MARKET RESEARCH NOTE

The Ambient IoT: The Emergence of a New Class of Bluetooth® IoT Devices

Bluetooth®

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As part of ABI Research's Enabling Platforms research team, Senior Analyst Tancred Taylor focuses on asset tracking and visibility, which includes data, trend, and forecast analysis of the devices, platforms, networks, and services empowering the emerging technology market, as well as the business transformation that Internet of Things (IoT) tracking will enable. Tancred's coverage spans many industries, from construction and heavy equipment to the supply chain and packages and parcels.

Introduction

Connected device technologies have evolved a long way over the past two decades. Starting by connecting expensive networking equipment, communication technologies have trickled down into increasingly simple devices — spawning machine-to-machine (M2M) communications, the Internet of Things (IoT), sensor networks, and subsequent iterations like Massive IoT. At each stage of the evolution of the IoT, lower-complexity devices, smaller form factors, and lower-power radio protocols have opened the door to low-cost and low-maintenance devices built for a particular function. As this trend toward easy-to-deploy, easy-to-maintain, and low-cost devices continues, IoT use cases have proliferated and connected devices have become increasingly pervasive.

One of the most significant constraints for the evolution and pervasive deployment of the IoT is how these low-complexity, small form factor devices are powered. Connected devices and equipment typically rely on mains power or batteries as their primary source of energy, but each of these can bring challenges to the IoT at scale. These challenges relate mainly to the autonomy and maintenance of devices deployed in the field and limitations on how devices can evolve from a form factor and cost perspective.

The Ambient IoT is the next stage of evolution for IoT devices. The Ambient IoT refers to a new class of connected devices primarily powered by harvesting energy from any viable ambient source. Ambient energy sources can include radio waves, light, motion, and heat, among others. The Ambient IoT contributes to innovative form factor designs and low-maintenance or maintenance-free devices.

Over the past two years, the Ambient IoT has been a growing topic of discussion. Standards bodies have begun to explore how best they can support this new class of device and have been active in driving the conversation around this topic. Still, one of the difficulties with understanding the opportunities in this market is the lack of a standard definition of the Ambient IoT, such that it can engage companies from across the ecosystem.

This research note establishes guidelines for comprehending the Ambient IoT, intending to align IoT ecosystem strategies to create Ambient IoT devices. It also evaluates the role of Bluetooth® technology, notably Bluetooth® Low Energy (LE), in addressing Ambient IoT use cases. Bluetooth® LE, as a low-power protocol, already has a central position in enabling this device class. It is the de facto choice for many IoT solution providers building applications based on ambient energy harvesting devices. This research note examines the further work needed to ensure long-term support for an IoT ecosystem looking to take advantage of the Ambient IoT opportunity.

What Is the Ambient IoT?

Defining the Ambient IoT

The Ambient Internet of Things (IoT) refers to a new class of IoT devices primarily powered by harvesting ambient energy from radio waves, light, motion, heat, or any other viable ambient energy source.

The Ambient IoT is an extension of the existing IoT. Ambient IoT devices carry out many of the same functions as IoT devices and target many of the same use cases but require additional design choices to meet solution demands. By relying on energy harvested from ambient sources, the Ambient IoT makes it possible to develop lower-cost, smaller, and maintenance-free devices, allowing the IoT to become more scalable in existing use cases and in use cases still to be developed. For instance, original equipment manufacturers (OEMs), depending on the use case and environment, may choose to make self-sustaining devices, assisted by batteries or capacitors, by powering them with ambient energy. Alternatively, they may decide to go a step further and create battery-free devices with more flexible form factors and a lower bill-of-materials (BOM) cost.

Harvesting energy from ambient sources generates only minimal amounts of power. This creates the inherent requirement for Ambient IoT devices to be less complex and more power efficient. This can be addressed by optimizing the radio protocol and adding features, such as embedded intelligence, to make devices wake up and collect or transmit data less frequently.

The Ambient IoT Overview

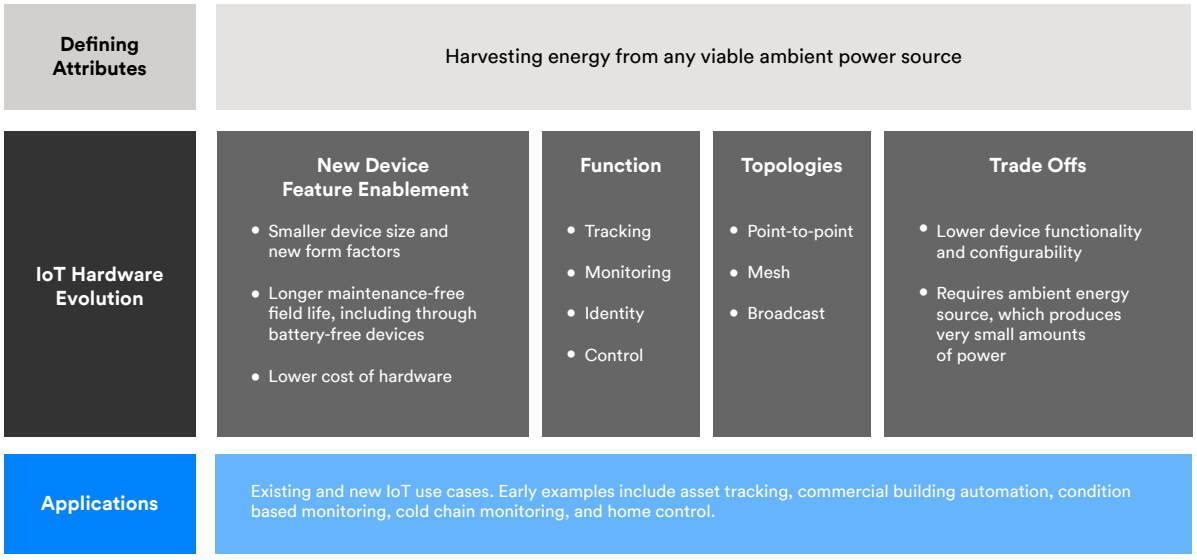

Figure 1: Defining Attributes, IoT Hardware Evolution, and Applications of Ambient IoT (Source: ABI Research)

The market opportunity for this new class of IoT devices is extensive. Ambient energy harvesting devices today are primarily centered on short-range wireless connectivity, particularly Bluetooth® technology. Looking ahead, there is widespread interest in comprehending and aiding the development of this emerging category of devices. The 3rd Generation Partnership Project (3GPP), overseeing cellular standards, the Institute of Electrical and Electronics Engineers (IEEE), responsible for Wi-Fi and network standards, and the Bluetooth Special Interest Group (SIG), responsible for Bluetooth® technology standards, are engaged in consultations with IoT developers. They aim to explore ways to facilitate the growth of the Ambient IoT. This collaborative effort underscores the cross-industry support and commitment to defining and supporting the Ambient IoT.

Why Do We Need the Ambient IoT?

The Ambient IoT addresses the needs of technology adopters by expanding the IoT in directions that are impossible to achieve with traditional devices. Key ways in which the Ambient IoT will contribute to the expansion of the IoT include:

- **Maintenance-Free Devices:** Maintaining IoT installations in the field can be a time-consuming and costly exercise, adding a layer of complexity to operations that the IoT is designed to make more efficient. Ambient IoT devices can be deployed in autonomous settings without maintaining a continuous power supply or replacing batteries. Low-maintenance or maintenance-free devices can change paradigms for return-on-investment (ROI) calculations by guaranteeing the longevity of deployments.
- **Low Complexity and Cost:** The Ambient IoT continues the trend toward lower cost and simpler devices. By relying primarily on ambient energy sources, the Ambient IoT will encourage the design of devices that communicate less frequently and are designed to fulfill specific functions, driving an evolution away from highly configurable devices streaming real-time data.
- **Sustainable Devices:** Replacing batteries, or throwing away battery-powered devices, is a challenge to the sustainable growth of the IoT. According to the European Union (EU)-funded project, EnABLES, a forecasted 78 million batteries will be discarded daily by 2025, assuming an average two-year battery life for IoT devices. Harvesting energy from ambient sources can create longer-lasting and self-sustaining Ambient IoT devices, whether by extending the life of battery- or capacitor-powered devices indefinitely or by removing batteries from devices entirely.

Targeted Use Cases for the Ambient IoT

Use cases for the Ambient IoT can be applied to any existing or new IoT application or vertical market. However, the Ambient IoT is expected to see the highest volumes in applications with the following characteristics:

- **Low Functionality:** Applications requiring devices designed for one specific function with low configurability.
- **Low Cost:** Applications in which scalability is essential and the cost of traditional IoT devices is prohibitive. Some Ambient IoT use cases rely on disposable tags, requiring a very low cost point.
- **Fully Autonomous:** Applications requiring full maintenance-free device autonomy for the device's lifecycle, be it two months or 20 years.
- **Supported by Assisting Devices:** While any network topology can be used for the Ambient IoT, in practice, early Ambient IoT applications will require assisting devices such as gateways, control units, or smartphones to support the limited range of energy-harvesting devices.
- **Controlled Energy Environment:** Applications where an ambient energy source is predictable, including the potential use of energizing devices.

While use case opportunities are vast, ABI Research expects to see most volumes in the near term going into supply chain tracking and monitoring from point of manufacture to point of sale and beyond. Many of these use cases are strictly outside the supply chain but relate to the tracking, monitoring, and identification of products and goods that move through the supply chain until they are sold to their end users. Growth in this area is driven by the following factors:

- Market demand for product and asset-level visibility at different stages of the life of products in the supply chain
- The variety of use cases that can be built in this market to benefit different stakeholders
- Technology innovation around Ambient IoT smart labels

Supply Chain Tracking and Monitoring Use Cases

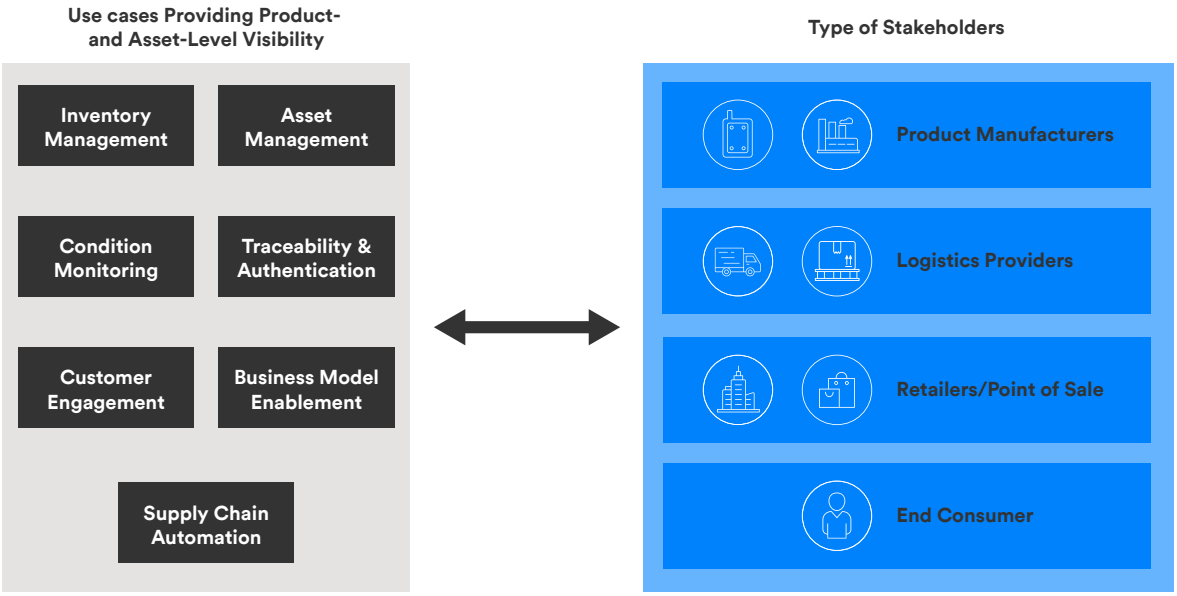

Figure 2: Factors Driving Supply Chain Tracking and Monitoring Use Cases (Source: ABI Research)

As technologies supporting the Ambient IoT devices mature, and support ambient energy harvesting, use cases outside of goods tracking and monitoring will multiply. Use cases span many vertical markets. In industrial markets, potential use cases involve sensor-based monitoring of machine conditions, equipment status, environmental conditions, or electronic labeling. In commercial markets, use cases include building automation and control, air quality monitoring, and electronic shelf labels (ESLs) in retail markets. In consumer markets, use cases include personal tracking or various home automation systems. As these use cases demonstrate, the Ambient IoT will initially serve existing IoT applications with a new device class. As the market expands, it will help create entirely new application areas. Figure 3 highlights some key statistics for markets that the Ambient IoT can target.

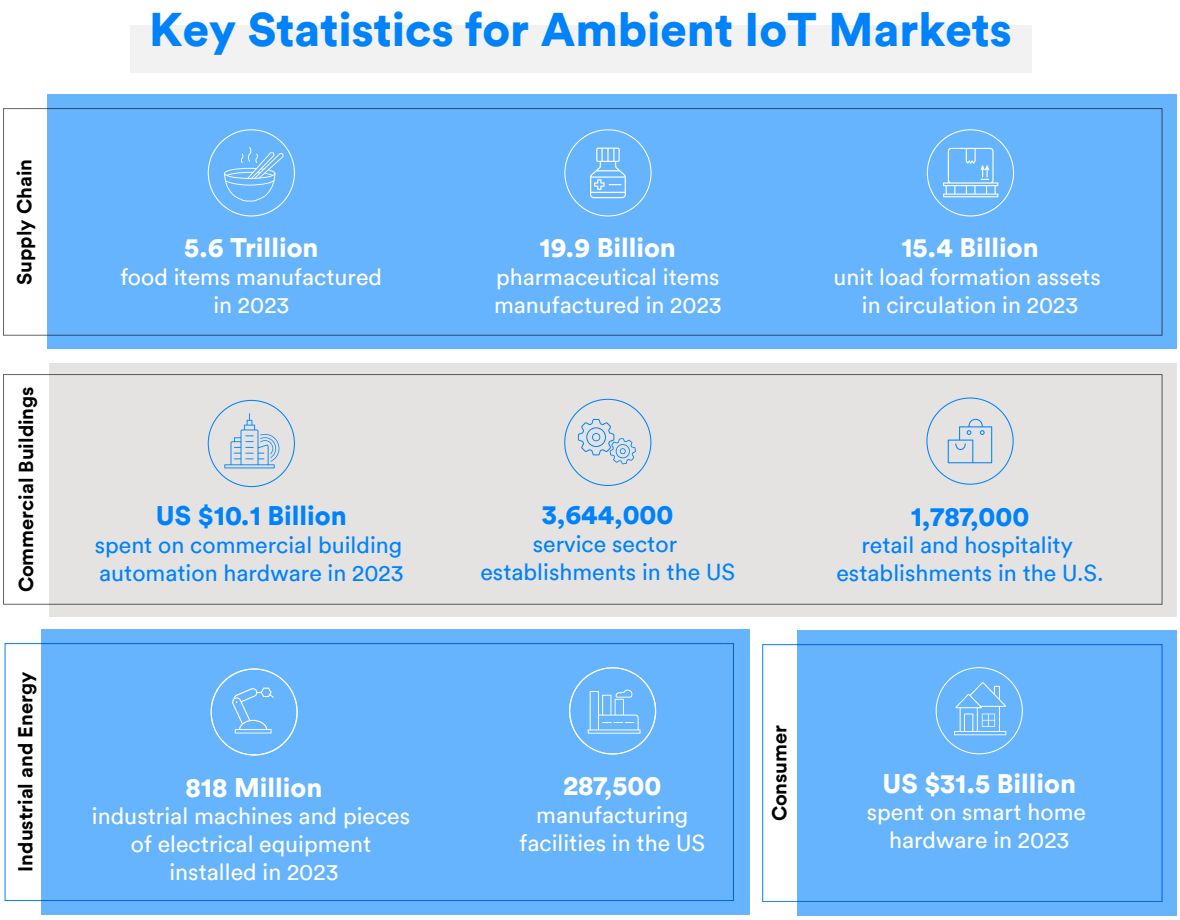

Figure 3: Ambient IoT Opportunities and Key Market Statistics (Source: ABI Research)

Solution providers have already built Ambient IoT devices to address several use cases. EnOcean's smart switches are an example of an early use case, relying on kinetic energy to send a signal to a controller unit. Kontakt.io and Paragon ID are examples of vendors offering battery-free tags for real-time location system (RTLS) applications. Wiliot has innovated around the form factor and cost of smart labels to address a variety of use cases, initially in the supply chain for product monitoring and inventory management but with possible applications in many other fields. Everactive is an example of a vendor performing condition-based monitoring for rotating equipment and steam traps by harvesting energy from multiple ambient sources. Some vendors are also planning use cases in smart homes, such as Ambient IoT voice control or remote controls.

The Role of Bluetooth® in the Ambient IoT

Bluetooth® technology, and specifically Bluetooth® LE, holds a central role in the evolution of the Ambient IoT. Reasons for this central role include the technology feature set of Bluetooth® LE, which makes it a go-to technology for the Ambient IoT, and the Bluetooth SIG's position within the ecosystem supporting the ongoing development of Bluetooth® technology and creating a developer base for low-power IoT solutions.

Benefits for Developers

- **Leading Very Low-Power Technology:** Bluetooth® LE is one of the lowest-power IoT protocols available today. It is often the first port of call for solution providers building use cases based on ambient energy harvesting, and many of the first Ambient IoT use cases rely on Bluetooth® LE technology. As a result, Bluetooth® LE's lead in low-power technology plays a central role in enabling the new class of Ambient IoT devices, which rely on gathering tiny amounts of energy from ambient sources.
- **Low Integrated Circuit (IC) Costs:** Bluetooth® chips are some of the most commoditized radios available for wireless markets, allowing developers to build low-cost devices. Unlike many other wireless protocols, system-on-chip (SoC) and system-in-package (SiP) development is very common with Bluetooth® technology, allowing highly integrated, low-power, and low-cost solutions. The low cost of Bluetooth® chips, in relation to other connectivity technologies, gives Bluetooth® technology an essential role in helping solution providers design and build Ambient IoT devices.
- **Supports Flexible Topologies:** Bluetooth® LE supports multiple implementation topologies as shown in Figure 1, including point-to-point, mesh, and broadcast. In addition, use cases with Bluetooth® technology can be internet based, via a gateway, or peer-to-peer. Ambient IoT use cases may be implemented in many ways based on the targeted user and the environment in which a solution is deployed. Bluetooth® LE, through its flexible topologies, plays an important role in enabling solution providers to develop Ambient IoT solutions in any way that best suits the use case and environment.

Figure 4 shows different implementation architectures for the Ambient IoT. Bluetooth® LE can be used in all network topologies. It can also be used for both data transmission and energy harvesting.

Implementation Architectures for the Ambient IoT

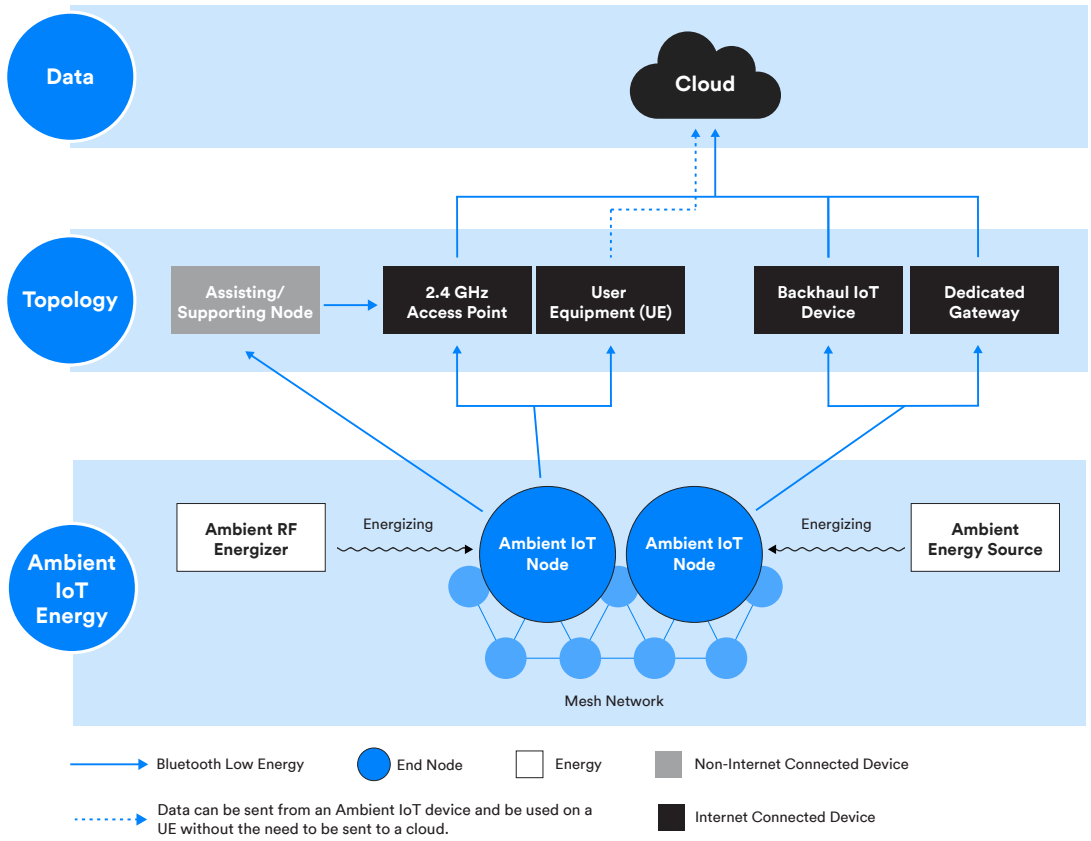

Figure 4: Ambient IoT Implementation Architectures (Source: ABI Research)

Benefits of the Bluetooth® Ecosystem

In addition to its technology strengths, Bluetooth® is a standard backed by the Bluetooth SIG with a large developer base. Advantages to developing within this ecosystem include:

- **Long-Term Technology Support:** Ambient IoT devices require long-life support in the field without maintenance or equipment replacement. With the sunsetting of 2G and 3G technologies, IoT adopters are increasingly forward thinking when selecting a technology that will permit longevity without replacing equipment. As an open and standard-backed technology, Bluetooth® LE plays an important role in giving the confidence of long-term support to developers building Ambient IoT devices and customers adopting Ambient IoT use cases and devices.

- **Feature Development:** Ambient IoT devices perform many of the same functions as existing IoT devices — sensing, location, ID, and control. Bluetooth® LE already includes features to address several of these requirements, such as multiple approaches to device positioning. The Bluetooth SIG is playing a role in further developing features that can support Ambient IoT use cases based on ongoing interaction with stakeholders across the Bluetooth® value chain; these features could involve harvesting energy from Bluetooth® radio waves, radio frequency (RF)-based sensing, or data formats for different ID applications.
- **Large Infrastructure Installed Base:** For the Ambient IoT to be able to reach its full potential, it must be able to communicate with multiple types of infrastructure and equipment — such as dedicated or multi-use access points (APs) and gateways, user equipment (UE) like smartphones, or other forms of IoT devices. Bluetooth® technology is widely accepted across multiple industries and has a large existing base of Bluetooth® devices that creates a Bluetooth® capable infrastructure. The ecosystem's strength is an important reason why Bluetooth® technology plays a central role in the Ambient IoT; it enables industrial, enterprise, and consumer markets to build use cases with minimal additional infrastructure, helping to lower the entry barriers of the Ambient IoT at scale.
- **Interoperability and Scalability:** Ambient IoT devices need to be easily deployed and maintained by users, whether for consumers or for enterprises. Interoperability may take different forms; some examples include cross-vendor implementations, implementations requiring multiple Ambient IoT device suppliers, or interoperability and easy provisioning with different UE or APs. The large ecosystem of solution providers using Bluetooth® technology and its acceptance across industries allows customers to choose solutions based on their unique requirements while knowing that devices will simply work together. Supporting the development of the Ambient IoT, the Bluetooth SIG plays a role in facilitating the interoperability of Ambient IoT devices by adopting standards that eliminate the need for solution vendors to focus on proprietary solutions and eliminate the need for adopters to rely on a single solution provider.

The features and ecosystem of Bluetooth® technology are well evolved. As a result, solution providers and adopters can focus on innovation, such as form-factor designs, data management, and use cases targeting specific pain points rather than developing an entire technology stack from scratch. By further supporting the development of the Ambient IoT, Bluetooth® technology can bring these existing features and ecosystem advantages to a new class of IoT devices, thereby providing long-term support and reliability to solution providers and technology adopters.

Next Steps For The Ambient IoT

The Ambient IoT is still in its early development phase. While standards organizations are figuring out how to back and empower this new class of IoT devices, solution providers are creating solutions for various uses and markets. This means that progress in this field will mainly be driven by the broader IoT community. However, the IoT market currently lacks a clear understanding of the unique features and possibilities of the Ambient IoT. As a result, efforts are often scattered in various directions. To capitalize on the opportunity for the Ambient IoT, the following areas need to develop in tandem:

- **Market Education on the Ambient IoT Opportunity:** The Ambient IoT market is presently dominated by a select group of vendors. Among those developing solutions based on ambient energy harvesting, only a few identify themselves as part of the Ambient IoT landscape. This can largely be attributed to the absence of well-defined parameters delineating the realm of the Ambient IoT. There is a pressing need to propel the Ambient IoT out of its current stage characterized by discussions on attributes and terminology and to drive it toward cultivating an ecosystem that is not only actively engaged but also fully cognizant of the vast opportunities presented by this emerging category of IoT devices.
- **Energy-Harvesting Standards:** Companies offering energy-harvesting ICs are proliferating and investment in this market is growing, but much work remains to be done to enable scaling of Ambient IoT use cases. Currently, many IoT solutions leveraging ambient energy harvesting that have reached scale are based on proprietary energy-harvesting technologies from the solution provider rather than on standard off-the-shelf components from third parties. This is partly because the low amount of energy that can be harvested from ambient energy sources requires application-specific development. For the Ambient IoT to reach its full potential, however, more work is needed to make these technologies available to an extensive range of vendors. In addition to more mature energy harvesting technologies, lower-power wireless ICs will help meet the requirements of the Ambient IoT by supporting the small amounts of energy that can be harvested from ambient sources. A two-pronged approach from energy-harvesting vendors and IC designers will precipitate the development of Ambient IoT use cases.

- **Simpler Sensor Deployment and Management:** The Ambient IoT needs innovation not only in technology design but also in deployment management. IoT deployments can be cumbersome to scale from an installation and provisioning perspective, and managing large fleets of devices once deployed also brings a series of challenges in device management. Suitable physical and cloud infrastructure is necessary to make Ambient IoT deployments practical at the anticipated massive volumes. This could relate to physical labeling machines that automatically apply and activate smart labels in a supply chain or retail context, cloud infrastructure for device provisioning and deprovisioning, or data management.
- **Assess the Need for Standards:** The Ambient IoT is market driven, and standards are not likely to appear for several years. Standards bodies must listen to the IoT ecosystem to understand what needs to be standardized to best support the growth of the Ambient IoT ecosystem. Topics for standardization could take multiple forms based on market demand. They could focus on support for Ambient IoT devices as a holistic device class or on a particular use case for the Ambient IoT in the same manner as the Bluetooth SIG standard for ESLs. Within this, topics could focus on support for energy harvesting using RF signals, data formats for interoperability, security, support for use cases with multiple radio transport requirements, interference-free scalability in select frequency bands, or other topics.

Conclusion

The Ambient Internet of Things (IoT) refers to a new class of IoT devices primarily powered by harvesting ambient energy from radio waves, light, motion, heat, or any other viable ambient energy source. This research note has contextualized this definition and shown what role the Ambient IoT will play in expanding the IoT.

The emergence of Ambient IoT devices represents a significant leap in the evolution of IoT devices, offering a promising future for the IoT ecosystem. By relying on ambient energy sources, the Ambient IoT enables the development of lower-cost, smaller form factor, and maintenance-free devices, thus opening new possibilities for IoT applications across various industries.

The market potential is extensive with early adoption focused on short-range wireless connectivity, particularly Bluetooth® LE technology. Bluetooth® LE will play a central role in the evolution of the Ambient IoT. From a technology perspective, it is a leading, very low-power protocol that supports a wide range of network topologies and is available on many low-cost ICs. From an ecosystem perspective, Bluetooth® LE is an open, standard-backed technology that promises long-term support and feature evolution. Consequently, it has built a large developer base and a ubiquitous installed base of dedicated or multi-use infrastructure, facilitating further solutions built with the technology.

Looking ahead, the Ambient IoT is still in its early stages, and market education, energy harvesting advancements, low-power IC advancements, potential standards development, and approaches to facilitate sensor deployment and maintenance in the field are crucial to nurturing its growth. Collaboration among standards bodies, industry leaders, and solution providers underscores the cross-industry support for the Ambient IoT's development. Setting clear definitions and fostering collaboration among stakeholders will be essential to unlock the full potential of this new class of IoT devices.

The Ambient IoT addresses the pressing need for maintenance-free operation, low complexity and easily deployed devices, and sustainable growth of the IoT. Use cases for the Ambient IoT are diverse and expected to grow. While the initial focus revolves around supply chain tracking and monitoring, driven by the demand for product and asset-level visibility, the Ambient IoT promises to enhance existing applications and pave the way for entirely new use cases, reshaping how enterprises and consumers interact with their environment.

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