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**Abstract:** This document contains the output text of draft Technical Report YSTR.Ambient-IoT, “Analysis on requirements and use cases of ambient power-enabled IoT”, Q2/20 meeting (Virtual, 22, 25-26 and 28-29 March 2024).

This updated version of draft draft Technical Report YSTR.Ambient-IoT, “Analysis on requirements and use cases of ambient power-enabled IoT” is the output of the Q2/20 meeting (Virtual, 22, 25-26 and 28-29 March 2024). It is based on TD1042-R1, output of SG20 meeting (Arusha, 13 - 22 September 2023), according to the March 2024 Q2/20 agreements on meeting discussions, including on the received contributions as follows:

The following table shows discussion results on the received contributions:

No.	Source	Title	Proposals	Discussion and results
Q2- March 2024-C4	China Mobile Communications Co. Ltd.	Proposal to update summary and clause 5 of Technical Report YSTR.Ambient-IoT, “Analysis on requirements and use cases of ambient power-enabled IoT	This contribution proposes to modify clause summary and clause 5.1 Proposals:	The draft Recommendation was revised to reflect this contribution.
			- Proposes to update summary	- Agreed with editorial changes
			- Proposes to update the table of content	- Agreed
			- Proposes to update clause 4	- Agreed
			- Proposes to update clause 5	- Agreed with editorial changes
Q2- March 2024-C5		Proposal to update clause 5 and clause 6 of Technical Report YSTR.Ambient-IoT,	This contribution proposes to modify clause summary	The draft Recommendation was revised to reflect this contribution.

No.	Source	Title	Proposals	Discussion and results
		<p>“Analysis on requirements and use cases of ambient power-enabled IoT</p>	<p>and clause 5.2, 5.3 and 6.1 Proposals:</p> <ul style="list-style-type: none"> <li>- Proposes to update clause 5.2</li> <li>- Proposes to update clause 5.3</li> <li>- Proposes to update clause 6.1</li> </ul>	<ul style="list-style-type: none"> <li>- Agreed with editorial changes</li> <li>- Agreed with editorial changes</li> <li>- The term “express” changed to “mails and packages” for better understanding</li> <li>- Agreed with editorial changes</li> <li>- The sentence “one additional energy transmission capability” is modified for further elaboration</li> </ul>
<p>Q2- March 2024-C6</p>		<p>Proposal to update clause 6 of Technical Report YSTR.Ambient-IoT, “Analysis on requirements and use cases of ambient power-enabled IoT</p>	<ul style="list-style-type: none"> <li>- Proposes to update clause 6.2</li> </ul>	<ul style="list-style-type: none"> <li>- Agreed with editorial changes</li> <li>- A Note is added to further explain ID reporting</li> <li>- A Note is added to further explain active communication</li> </ul>

## **Draft Technical Report YSTR.Ambient-IoT**

### **Analysis on requirements and use cases of ambient power-enabled IoT**

#### **Summary**

In IoT systems, a large number of physical terminals may not have the space to hold batteries or bear the cost of batteries, such scenarios include but are not limited to fast-moving consumer goods, logistics packages, product line packaging, warehouse goods inventory, etc. Huge scenarios may involve up to more than ten thousand IoT nodes, which conventional IoT devices are not able to implement in terms of cost, size, and power mode.

An Ambient power-enabled IoT is a global infrastructure for the information society, enabling IoT services by harvesting ambient energy to power the IoT devices. Instead of using batteries to power the devices, Ambient-IoT devices are capable of harvesting ambient energy to power electronic modules. The ambient power can be provided by distributed power transfer nodes (e.g., existing network infrastructure, dedicated power transfer device) or natural power (e.g., light, vibration, thermal).

#### **Keywords**

Ambient power enabled IoT, energy harvesting,

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## Draft new Technical report YSTR.Ambient-IoT

### Analysis on requirements and use cases of ambient power- enabled IoT

#### 1 Scope

This Technical Report conduct an analysis es on requirements and use cases of ambient power-enabled IoT.

The scope of this Technical Report includes:

- Overview of ambient power-enabled IoT
- Analysis on requirements of ambient power-enabled IoT
- Use cases of ambient power enabled IoT

#### 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of Internet of things*.

[ITU-T Y.4105] Recommendation ITU-T Y.4105/Y.2221 (2010), *Requirements for support of ubiquitous sensor network (USN) applications and services in the NGN environment*.

[TBD]

#### 3 Definitions

##### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 **Ambient IoT device** [3GPP TR 22.840]: An ambient power-enabled Internet of Things device is an IoT device powered by energy harvesting, being either battery-less or with limited energy storage capability (e.g., using a capacitor).

3.1.2 **Internet of things (IoT)** [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

3.1.3 **Sensor** [ITU-T Y.4105]: An electronic device that senses a physical condition or chemical compound and delivers an electronic signal proportional to the observed characteristic.

##### 3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 **Charging node**: An electronic device that transmits energy to Ambient IoT devices for the purpose of power-up or continuous operation of the devices.

[TBD]

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

Ambient-IoT	Ambient Power-enabled Internet of Things
AC	Alternating Current
DC	Direct Current
IoT	Internet of Things
LoRa	Long Range Radio
LPWAN	Low Power Wide Area Network
MMTC	Massive Machine Type Communication
NFC	Near Field Communication
RFID	Radio Frequency Identification
UE	User Equipment
WUS	Wake-Up Signal

*[TBD]*

## 5 Overview of ambient power enabled Internet of Things

The goal of IoT is to realize ubiquitous connectivity among humans, machines, and objects. However, most IoT devices are powered by batteries, and the replacement or charging of the battery limits the applicability of IoT. This is especially true when considering massive deployments of hundreds of thousands of devices, such scenarios including, but not being limited to express tracking in smart logistics, personnel tracking in smart park, assets inventory in smart warehouse, personal objects finding in smart home, busbar monitoring in smart grid, etc. Huge scenarios may involve up to more than ten thousand IoT nodes, which conventional IoT devices are not able to implement in terms of cost, size, and power mode. In addition, conventional battery-powered IoT devices also raise environmental concerns since the devices use huge amounts of batteries.

To address these concerns, the Ambient -IoT has emerged. An Ambient- IoT is a global infrastructure for the information society, enabling IoT services by harvesting ambient energy to power the IoT devices. Instead of using batteries to power the devices, the Ambient-IoT devices are capable of harvesting ambient energy to power their internal electronic modules. The ambient power can be provided by distributed power transfer nodes (e.g., existing network infrastructure, dedicated power transfer device) or natural power (e.g., light, vibration, thermal). This battery-less feature enables Ambient-IoT devices acting as tags or labels to perform IoT services , this allowing Ambient-IoT devices to be deployed on narrow or non-flat surfaces. Commercialization of related technological features is already active. Products such as RFID [b-RFID] and NFC [b-NFC] are very mature, and new technologies such as Wiliot's IoT Pixel [b-IoTPixel], oppo's Zero-Power Tag and Ericsson's zero-energy tactile textiles [b-ZeIoT] have also emerged. Standards development organizations such as IEEE and 3GPP have also initiated the standard process on WLAN-based Ambient-IoT and cellular-based Ambient-IoT. This worldwide interest shows that Ambient-IoT has the potential to enable more objects to connect to the internet and significantly expand the application scenarios of IoT.

This Technical Report provides an introduction of the current state of Ambient-IoT in terms of currently available technological solutions, ongoing research, and recent and ongoing standardization activities in the area. This Technical Report also analyzes the requirements of Ambient-IoT and use cases to illustrate the market needs.

## 5.1 Currently available commercial technologies and ongoing research for ambient power-enabled Internet of Things

### 5.1.1 Ambient power harvesting technologies

One of the most important technologies of Ambient IoT is energy harvesting. With energy collection from the environment, Ambient-IoT devices can further extend communication range and expand more functions. Common energy harvesting methods, including radio waves, solar, thermal, and vibration energy, have been used by several companies in prototypes or commercialized products based on these technologies.

- **RF Energy:** The most common solution of Ambient-IoT is radio wave energy harvesting. The antenna of the device collects the radio wave at the selected frequency into useful electrical energy. It uses an antenna to pick up these signals, and then converts the RF signal from AC to DC through an integrated rectifier circuit. Take passive RFID as an example, an RFID tag could transfer -24dBm radio wave (@900MHz) to nearly  $10 \mu w$  to support demodulation, decode, and uplink communication of the tag. Many companies have proposed technology to harvest energy from different RF signals, such as Wi-Fi [b- WirelessPower] and Bluetooth [b-IoTPixel].
- **Solar Energy/Light:** Solar or light energy is another available solution for the power supply of Ambient-IoT devices. From outdoor sunlight to indoor artificial illuminating equipment, light energy harvesting has a wide range of possible sources. Solar power can be transformed into useful electrical energy through photovoltaic cells with a 10-40% conversion efficiency, which makes this technology suitable for outdoor IoT services. Due to solar power could only be available in the daytime, several companies have developed indoor solutions for Ambient-IoT: those solutions often require additional light transmitters [b-AirCord], or a highly efficient power converter [b-EnOcean], and those products can charge surrounding devices such as smart door lock, digital signage, and sensors to provide IoT service.
- **Thermal Energy:** The difference between temperatures can also be used for energy harvesting. Many industry scenarios consist of engines and pumps, the operation of those equipment being always accompanied with high temperature, and the temperature difference between the equipment surface and environment can convert into electrical power by taking advantage of the Seebeck or Thomson effect. Though its conversion efficiency is below 10% [b- Nadaf], the output power can still be able to support overheating alarms, engine temperature detection, etc. The harvested energy level is highly dependent on the temperature difference, thus this type of Ambient IoT is often deployed in industrial environments [b-Perpetuum] or extreme environments [b- Prometheus].
- **Vibration Energy:** Vibration energy includes many types of ambient power, such as pressure, friction, and contact. Representative application scenarios are wearable devices where humans frequently move [b-ZpIoT] and industries where machines produce abundant vibrations [b-FINSIOT]. However, even though vibration energy owns acceptable harvesting efficiency, it is not suitable for static objects..

### 5.1.2 Ultra-low power consumption communication technologies

#### Backscatter Communication

A technology known as backscatter communication can significantly reduce the power consumption of communications. A typical backscatter communication system includes three components: the signal source, the backscatter transmitter(device), and the backscatter receiver. Differently from the common communication systems, the backscatter system conveys information by remodulating and reflecting signals from other signal sources instead of generating a carrier signal at its transmitter.

The signal source generates the signal and transmits the signal to the backscatter transmitter. The antenna of the backscatter transmitter can pick up the signal, a portion of the signal will be rectified into DC to power up the backscatter transmitter, and another portion of the signal will be remodulated and reflected by the backscatter antenna to deliver information [b-Niu]. The backscatter receiver detects the information after receiving the reflected signal from the backscatter transmitter. This method makes it possible to improve existing communication technologies. Researches such as backscatter LoRa[b-Guo], backscatter Wi-Fi[b-Dehbashi], and backscatter Bluetooth[b-Ensworth] have been proposed over the past decade, and these researches demonstrated that existing communication systems can be optimized to sub-10mW level power consumption by using backscatter communication.

## Wake-Up Signal

A technology known as Wake-Up Signal (WUS) was introduced in 3GPP Rel. 15 to meet the requirements of both long battery life and low latency. By using a wake-up signal to trigger the main radio and a separate receiver that has the ability to monitor the wake-up signal with ultra-low power consumption, the UE can be turned off or set to deep sleep at most of its life cycle and can wake up only when it is triggered, therefore, improving energy efficiency as well as for better user experience.

## 5.2 Recent and ongoing standardization activities on Ambient-IoT

*Editor's note: further information is expected to be considered based on liaison feedback from other organizations.*

Recently, two standard organizations are developing studies on Ambient Power-enabled IoT or similar technology.

- **3<sup>rd</sup> Generation Partnership Project (3GPP):** 3GPP has bring Ambient IoT into 5G-Advanced technical system. 3GPP has established SI (Study Item) in both SA (TSG Service & System Aspects) and RAN (TSG Radio Access Network) to conduct relevant research. The SA1 working group has established the Ambien-IoT project to identify potential use cases, deployment scenarios, key service requirements, and critical performance indicators, SA1 concluded its work in Dec 2023 delivering the technical report 3GPP TR 22.840[b-3GPP22840]. SA2 has also started research on network architecture, identification, subscription, registration and services in Jan 2024. Based on the SA1 research of use cases, the RAN working group discussed the impact of these aspects on network architecture and device types, and this work was approved in Sep 2023 as technical report 3GPP TR 38.848 [3GPP38848]. The RAN working group also started a new Ambient IoT study item in Dec 2023, the research including but not being limited to evaluation methodology, Ambient IoT device architecture solutions for ambient IoT (physical layer, protocol stack and signaling procedure, RAN architecture aspects, waveform, etc.), and coverage evaluations.
- **Institute of Electrical and Electronics Engineers (IEEE):** A Technical Interest Group (TIG) focused on Ambient power-enabled (AMP) IoT was established during the IEEE 802.11 meeting in May 2022. This TIG group mainly focused on Ambient- IoT working under the current WLAN network structure, and concluded its work in March 2023 delivering the AMP technical report, which included use cases, requirements, prototypes, and technical and economic feasibility analysis. Following the TIG, the IEEE 802.11 AMP Study Group (SG) was formed in March 2023. The objective of the SG is to develop a Project Authorization Request (PAR) and Criteria for Standards Development (CSD) for an 802.11 standard project on WLAN AMP Communication. Discussions within the AMP SG cover aspects such as transmit and receive architectures, deployment topologies, and operational frequency bands. Based on the work in the AMP SG, the AMP technical report has been further updated [b-

IEEE]. A Project Authorization Request (PAR) and Criteria of Standard Development (CSD) were finally approved by IEEE 802 LAN/MAN in March 2024.

### 5.3 Potential application scenarios of Ambient-IoT

Due to the feature of energy harvesting, Ambient-IoT devices can operate without batteries or at least not using batteries as the main power source, thus the Ambient-IoT is appropriate for scenarios with requirements of battery restrictions, maintenance-free, frequent communications, and massive thing type communications.

- **Battery-restricted scenario:** Current IoT technology cannot work in some specific scenarios, such as high-voltage power grid monitoring and oil pipeline monitoring, because extreme environmental impacts can lead to battery failure, often resulting in fires, explosions, and release of toxic gases. In such environments, batteries are not allowed for safety issues but the Ambient-IoT can harvest energy from the environment, then directly consume the energy or store energy in a capacitor, instead of storing energy in a battery. Thus, the industry does not need expensive explosion proof modifications of devices.
- **Maintenance-free scenario:** Battery-powered IoT devices require periodic charging or replacement, which is extremely difficult for deployments with a large number of IoT devices. The replacement of batteries could be a large expenditure and human resources waste, and the replaced batteries are also a type of hazardous for the environment. Due to the energy harvesting feature, an Ambient-IoT device can constantly charge itself from ambient power, instead of depending on a finite life battery. Once the Ambient-IoT device is installed on the intended place, it can work with the ambient power supply automatically, and this can be beneficial for deploying devices in remote areas, or areas with limited human resources.
- **Massive thing type communications (MTTC):** In conventional massive machine type communication scenarios, most communications are built between electronic devices (e.g. UE, refrigerator, etc.), but many non-electronic things (e.g. desks, keys, mails, packages, etc.) are not connected to the network, and those non-electronic things have the same tracking and monitoring requirements with machines. However, unlike machines, those objects cannot be easily integrated with a communication module due to the size, cost, and power consumption. In vertical applications, scenarios such as cold chain, warehouse, and logistics often consist of over 100 thousand non-electronic things required to be tracked or inventoried, the high complexity of 5G, LTE, and LPWAN devices makes it impossible to deploy in such scenarios. However, Ambient-IoT devices can be very low complexity since it is mainly used for identifier transmission. The Ambient-IoT will have limited processing and storage capabilities, short-codeword, and low complexity channel encoding methods, along with power harvesting technologies, which reduce the size and cost of Ambient-IoT devices, make it possible and affordable to deploy on any surface of anything.

## 6 Analysis on requirements of ambient power-enabled IoT

### 6.1 Analysis on requirements of ambient power-enabled IoT system

The Ambient IoT system is located in the device layer of the IoT reference model described in [ITU-T Y.4000].

The main concept of the Ambient IoT system is that the devices can harvest energy from ambient, instead of finite-time batteries. The ambient energy can be distinguished into three different types: environmental, auxiliary, and intentional energy.

The environmental type refers to natural energy or energy from target objects, such as heat or vibration of the engines, and sunlight. Those energies are usually uncontrollable and unstable, thus this type of system can only be used in specific scenarios.

The auxiliary type refers to RF energy from network infrastructures, such as the carrier wave from cellular base stations, Wi-Fi routers, or Bluetooth gateways. This type of energy is usually more controllable, but unstable due to the penetration loss or the impact of the metal environment, and the balance of coding efficiency and power efficiency also needs to be considered. Therefore, the ambient IoT devices may only directly interact with the communication network in an ideal environment, and indirectly interact with the communication network through gateway or UE in other cases, in order to receive enough RF energy. The above illustrated two energy types demonstrate the ideal Ambient IoT system, where only Ambient IoT devices and lightweight protocols are needed. However, due to the unstable characteristic of environmental energy and auxiliary energy, the intentional energy type is needed: an optional charging node may be needed for additional energy provision, with the charging node that may be set up independently or integrated with the gateway to provide specific energy for Ambient IoT devices.

As shown in Figure 1, a potential Ambient IoT conceptual framework may consist of the following four components:

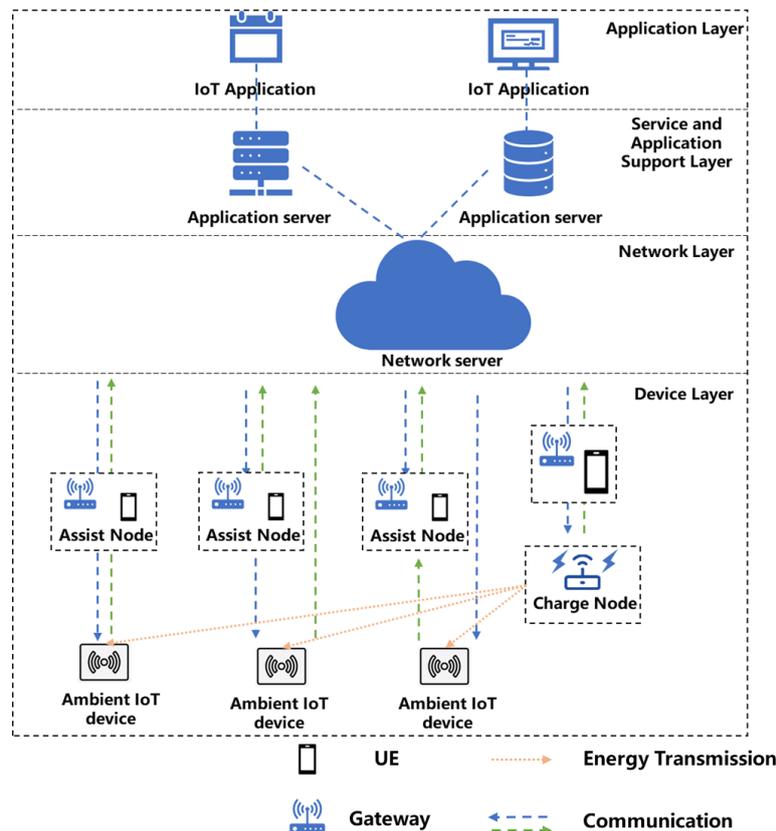


Figure 1: Ambient IoT conceptual framework

- **Ambient IoT Device:** The Ambient IoT devices are driven by the energy that harvest from the ambient, and support lightweight IoT applications, such as identification, sensing, and positioning applications.
- **Assist Node:** Assist node can be either UE or gateway. Ambient IoT devices (with different protocols) can connect to communication networks through one or multiple assist nodes. The gateway has similar capabilities than those specified in [ITU-T Y.4000], but the gateway may

have an optional additional capability, which allows the gateway to act as a charging node for the Ambient IoT devices.

- **Charging Node:** An optional charging node can be set up intentionally to provide stable and controllable energy to the Ambient IoT device, thus helping the Ambient IoT device to perform longer-range communications and more complicated tasks.

The Ambient IoT conceptual framework enables multiple connection methods. The Ambient IoT devices can connect to the communication network directly or through assist nodes: due to the limited capability of the Ambient IoT devices, an assist node can act as a relay to further extend the communication distance. Unlike from the conventional battery-assist or wired devices, the Ambient IoT devices may not have enough power to support both amplifiers for uplink and downlink, and different communication distances between uplink and downlink may exist: in such cases, the Ambient IoT devices can connect to the communication network directly on one link, and connect through assist nodes on another link. In some scenarios, where even the assist nodes are not enough for the Ambient IoT devices, an optional charging node can be used to provide stable and controllable energy, the charging node being either controlled by the assist node or directly controlled by the communication network.

## 6.2 Analysis on requirements of ambient power-enabled IoT devices

### 6.2.1 Requirements for Ambient IoT device

Based on the use cases specified in [b-IEEE] and [b-3GPP22840], the most essential and fundamental application for Ambient IoT is ID reporting, which usually requires very low data rate (e.g., less than 100kpbs).

NOTE 1 - ID reporting application refers to the report of Ambient IoT devices identifiers, as device identifiers can help the user in counting and checking the existence of assets. Inventory check, attendance check, and asset searching are examples of applications that are based on ID reporting, and used very often in vertical scenarios.

In some cases, Ambient IoT devices may also have sensing features, but these may only be used for simple monitoring of the environment or asset, instead of remote control or video transmission, with only small packets (e.g., less than 200 bits) transmission. Since the goal of Ambient IoT is the massive connection of all objects, the size and cost of Ambient IoT devices need to be considered, thus this type of Ambient IoT device is required to be very low complexity, and without any complicated components (e.g., crystal, LNA, amplifier). Due to this limited structure, backscatter communication could be an appropriate option. In these cases, the devices (tags) should have features such as ultra-low complexity, ultra-low power consumption, very small form factor, and battery-less (i.e., not using conventional battery).

However, in some other cases, the Ambient IoT devices may perform more complicated tasks, such as monitoring or actuating, which require higher volume bi-directional data exchange between the network and the devices. For outdoor scenarios, long-range communication being also needed, this device type may consist of more complicated components (e.g., amplifier, LNA, filter). In order to support these capabilities, batteries may be needed for this device type, but it is required they are rechargeable from ambient energy, instead of manually recharging or maintenance. Therefore, a different type of Ambient IoT device with enhanced features is required. Since this type of device requires more energy, backscatter communication and active communication can be supported at same time. NOTE 2 - Compared to backscatter communications, “active communication” [Reference needed] refers to device-originated autonomous communications. The device does not need to wait hearing the external signal. Instead, the device “actively” generates the internal signal due to the pre-defined configuration, and sends it out to the network for interaction.

At least the above illustrated 2 types of Ambient IoT devices should be considered for different application scenarios: they can be denoted as “low-end” and “high-end” device types depending on features.

The “low-end” device for Ambient IoT has the following set of requirements:

- The device is required to have ultra-low complexity (e.g., no crystal, no LNA, no MCU) and ultra-low power consumption ( $\sim\mu\text{W}$ ).
- The device is required to support ambient energy harvesting.
- The device is required to be battery-less, and it may have no energy storage or very limited energy storage (e.g., capacitor).
- The device may support lightweight applications, such as identification, sensing, and positioning.

The “high-end” device for Ambient IoT has the following set of requirements:

- The device is required to have low complexity and low power consumption ( $\sim 1\text{ mW}$ ).
- The device is required to support ambient energy harvesting.
- The device may have energy storage, but the device is required to be driven by ambient energy.
- The device may support lightweight applications, such as identification, sensing, and positioning, actuation.

### **6.2.2 Requirements for Ambient IoT charging node**

In some cases, the energy harvested from the surrounding environment is enough to power up the Ambient IoT devices and keep stable performance. However, the environmental power may be very limited and sometimes unstable and uncontrollable, thus an additional charging node may be needed to provide additional energy to the Ambient IoT device.

The charging node for Ambient IoT has the following set of requirements:

- The charging node is required to wirelessly transmit energy to the Ambient IoT devices.  
NOTE - , Such energy includes but is not limited to RF energy and light energy.
- The charging node may support carrier wave to help ambient IoT devices perform frequency shift.
- The charging node is required to be controlled by the network or assist nodes.

### **6.3 Analysis on challenges of requirements of ambient power-enabled IoT**

## **7 Use cases of ambient power enabled Internet of Things**

*TBD*

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