRa-related applications leverages Bluetooth® LE for the initial wake up and handover process to reduce the overall power consumption. Wi-Fi- and Bluetooth®-enabled devices looking to integrate secure fine-ranging or radar capabilities will also need to integrate UWB. Bluetooth® headsets looking to provide support for lossless audio and extended range experiences can benefit from low-power Wi-Fi integration. Devices with higher throughput requirements for video streaming may need to integrate Wi-Fi alongside Bluetooth® for audio streaming. Meanwhile, other low-power 802.15.4 sensors may benefit from integrating Bluetooth® LE for provisioning, faster firmware updates or location services.

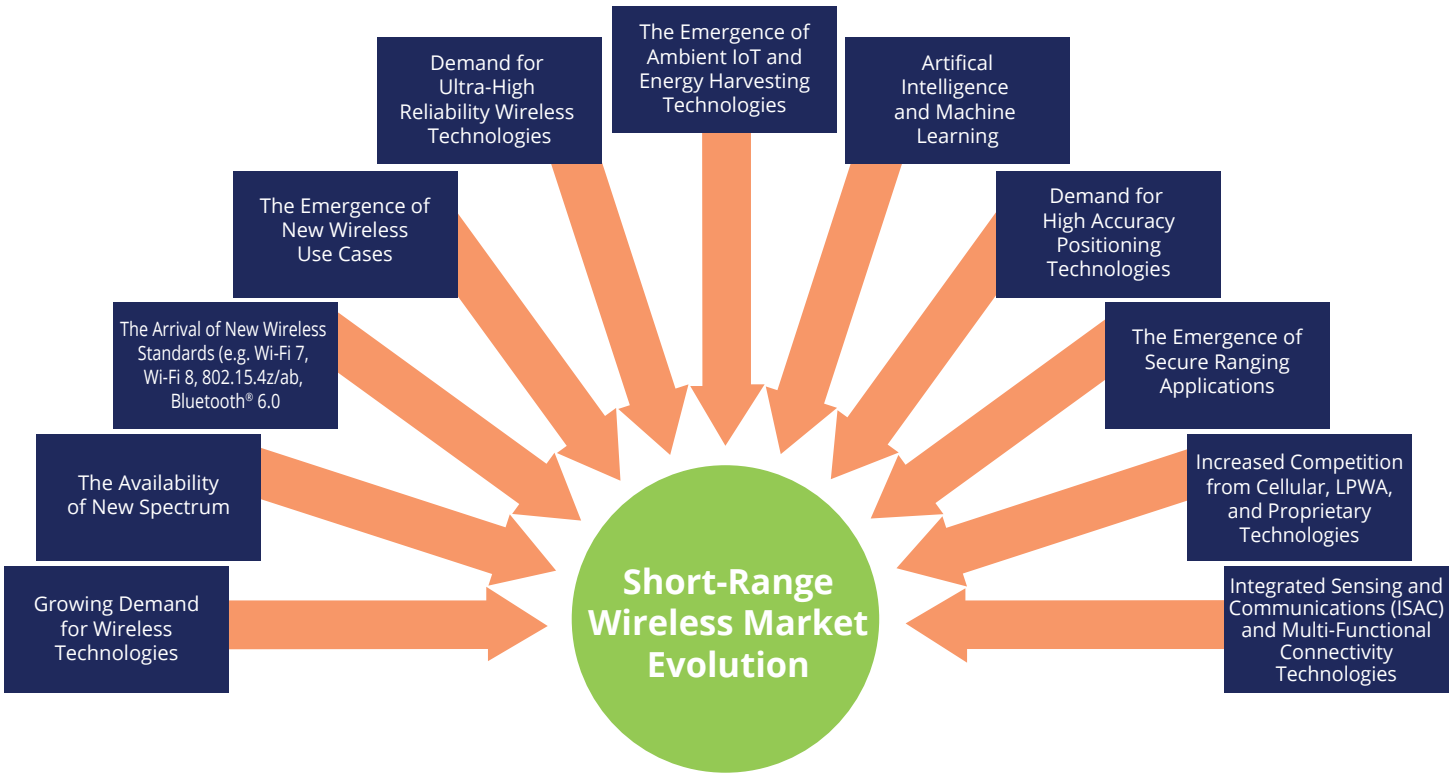
As this diversity also increases, different environments will also deploy multiple connectivity technologies. Here, there will be a growing need for multi-protocol Integrated Circuits (ICs) that can ensure effective communication and interoperability between different end nodes. For example, in the smart home, there will be a combination of wireless standards at play, including Wi-Fi, Bluetooth®, 802.15.4, and, increasingly, UWB. Similarly, enterprise environments such as smart buildings, gateways, and wireless infrastructure that support multiple different protocols will enable several valuable IoT use cases ranging from wireless sensor networks to video surveillance, ESLs, connected lighting, RTLS, and indoor navigation, among others.

Perhaps most importantly, combo and multi-protocol ICs can help enable higher performance devices, activate new features to differentiate from the competition, and help build innovative user experiences and valuable new services that transcend what we have today. Implementing multiple protocols on a single chip can help maximize the value proposition of that chipset by enabling new features, while keeping costs, complexity, and time to market as low as possible. This can help chipset vendors compete more effectively in multiple market segments, and stand out better in a highly competitive and crowded landscape.

This complexity and diversity will only increase in the coming years as new features and capabilities emerge. Figure 1 summarizes some of the key drivers impacting the continued evolution within the short-range wireless connectivity space. Growing demand for wireless solutions combined with continued technology evolution, availability of new spectrum, integration of new capabilities such as ranging, positioning, and sensing, desire for higher performance and reliability, as well as future ambient IoT, energy harvesting, and Edge AI integration, is bringing both new complexity and opportunities to the market, which only a combination of multiple technologies can possibly solve.

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

(Source: ABI Research)



While it is hard to envision all the new applications that could emerge, over the next decade, more and more devices will leverage multiple technologies to maximize performance, enhance interoperability, and enable continued innovation. Wi-Fi, Bluetooth®, 802.15.4, and UWB, and various multi-protocol combinations of each, will all play a key role in defining this future landscape.

THE BENEFITS OF MULTI-PROTOCOL ICS

This combination of more and more wireless devices, new and innovative use cases, and the emergence of new types of connectivity such as radar and sensing, among others, are all leading to a growing need for combo and multi-protocol solutions that can effectively address them. In a nutshell, the main benefit of combo and multi-protocol ICs is their ability to combine the best of multiple individual technologies in a unified solution that can maximize the performance, utility, and value proposition of each. This can be achieved by the following benefits, notably:

- **Reduced Costs:** Combining multiple wireless connectivity technologies onto a single chip can help reduce the overall Bill of Materials (BOM) cost of a solution. This can be achieved through fewer components, simplified antenna designs, and reduced design time and complexity. This may be vital in helping to scale up new technologies such as UWB.

- **Reduced Power Consumption:** Combo and multi-protocol solutions can provide lower power consumption compared to discrete solutions. This is due to several reasons, including better optimization of resources, the ability to share resources, improved coexistence, and more efficient communication between the different protocols.

- **Smaller Form Factors:** Deploying multiple connectivity protocols on the same chip can result in smaller devices compared to those that need to integrate multiple discrete solutions and additional components.

- **Improved RF and Coexistence Performance:** Multi-protocol solutions can also offer better performance, robustness, and reliability thanks to enhanced coexistence mitigation techniques due to the higher level of integration between the different protocols. This is particularly important for devices that require regular concurrent operation on the same frequency bands.

- **Reduced Design Complexity and Faster Time to Market:** Using fewer components significantly reduces the overall design complexity. It can also help minimize any points of failure in the design process once the solution is deployed to the market. These benefits can also help accelerate development time and get products to market much faster, enabling valuable resources to be spent elsewhere in the design process. Combo solutions can also help reduce the time it takes for devices to be certified ahead of production.

- **Creating Valuable New Features and Use Cases:** Nearly all connected devices are growing in complexity. Wi-Fi is targeting both ends of the performance spectrum, while also incorporating advanced sensing and positioning capabilities. Bluetooth® is capable of multiple different topologies and features, including support for Mesh, AoA/AoD Direction Finding, Channel Sounding based ranging, LE Audio and Auracast™ broadcast audio, PAwR, and extended range capabilities. Meanwhile, UWB continues to develop at a rapid pace to provide secure ranging and high-accuracy location capabilities, alongside radar capabilities for presence and gesture detection. Combining the best of all of these technologies in a seamless manner can enable chipset manufacturers and OEMs to create truly innovative user experiences and valuable additional features for their portfolios.

OPPORTUNITIES FOR MULTI-PROTOCOL ICS BY VERTICAL

Given this growing device and use case complexity, it is perhaps unsurprising that the opportunities for multi-protocol ICs have grown significantly in recent years. The following section identifies some of the key emerging use cases and potential market verticals for multi-protocol ICs. Many of these currently integrate multiple technologies separately, or at the module level, but are likely to take advantage of new multi-protocol solutions as they emerge in the market.

Mobile Devices

Smartphones and tablets have been using combo Wi-Fi and Bluetooth® dual-mode ICs for well over a decade, with both technologies now ubiquitous in these devices. However, there is a growing desire to embed additional technologies such as UWB and 802.15.4 to support new use cases. For UWB, this includes a variety of secure ranging applications, including automotive keyless entry and access control, personal tracking, and audio handover. Over time, this has the potential to extend to new point-and-trigger applications, tap-free mobile payments, and indoor navigation, among others, as defined by future FiRa Consortium use cases. New multi-protocol ICs such as Qualcomm's FastConnect 7900, a highly integrated Wi-Fi 7, Bluetooth®, and UWB combo chip, are likely to help accelerate UWB adoption beyond flagship devices in the coming years, reducing the cost and complexity of adoption. For 802.15.4, the first smartphone to embed the technology has arrived in the form of the Apple iPhone 15 Pro. Here, the radio can potentially be used for direct communication with a Thread-enabled smart home device or to act as an additional border router or control device for smart home applications. Tablets, which are more traditionally left at home, could use 802.15.4 to act as smart displays and control hubs, as opposed to purchasing dedicated smart home controllers. Broadcom's latest BCM4390 multi-protocol chip incorporates Wi-Fi 7, Bluetooth®, and 802.15.4 for the smartphone and tablet markets.

Home Entertainment and Smart Home

The growing diversity of home entertainment smart home devices demands the need for multiple technologies to address different use cases. Wi-Fi may be needed for video applications, always-on connectivity, or streamlined cloud connectivity, Bluetooth® may be leveraged for audio applications, proximity detection via channel sounding, or interaction with mobile devices and wearables, and 802.15.4 may be leveraged for ultra-low power applications or scalable mesh networks for lighting control.

The move toward Matter is also accelerating the need for multi-protocol solutions that can help overcome the huge interoperability and installation issues that have plagued the smart home market for the last decade or so. IP-enabled Matter devices that run over Thread or Wi-Fi network layers can simplify the development of smart home devices and reduce the risk of a device from one vendor or ecosystem not working with another. A growing number of Wi-Fi- and Bluetooth®-enabled home entertainment and connected home devices are now also embedding 802.15.4 technology to enable them to act as smart home hubs, display devices, and border routers, without the need for an external module or dedicated smart home controller. Over the last 12 to 24 months, several of Samsung's smart TVs, smart monitors, and soundbars have embedded Zigbee, Thread, and Matter support directly into the device. This is part of Samsung's wider "Hub Everywhere" to enable multiple devices within the home to act as Matter controllers to simplify setup, management, performance, and reliability of the smart home network. In a similar vein, Apple has also started to embed Thread support in its Apple TV 4K models,

alongside its HomePod and HomePod Mini smart speakers to enable control of devices as part of its HomeKit ecosystem. Other recent smart speakers such as Amazon's Echo 4th generation incorporate Wi-Fi, Bluetooth® and 802.15.4 for networked audio, the ability to act as an eero Wi-Fi extender, Bluetooth® audio and mesh support, alongside the ability to act as a smart home hub. Given the need for Wi-Fi and Bluetooth® functionality for video streaming, remote control, and audio use cases, the growth of Matter could accelerate the need for multi-protocol ICs that incorporate all three technologies in various connected home devices.

Meanwhile, Bluetooth® LE is increasingly becoming a prerequisite commissioning technology to simplify connecting a new Matter device to the existing network. As more and more devices continue to be added to the Matter specifications, this will accelerate the need for multi-protocol solutions that can streamline development, ensure interoperability, and ensure seamless provisioning.

Many smart appliances come equipped with Wi-Fi and Bluetooth® combo chips for direct, always-on connectivity to an existing home AP, alongside the ability to provide direct smartphone interaction or seamless provisioning via Bluetooth®. Similarly, there are numerous 802.15.4 and Bluetooth® combo solutions already on the market that are targeting smart home and other IoT applications. For example, STMicroelectronics' STM32WB solution targets Matter devices due to its ability to run Thread and Bluetooth® LE for device commissioning concurrently. Other solutions such as Espressif's ESP32-H2, NXP's MCX W71X and W72X, Alif Balletto and Atmosic's ATM34/e all combine support for 802.15.4 with Bluetooth® LE to target similar smart home and IoT applications.

Some notable products in the market today that require all three protocols include Google's Nest Learning Thermostat and the Nest Doorbell, which combine Wi-Fi 4 with Bluetooth® LE and 802.15.4. Meanwhile, numerous vendors such as Qualcomm, NXP, Synaptics, and Espressif have developed tri-radio Wi-Fi, Bluetooth®, and 802.15.4 SoCs. These can be leveraged to target smart home hubs and displays, border router devices, smart appliances, thermostats, smart doorbells, and connected lighting, among others.

Finally, new technologies such as UWB have the potential to enable additional security and new experiences in applications such as access control, point-and-trigger appliance control, gesture control, and proximity-based device activation in the future. As the penetration of UWB in mobile devices increases, there will likely be additional incentives to integrate this within a range of smart home devices and appliances. Today, Apple's 2nd generation HomePod smart speaker already supports Wi-Fi, Bluetooth®, Thread, and UWB technology, with UWB being used to handover audio from an iPhone. In addition, the new Huawei Lingxi Pointing Remote Control is further evidence of smart TV companies looking to revolutionize the User Interface (UI) experience using a fusion of UWB, Bluetooth® LE, and motion sensing edge AI.

Consumer and Enterprise Wi-Fi Networking Infrastructure

Home Wi-Fi APs are increasingly combining multiple connectivity protocols to enable Matter support and can act as an alternative to separate dedicated smart home hubs and controllers. Some recent examples include Google's Nest Wi-Fi Pro, which combines Wi-Fi 6E with Thread and Bluetooth® LE, and the latest eero Max 7, which combines Wi-Fi 7 with Thread and Bluetooth®. Enterprise Wi-Fi APs and IoT gateways are also increasingly incorporating multiple additional wireless connectivity technologies such as 802.15.4, Bluetooth®, and UWB to help enable a range of IoT applications, including wireless sensor networks, networked lighting control, asset tracking, indoor navigation, and ESLs, among others. This enables enterprises to take advantage of the

unique benefits of each technology such as precise indoor localization using AoA and Channel Sounding, scalable low-power mesh networks, and connectionless bidirectional communication topologies such as PAwR. Broadcom's BCM47722 is one recent example of a multi-protocol Wi-Fi 7, Bluetooth® LE, and 802.15.4 System-on-Chip (SoC) targeting the AP market.

Automotive Keyless Entry, Access Control, and Personal Tracking

In many applications, technologies also work best when they are paired with others. For example, in all FiRa and CCC tracking and access control applications, UWB is being paired with Bluetooth® LE to reduce the overall power consumption of UWB fine-ranging. Bluetooth® LE is utilized for low-power discovery and initial wake-up and hands over to UWB to provide the secure ranging capability and gain access. Similarly, personal trackers such as Apple AirTags and Samsung SmartTags combine UWB and Bluetooth® LE to enable high-accuracy location capabilities without compromising too heavily on power consumption.

In November 2023, the CSA announced Aliro, a new communication protocol that aims to help ensure interoperability for consumer and commercial access control applications using mobile devices such as smartphones and wearables. Similar to the CCC Digital Key 3.0 Specification in the automotive keyless entry market, the foundation of the standard is based on combining UWB, Bluetooth® LE, and NFC technology to maximize performance, power consumption, and reliability. This standardization process may help accelerate the growth of UWB and Bluetooth® combo solutions in the years to come.

There are already several module solutions in the market today that combine UWB and Bluetooth® functionality. ABI Research expects that, over time, new UWB and Bluetooth® combinations will also be enabled at the chipset level to further reduce design complexity, power consumption, form factors, and cost.

Wearable Devices

Wearable devices such as smartwatches are now equipped with a similar connectivity arsenal as that of smartphones. For example, the latest Apple Watches incorporate Wi-Fi, Bluetooth®, UWB, and NFC, while there is potential in the future that 802.15.4 could also be embedded as another option that can directly control Thread-enabled smart home devices.

XR Devices

While most XR devices such as Virtual Reality (VR) headsets and Augmented Reality (AR) smart glasses already incorporate Wi-Fi and Bluetooth® combo solutions, in the future, there is also potential to embed UWB technology for enhanced navigation, location services, item detection, and low-latency peripheral interaction.

Audio Devices

New combos have also recently emerged in the audio space. Qualcomm's latest S7 Pro Gen 1 Sound platform combines ultra-low power Wi-Fi with Bluetooth® to enable lossless audio, alongside extended range untethered listening over the home Wi-Fi network. New "talking sensor" prototypes have also recently emerged that could enable wireless sensors or appliances to be equipped with LE Audio to broadcast status information, safety, or security announcements directly into an employee or consumer headset. These could theoretically require multiple connectivity technologies such as Wi-Fi and 802.15.4, in addition to Bluetooth®, depending on their deployment environment and device requirements.

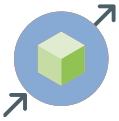
Point of Sale (POS) Terminals

Another potential future use case for UWB technology is within payments applications. In 2022, ING partnered with NXP and Samsung to demonstrate the first UWB peer-to-peer payment that enables users to send money by pointing their mobile phone at another user. The FiRa Consortium has also identified tap-free mobile payments and automotive in-vehicle payments as a key use case for UWB technology going forward. This could lead to the development of UWB-enabled payment terminals, which already come equipped with Wi-Fi, Bluetooth®, and NFC technology today.

IoT Applications

Combo and multi-protocol solutions are also being leveraged in a wide range of other consumer, commercial, and IIoT applications. Applications include access control readers and door locks, commercial lighting fixtures, wireless sensors, RTLS tags, and anchor points, among others.

As these technologies continue to evolve, there are likely to be even more reasons to integrate multiple connectivity technologies over time. This could range from support for LE Audio and Auracast™ broadcast audio to sensing capabilities, gesture control, proximity services, channel sounding, swifter firmware updates, and new connectionless topologies to enable more scalable rollouts of sensors or connected labels. For example, UWB may also be leveraged as a proximity sensing technology in devices such as tablets and laptops to enable automated locking and unlocking, or within smart home and commercial building automation as a higher accuracy presence detection technology to enable better HVAC and lighting control.



Future Innovation

With new Bluetooth® technologies such as LE Audio, Auracast™ broadcast audio, and Bluetooth® channel sounding, as well as potential future expansion for Bluetooth® into higher frequency bands and support for higher data rates, alongside UWB still being in its very early days of maturity both from ranging, data, and sensing, and standardization perspectives, it is difficult to say what new device types will emerge over the next 5 to 10 years and what continued improvements to range, power, and throughput this could also enable. However, future innovation in these areas will inevitably open new opportunities and combinations for multi-protocol solutions over time.

THE GROWING MARKET OPPORTUNITY FOR MULTI-PROTOCOL ICS

Of course, combo and multi-protocol ICs are not a new thing. The first Wi-Fi and Bluetooth® combo chips arrived as early as the mid-2000s, and over the last 8 to 10 years, there has been a rapid expansion in the availability of different combo and multi-protocol chipsets from numerous leading chipset vendors. In the last 12 to 24 months, new combos have emerged, and chipset vendors are developing more and more unique combinations to better target this aforementioned diversity of consumer and IoT applications. These include high-performance triple radio Wi-Fi, Bluetooth®, and 802.15.4 solutions for smartphones and APs, low-power 802.15.4 and Bluetooth® wireless Microcontroller Units (MCUs) for smart home and IoT, and new solutions that are combining Wi-Fi, Bluetooth®, and UWB, to accelerate the rollout of secure ranging technology in mobile and other platform devices.

Some notable examples of combo and multi-protocol ICs released over the last few years are identified in Table 1.

Table 1: Key Multi-Protocol Chipsets by Vendor

(Source: ABI Research)

Chipset Vendor	Chipset Model	Wi-Fi	Bluetooth®	802.15.4	Ultra-Wideband	Key Target Markets
Alif	Balletto	N/A	Bluetooth® Low Energy 5.3	Zigbee/Thread/ Matter	N/A	IoT
Atmosic	ATM34/e	N/A	Bluetooth® Low Energy 5.4	Zigbee, Thread	N/A	IoT
Broadcom	BCM4390	Wi-Fi 7 2x2	Bluetooth® 5.4	Zigbee, Thread	N/A	Smartphones and Tablets
Broadcom	BCM47722	Wi-Fi 7 2x2	Bluetooth® 5.4	Zigbee, Thread	N/A	Enterprise Access Points
Espressif	ESP32-C6	Wi-Fi 6 Single Band 1x1	Bluetooth® Low Energy 5	Zigbee, Thread	N/A	IoT
Infineon	CYW30739	N/A	Bluetooth® Low Energy 5.3	Zigbee, Thread	N/A	IoT
Microchip	PIC32CX-BZ	N/A	Bluetooth® Low Energy 5.2	Zigbee, Thread	N/A	IoT
Nordic Semi-conductor	nRF52840	N/A	Bluetooth® Low Energy 5.4	Zigbee, Thread	N/A	IoT
NXP	IW612	Wi-Fi 6 Dual Band 1x1	Bluetooth® 5.4	Zigbee, Thread	N/A	IoT
NXP	MCX W71	N/A	Bluetooth® Low Energy 5.3	Zigbee, Thread	N/A	IoT
NXP	MCX W72	N/A	Bluetooth® Low Energy 5.3	Zigbee, Thread	N/A	IoT
Qualcomm	FastConnect 7900	Wi-Fi 7 2x2	Bluetooth® 5.4	N/A	IEEE 802.15.4z	Smartphones and Tablets
Qualcomm	QCC740	Wi-Fi 6 Single Band 1x1	Bluetooth® 5.3	Zigbee, Thread	N/A	IoT
Qualcomm	QCA4020	Wi-Fi 4 Dual Band 1x1	Bluetooth® 5	Zigbee, Thread	N/A	IoT
Qualcomm	QCA4024	N/A	Bluetooth® 5	Zigbee, Thread	N/A	IoT
Qualcomm	S7 Pro Gen 1	Wi-Fi 4 Dual Band 1x1	Bluetooth® 5.4	N/A	N/A	Wireless Audio
Silicon Labs	SiWx915	Wi-Fi 6 Single Band 1x1	Bluetooth® Low Energy 5.4	N/A	N/A	IoT
Silicon Labs	EFR32MG24	N/A	Bluetooth® Low Energy 5.3	Zigbee, Thread	N/A	IoT
ST Micro-electronics	STM32WB55	N/A	Bluetooth® Low Energy 5.4	Zigbee, Thread	N/A	IoT
Synaptics	SYN4381	Wi-Fi 6 Tri-Band 1x1	Bluetooth® 5.3	Zigbee, Thread	N/A	Automotive, Home Entertainment, IoT
Synaptics	SYN4382	Wi-Fi 6 Tri-Band 2x2	Bluetooth® 5.3	Zigbee, Thread	N/A	Automotive, Home Entertainment, IoT
Telink	TLSR922x	N/A	Bluetooth® Low Energy 5.3	Zigbee, Thread	N/A	IoT
Texas Instruments	CC2652R	N/A	Bluetooth® Low Energy 5.2	Zigbee, Thread	N/A	IoT

These multi-protocol chipsets all bring unique benefits thanks to their integration. This includes a combination of lower system costs, smaller external BOM, more effective coexistence between internal and external radios, reduced system complexity, and faster development and time to market. These chipsets will be essential in helping to scale up certain technologies, reduce cost and complexity of integration, bring unique performance benefits, improve interoperability in key verticals, and enable innovative use cases and user experiences in the years to come. ABI Research expects many more combo and multi-protocol ICs to emerge over the next few years to better service new emerging use cases and to create unique value propositions across different applications.

ACCELERATING THE WIRELESS CONNECTIVITY AND MULTI-PROTOCOL CHIPSET MARKET

To help chipset vendors and OEMs take advantage of these growing opportunities for wireless devices, leading licensors of silicon and software Intellectual Property (IP), Ceva, provides a comprehensive suite of wireless connectivity, processing solutions for Edge AI, and audio, voice interaction, and sensor fusion solutions that can help address the evolving needs of the connected device market. The company has been licensing its IP for over 30 years and is the leading provider of wireless connectivity IP, with its solutions being deployed in over 1 billion devices annually. To date, more than 18 billion devices have been shipped with Ceva silicon and software IP across hundreds of licensees. Notable licensees of Ceva's wireless connectivity solutions include NXP, Nordic Semiconductor, Espressif, Renesas, Onsemi, Ambiq, Atmosic, Alif, UNISOC, Beken, Bestechnic, Actions Semiconductor, AIC Semiconductor, and WinnerMicro, among many others

In April 2024, Ceva launched its multi-protocol wireless platform IP family, Ceva-Waves Links™. This new family builds upon Ceva's existing extensive and versatile Ceva-Waves™ portfolio of Wi-Fi, Bluetooth®, 802.15.4, and UWB connectivity IP, which is capable of addressing many of the growing connected device markets discussed throughput this whitepaper. Some of the key features of this existing IP portfolio include:

- **Ceva-Waves™ Wi-Fi IP:** Ceva's flexible Wi-Fi IP suite is capable of supporting Wi-Fi 4, Wi-Fi 5, Wi-Fi 6/6E, and Wi-Fi 7 across Wi-Fi APs, high-performance station devices, and low-power, low-cost, small form factor IoT devices. The solutions are optimized depending on the performance requirements of each application, encompassing both 1x1 and 2x2 configurations, and support for 20 MHz, 40 MHz, 80 MHz, and 160 MHz channel bandwidths, across all three 2.4 GHz, 5 GHz, and 6 GHz frequency bands.

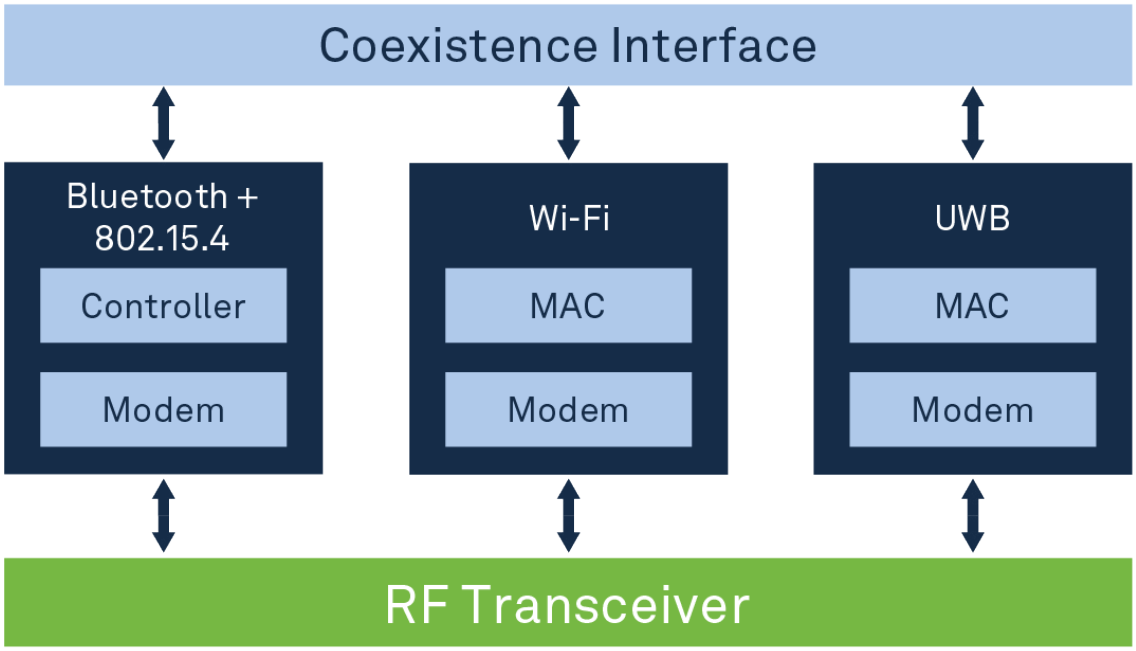
- **Ceva-Waves™ Bluetooth® IP:** Ceva's Bluetooth® IP solutions support dual-mode BR/EDR (Classic) and Bluetooth® LE, alongside the latest features up to and including those from the most recent 6.0 specification. This includes Bluetooth® mesh, Classic and LE Audio with Auracast™ broadcast audio, Coded PHY (Long Range), AoA /AoD, and PAwR and Channel Sounding. This is complemented with a software protocol stack for audio, wearable, smart home, healthcare, and IoT applications. Furthermore, 802.15.4 can be seamlessly supported as an add-on option or be made available as standalone Ceva-Waves™ 802.15.4 IP.

- **Ceva-Waves™ UWB IP:** Ceva's UWB IP is a low-power, high-performance MAC and PHY platform capable of supporting secure ranging for CCC Digital Key 3.0 and FiRa 2.0 specifications for indoor navigation, item finding, and point and trigger applications. In addition, the platform supports UWB Doppler Radar to enable applications such as automotive in-cabin child presence detection, alongside AoA support for centimeter-level position tracking. These solutions are also complemented by extensive software packages supporting these varied UWB use cases.

As Figure 2 demonstrates, the new Ceva-Waves™ Links™ product family provides a fully integrated multi-protocol wireless communication platform from the radio to upper layer software stacks, helping to streamline development and speed up the time to market for innovative wireless SoCs and MCUs.

Figure 2: The Ceva-Waves Links™ Wireless Platform

(Source: Ceva)



By offering support for multiple technologies, chipset vendors and OEMs can target this growing diversity of wireless applications, while enabling new innovative value-added features such as fine-ranging, radar and sensing, high-accuracy positioning, and support for new topologies. The Ceva-Waves Links™ family has also been designed with versatility in mind, with customers able to adapt the architecture to their specific needs, as well as being adaptable to a range of radios across different process nodes. In addition, the solution has been optimized for low power, thanks to effective resource sharing between different Ceva-Waves™ IP technologies, alongside benefiting from coexistence schemes that are tailored to each specific configuration.

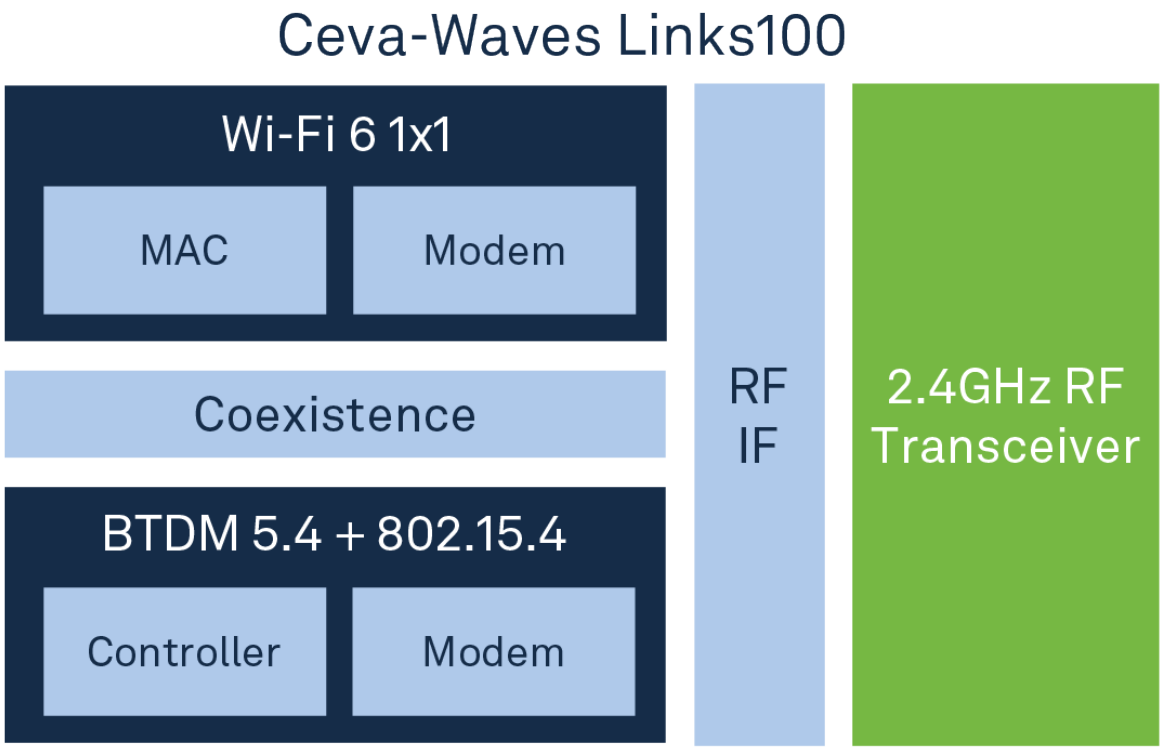
Ceva-Waves Links™ Family's Links100

The first product to arrive as part of the Ceva-Waves Links™ family is Links100. Designed for low-power and cost-sensitive applications within the smart home, wearable, and IoT markets, the Links100 combines 2.4 GHz Wi-Fi 6 1x1 with dual-mode Bluetooth® 5.4 and support

for 802.15.4. As Figure 3 shows, thanks to a shared 2.4 GHz RF transceiver, coexistence is fully optimized, and Time Division Multiple Access (TDMA) can ensure high-performance, simultaneous operation between the different technologies. The solution has been pre-integrated on the TSMC 22nm process and is currently being deployed by a leading OEM customer.

Figure 3: The Ceva-Waves™ Links100 Wireless Platform

(Source: Ceva)



Of course, given the diversity of potential use cases and modularity of the Links™ platform, Ceva has identified a number of potential upcoming Links™ platforms combining various wireless technologies, including:

- Advanced Wi-Fi 6/6E/7 with MLO, for a variety of use cases, from power-efficient IoT to high-speed data streaming
- Bluetooth® channel sounding and next generation Bluetooth® higher data throughout
- UWB, supporting FiRa 2.0, CCC Digital Key 3.0, and radar, for innovative micro-location and sensing features

Adopting a multi-protocol solution from an established market leader such as Ceva with decades of experience in multiple wireless IPs can also help reduce the burden of licensing separate IPs, integrating them effectively, managing coexistence, interfacing to RF, and potentially having to do this each time a unique combination of technologies is required. Combined with extensive software stacks that continue to evolve to support the latest enhancements for

each technology across both high-performance and cost-sensitive applications, this reduces any potential development risks and ensures a much quicker time to market. Meanwhile, Ceva's complementary portfolio of Ceva-NeuPro-M Neural Processing Units (NPUs) for Edge AI, alongside its audio, voice, and sensing solutions, can enable it to act as a one-stop shop for connectivity providers looking to develop SoCs and MCUs for IoT and Edge AI applications. Recently, Ceva unveiled its latest Ceva-NeuPro-Nano NPUs to enable wider adoption of on-device AI. This solution can more effectively address some of the power, performance, and cost challenges of enabling always-on Edge AI use cases such as voice, machine vision, and sensing capabilities for battery-operated wireless devices such as True Wireless Stereo (TWS) headsets, wearables, sensors, cameras, and home automation devices. These combined solutions will be critical in accelerating the adoption Edge AI in the coming years, with over 40% of Tiny Machine Learning (TinyML) shipments to be powered by dedicated TinyML hardware, rather than all-purpose MCUs by 2030, according to ABI Research.

KEY TAKEAWAYS

Thanks to the unique capabilities of different connectivity technologies, the wireless device market continues to evolve to enable valuable new applications and use cases across many consumer, enterprise, and industrial applications. Increasingly, these technologies are being combined together to enable enhanced performance, reduce power consumption, deliver smaller device form factors, speed up time to market, enhance user experiences, and enable compelling and valuable new features such as positioning and sensing to differentiate from the competition. Meanwhile, continued standards evolutions will inevitably open new opportunities and combinations for multi-protocol solutions over time.

To help chipset vendors and OEMs take advantage of these growing opportunities for wireless devices, Ceva provides a comprehensive suite of wireless connectivity, processing solutions for Edge AI, and audio, voice interaction, and sensor fusion solutions that can help address the evolving needs of the connected device market

As a result, the new Ceva-Waves Links™ family, combining a broad suite of wireless connectivity, processing solutions for Edge AI, and audio, voice interaction, and sensor fusion solutions, offers a significant value proposition to semiconductor companies and OEMs, thanks to its ability to lower the risk and investment required to integrate multi-protocol wireless connectivity into chip designs. Such solutions will be vital in enabling chipset vendors and OEMs to create unique end products that can better address the growing diversity of the connected Edge AI device market in the years to come and create compelling new value propositions for its customers and partners.

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