6G White Paper

Ambient IoT

LG U+

Table of Contents

1. Introduction

1.1 Evolution of mobile communication technology beyond 5G

Over the years, mobile communication technology has focused on developing systems that can transmit larger amounts of information more quickly. As a result, networks capable of streaming high-definition videos in real time and rapidly transmitting large files have been established. As with all technological advancements, the initial focus is on enhancing the basic performance of the technology. However, once the technology matures, there will be a natural demand to expand service areas. Current mobile phones have evolved into smartphones, incorporating the functions of other portable devices, such as digital cameras and Portable Media Players (PMPs), and, eventually, even replacing Personal Digital Assistants (PDAs). This leads to the consideration of how 6G technology will evolve in the future as the demand for increased speeds diminishes. Mobile communication based on the 3rd Generation Partnership Project (3GPP) is one of the most crucial technologies among current wireless communication standards. It has the potential to evolve into a platform that converges various other wireless communication technologies, thereby expanding service areas.

1.2 Current status of 5G IoT technologies

Among numerous technologies applied to 5G, those related to the Internet of Things (IoT) have not received much attention, but IoT is showing the greatest growth in the mobile communication market. In Korea, the number of mobile phone subscribers increased by only 0.9% from 2018 to 2023. However, during the same period, the number of LG Uplus's IoT lines surged from 1.75 million to 6.81 million, a rise of nearly 300%. This significant shift led to a change in the ranking of telecommunication subscribers in South Korea for the first time in 27 years, prompting the South Korean government to revise its statistical criteria for telecommunications subscribers.

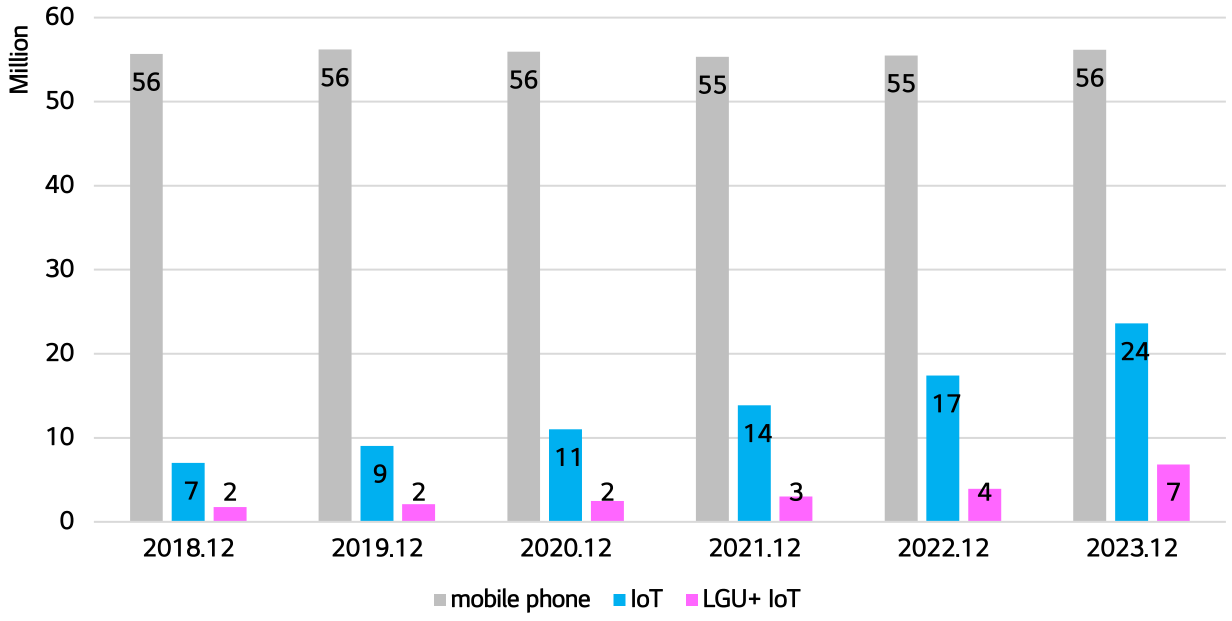

Figure 1. Number of mobile subscription lines in Korea

Looking at the evolution of IoT devices from a technical perspective, they have aimed for simpler hardware design and low power consumption, utilizing limited bandwidth and resources. Narrowband IoT (NB-IoT) technology is currently at the forefront of this trend. NB-IoT was able to achieve extremely low power and low cost within the existing 3GPP technology framework, but it has clear limitations because it relies on the 3GPP system, which is based on mobile communications. These limitations include the presence of batteries for power supply and the Universal Integrated Circuit Card (UICC) for subscriber authentication and mobility management.

Ambient IoT, considered a new 5G Advanced technology, operates with even less complexity and lower power than NB-IoT. While it may seem to follow the same line as 3GPP's IoT technology, its approach is fundamentally opposite to that of NB-IoT. Ambient IoT is similar to Radio Frequency Identification (RFID), and its communication method has significant structural differences from the existing 3GPP standard. From a device perspective, the two notable differences between existing User Equipment (UE) and Ambient IoT devices are as follows:

1) Some Ambient IoT devices are equipped with minimal capacity or no batteries at all.
2) Devices are not equipped with a UICC, and there is no UE-based mobility management.

Considering these differences, it is evident that Ambient IoT will bring significant changes to device management and network operation, representing a fundamentally different philosophy from the technology defined in 3GPP.

1.3 Why Ambient IoT?

In relation to Ambient IoT, which is currently being reviewed as a study item for 5G Advanced, discussions are underway about implementing functions such as RFID within the 3GPP network. However, the goal of Ambient IoT in the context of 6G is not merely to support the functions provided by RFID in mobile communication networks. Ambient IoT seeks to create new business opportunities by making sensor networks, logistics, and location services—previously difficult to provide with existing device technology—feasible and competitive.

For example, in logistics services, Ambient IoT can collect location data not just at predefined points but also along the entire product route, allowing for valuable statistical information to optimize distribution processes. Tags attached to product packaging can provide information about the collection and disposal routes of packaging containers through 6G base stations, aiding in resource recycling and environmental protection. Greater service opportunities will likely arise in business-to-consumer (B2C) rather than business-to-business (B2B) transactions. Customers can track the location and movement of their valuables simply by attaching Ambient IoT tags to them. For example, if Ambient IoT tags are embedded in character stickers that many people attach to their laptops, they will no longer need to waste time searching for lost items. Ambient IoT is also useful for building sensor networks that require data collection from numerous locations. By installing many low-cost Ambient IoT devices that can operate without batteries, maintenance can be minimized. From a network operation perspective, it can handle traffic without significant load because it does not need to manage numerous devices individually as UE. It would not be unreasonable to expect a truly ubiquitous network to be realized in 6G through Ambient IoT.

In this white paper, we will explore the service scenarios that we aim to realize through Ambient IoT based on 3GPP technology, as well as the technical requirements for implementation. This will help clearly clarify how Ambient IoT fundamentally differs from other technologies under the 3GPP umbrella.

2. Overview of Ambient IoT

2.1 Technical features

In 3GPP, IoT-related technologies such as enhanced Machine Type Communication (eMTC), NB-IoT, and Reduced capability (RedCap) were introduced to meet the industry's diverse requirements. Generally, IoT devices use commercial batteries, such as lithium batteries, which have a limited lifespan and require periodic replacement or recharging. These battery issues increase operating costs and create limitations in certain locations.

Ambient IoT is characterized by two key features: energy harvesting and backscattering. Energy harvesting allows devices to operate without a battery by receiving power from sources such as radio waves, light, vibration, or heat. Meanwhile, backscattering technology enables a device's antenna (tag) to transmit data by varying the intensity of the reflected signals by adjusting the absorption rate of the received continuous wave (CW) signals. In other words, the device does not directly generate and transmit radio frequency (RF) signals but instead reflects and transmits the reader's signals. This approach results in lower costs (less than a few cents per device), compact size (coin-sized), and minimal maintenance. These advantages make Ambient IoT a promising technology for various industries.

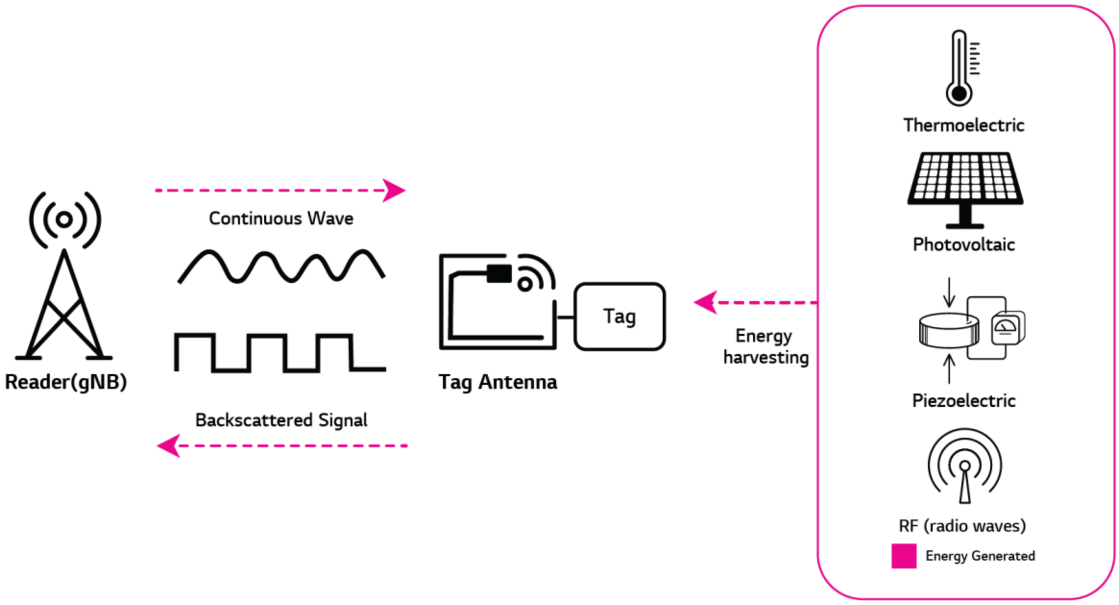

Figure 2. Energy Harvesting and Backscattering

The basic procedure for Ambient IoT communication is as follows:

1. Powered by energy harvesting
   : When an Ambient IoT device is located within the coverage of a base station acting as a reader, it prepares to receive downlink control information using the base station's radio signals as a power source.

2. Downlink control information transmission

   : The base station sends commands to individual devices or groups of devices through messages such as paging. Device groups can be categorized by business operators, manufacturers, tag types, etc., allowing for responses tailored to each group. At the time, information about the maximum time slot used to determine the transmission time of the devices is also provided.
3. Continuous Wave (CW) supply

   : For backscattering, a key function of Ambient IoT, CW signals should be supplied to the devices. These signals can be transmitted directly from the base station or through a separate emitter.
4. Device ID transmission through backscattered signals

   : The devices that have received downlink control information randomly select a time slot to transmit their device ID and attempt to transmit it. If multiple devices attempt to connect to the same time slot, only one is allowed to connect, and devices that fail should wait for the next time slot or downlink control information and then retry.

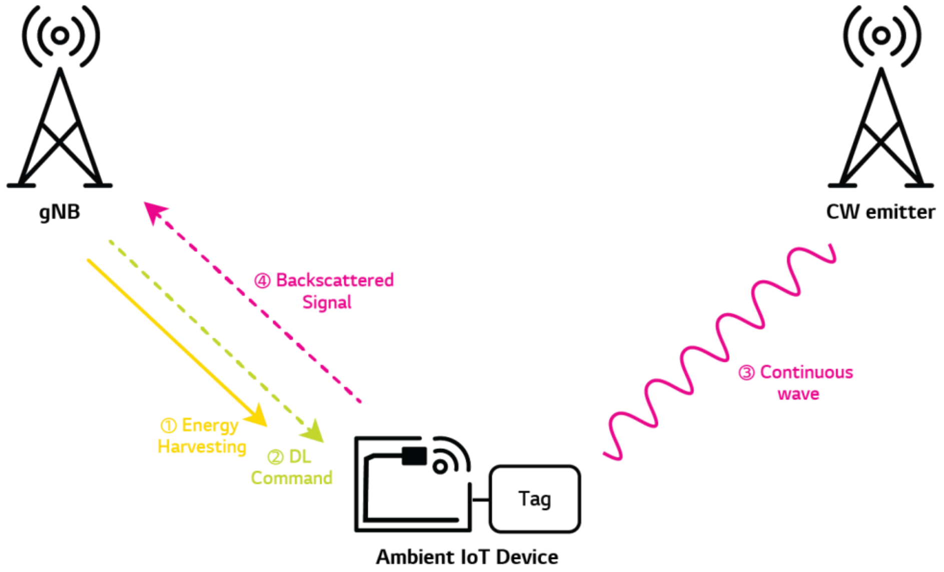

Figure 3. Ambient IoT Scenario

2.2 Standardization timeline

3GPP is also standardizing technologies to support Low-Power Wide-Area (LPWA) technology in licensed bands. In Release 13, low-end devices LTE-M and NB-IoT have been standardized, and technologies to support IoT in 5G systems are being developed. Release 15, the initial 5G standard, did not introduce separate IoT functions as it focused on the enhanced Mobile BroadBand (eMBB) function for the accelerated commercialization of 5G. However, starting from Release 16, IoT functions in the 5G system were supported. In Release 16, LTE-M and NB-IoT are supported within the 5G frequency band, allowing LTE IoT technology to be provided alongside other 5G services. In Release 17, 3GPP introduced support for reduced capability NR devices, marking an important step in further expanding the market for 5G NR.

	LTE Rel-16				Redcap Rel-17		Redcap Rel-18
	Cat.M1	Cat.M2	Cat.NB1	Cat.NB2			
Frequency	In-band FR1		In-band/Guard band & Standalone FR1		FR1	FR2	FR1
DL peak rate	~300kbps	~2.4Mbps	~27kbps	~127kbps	150Mbps	150Mbps	10Mbps
UL peak rate	~375kbps	~2.6Mbps	62kbps	~159kbps	50Mbps	50Mbps	10Mbps
Battery life	> 10 years				Up to few years		
Maximum Coupling Loss	164dB				144dB		TBD
Coverage	100km		120km		100km		
Latency	< 10 sec				5~10ms safety sensor, 100ms others		
Reliability	99% ~ 99.9%				99.99%		
Bandwidth	1.4 ㎒	5 ㎒	200 ㎑	200 ㎑	20 ㎒	100 ㎒	20 ㎒ (BB 5 ㎒)

Table 1. 3GPP LPWA technology comparison

In Release 18, Technical Specification Group (TSG) Radio Access Network (RAN) completed a RAN-level Study Item (SI) on Ambient IoT, providing a framework for future discussions. This study defined representative use cases, deployment scenarios, connectivity topologies, device categorization, RAN design targets, and required functionalities. It also conducted a preliminary assessment of feasibility and recommended scope for further Working Group (WG)-level. In Release 19, studies on Ambient IoT are ongoing, focusing on evaluation and feasibility, particularly for indoor inventory and command use cases.

Ambient IoT evolution, including positioning support and security, is expected to continue in Release 20 to support various use cases not considered in Release 19. Furthermore, many operators and manufacturers view it as a major candidate technology for 6G because of its features, such as powerless and large-scale connectivity. Therefore, standardization for Ambient IoT support is expected to be achieved in 6G as well.

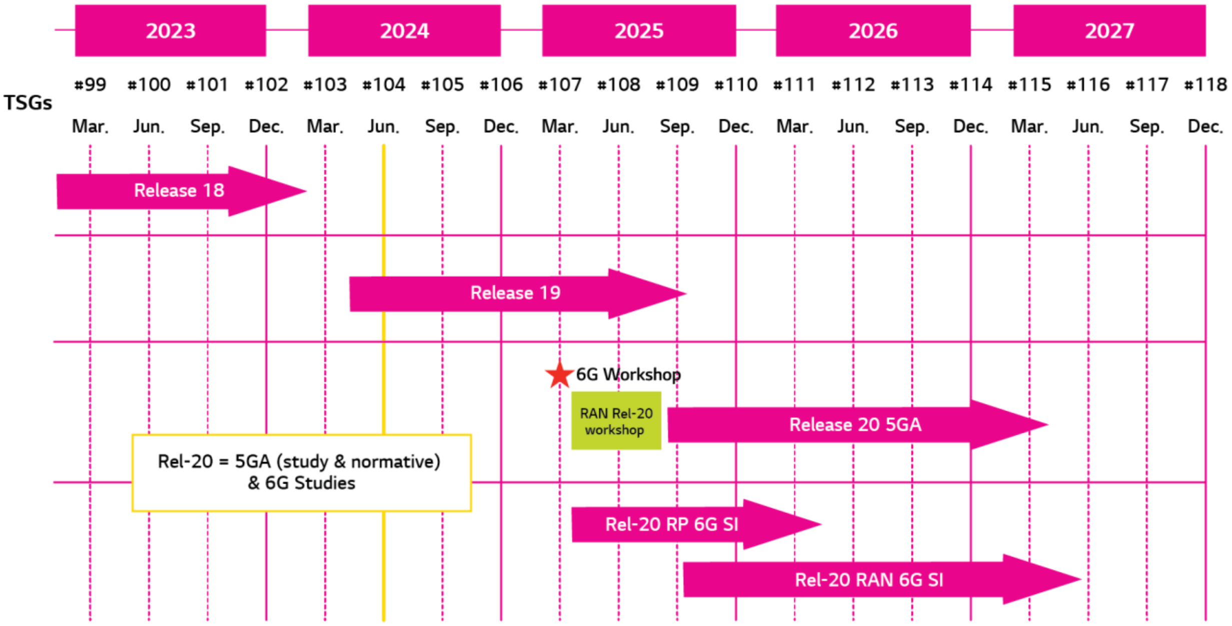

Figure 4. 3rd Generation Partnership Project (3GPP) timeline

3. Use Cases & Requirements of Ambient IoT

3.1 Use cases

By leveraging the features of Ambient IoT, it can be applied to various use cases. First, it is possible to supply tens or hundreds of billions of low-cost IoT devices, providing added value throughout the entire distribution and supply process. This makes it applicable to services such as inventory management, positioning, and logistics. Second, when combined with mobile communication networks, asset tracking services can be provided on a nationwide-scale. Third and lastly, as it can operate permanently without battery replacement by utilizing energy from the surrounding environment, it can be used in services that are difficult to maintain, such as environmental monitoring.

Various Ambient IoT use cases were discussed at the 3GPP Service and System Aspects Working Group 1 (SA1). A total of 30 use cases and three traffic scenarios, including environmental monitoring, healthcare, logistics/inventory management, and smart city/factory applications, were summarized in TR 22.840 (TR 22.840 “Study on Ambient power-enabled Internet of Things”). Based on this study, 3GPP RAN conducted a feasibility study on Ambient IoT within the 3GPP system and classified SA1 use cases into eight types as follows (TR 38.848 “Study on Ambient IoT in RAN”):

RAN Use Case	Applicable SA1 Use Case
Indoor inventory	Automated warehousing Medical instruments inventory management and positioning Non-Public Network (NPN) for logistics, Automobile manufacturing Airport terminal / shipping port, Smart laundry Automated supply chain distribution, Fresh food supply chain End-to-end (E2E) logistics, Flower auction, Electronics shelf label
Indoor sensor	Smart homes, Base station machine room environmental supervision Smart laundry, Smart agriculture, Smart pig farm
Indoor positioning	Finding remote lost item, Location service Ranging in a home, Personal belongings finding Positioning in a shopping center, Museum guide
Indoor command	Online modification of medical instruments status Device activation and deactivation, Elderly healthcare Device permanent deactivation, Electronic shelf label
Outdoor inventory	Medical instruments inventory management and positioning NPN for logistics, Airport terminal/shipping port Automated supply chain distribution
Outdoor sensor	Smart grids, Forest fire monitoring, Dairy farming Smart manhole cover safety monitoring, Smart bridge health monitoring
Outdoor positioning	Finding remote lost item, Location service Personal belongings finding
Outdoor Command	Online modification of medical instruments status Device activation and deactivation, Elderly healthcare Controller in smart agriculture

Table 2. Mapping between RAN and SA1 use cases and traffic scenarios.

3.2 Service scenarios and key use cases

Existing IoT services typically rely on Internet Protocol (IP) based End-to-End (E2E) communication, with the operator's role limited to simply providing connectivity through the network infrastructure. However, in the case of Ambient IoT, the key difference is that operators should implement functions within the network to directly control devices in service applications and build a platform that can easily link with various third-party services. This chapter will explore the scenarios for operators to provide Ambient IoT services in 6G, along with the main use cases they offer.

3.2.1 Service scenario

Figure 5 shows the architecture of the Ambient IoT service provided by operators. Ambient IoT services in mobile communication systems consist of 1) Device for Ambient IoT, 2) Network with RAN and Core for wireless access, 3) Platform for connecting networks and service applications, and 4) Service Application for Ambient IoT. The role of each service is as follows.

1) Device

   Devices can be sold directly by operators, or users can directly purchase and register certified devices provided by third parties.

2) Network

   A network consists of RAN for wireless connection of Ambient IoT devices and Core, which handles functions such as device authentication, management, and control.

   A device connects to a network through a base station or an intermediate node positioned between the base station and the device. This intermediate node may be a UE that is a subscription device of the relevant mobile communication service provider.

   A Core network performs device management, authentication, and control and provides access to information such as positioning and sensing data necessary for service provision through the exposure of network functions.

   When Ambient IoT services are delivered through a network, the advantage is the ability to utilize a nationwide-scale network. Furthermore, additional network functions, such as device management, authentication, and positioning, can be easily provided.

3) Platform

   A platform connects service applications and networks. An operator can implement this platform within the network, configure it as a dedicated platform separate from the network, or use a third-party platform. By using the standardized OpenAPI, network functions can be easily provided to applications, making interworking with various services easier.

4) Service Application

   Using Ambient IoT devices, operators can provide services such as warehouse management, supply chain distribution, inventory management for fresh food, location services for finding lost items, sensor networks for environmental monitoring, and smart farms. Depending on services, operators can provide applications directly or through third-party applications.

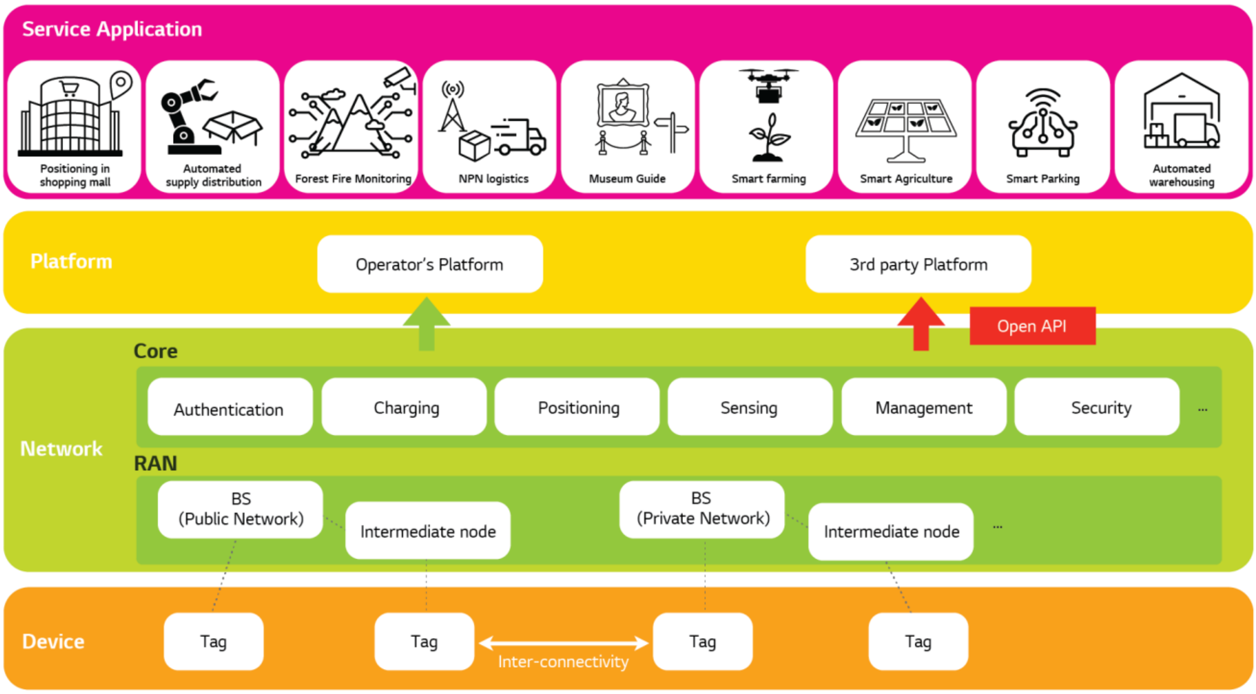

Figure 5. Ambient IoT service architecture

If we consider using Ambient IoT to find lost items as an example, actual services can be provided as follows:

1) Customers purchase Ambient IoT tags and attach them to desired items, such as character stickers on laptops.

2) To use a finding remote lost item service, users can register the tag information (tag ID) on an application server and select the service plan and network functions (location, sensing, etc.).

3) The attached tag connects to the network through a base station or intermediate node and communicates with the finding remote lost item service.

4) Once the connection and registration are completed between the tag and the finding remote lost item service, users can check the location of important items in real time through a mobile application.

Operators provide connectivity to Ambient IoT devices through a nationwide-scale network and support network functions such as device registration, authentication, and operation. Exposing network functions to third-party service providers establishes a platform that can be integrated into various service applications. In addition, operators can create new business models by providing services using sensor networks, such as advanced positioning services using multiple communication devices and monitoring various environments and objects.

Operators can offer service applications, platforms, mobile communication systems, and devices directly as a comprehensive service. Alternatively, they can expose network functions to third-party service applications and platforms to support the devices. This approach enables operators to generate various revenue streams by providing core network functions such as authentication, management, and control.

3.2.2 Key use cases

As it becomes possible to build large-scale IoT devices cost-effectively and monitor various objects through advanced positioning and sensing, these technologies can be applied to various smart services, such as smart healthcare and smart dairy farming. By addressing the limitations of tags like those used in traditional RFID, managing interference between multiple IoT devices, and supporting large-scale networks with a nationwide infrastructure, Ambient IoT can enhance the entire supply chain process. This application throughout logistics allows for comprehensive supply chain management. Furthermore, new services such as asset and child tracking will become possible by considering mobility and expanding the technology to outdoor environments. The main use cases for Ambient IoT are as follows:

1. **Asset finding and tracking:** When purchasing precious metals or expensive electronic products that support Ambient IoT or by attaching a separate Ambient IoT sticker to a desired product and registering the ID through a telecommunication membership service, users can access the item's location information and movement history.

2. **Child and pet location tracking:** By equipping a child or pet with an Ambient IoT device, multiple UEs acting as base stations and intermediate nodes provide accurate real-time location information to prevent loss. This service can also include alerts when a child or pet enters a dangerous area.

3. **Smart logistics:** Attaching Ambient IoT tags to multiple items in the logistics center enables management of inventory inflow and outflow, product tracking, automatic logistics classification, and real-time management based on information such as origin and destination.

4. **Cold chain logistics:** Combining real-time demand data from stores with product location, storage, and inventory management, considering the expiration date of marine products, meat, and fresh food maintains freshness. Environmental sensing information, such as temperature and humidity during transportation, provides detailed delivery status and history.

5. **Smart factory:** Ambient IoT can be used to monitor production progress, manage inventory for parts or finished products, check worker location and work progress, and manage key assets.

6. **Smart agriculture, livestock, and fisheries:** By collecting and monitoring sensing information necessary for agriculture, such as temperature, humidity, illumination, carbon dioxide, and pH levels, an optimal environment can be created. In dairy farming, measuring livestock body temperature helps monitor health status and detect diseases.

7. **Disaster prevention through environmental monitoring:** By leveraging Ambient IoT devices' capability to function in extreme environments, disasters like forest fires and floods can be prevented by monitoring environmental data in remote and inaccessible areas, such as high mountains.

3.3 Service requirements

To support Ambient IoT services in a mobile communication network, functional and performance service requirements should be considered. According to TS 22.369, a 3GPP standards document, the functional service requirements include communication, positioning/location, management, collected information and network capability exposure, charging, security, and privacy. Performance service requirements are specified for each service, such as inventory, sensor data collection, and tracking.

Moreover, the 3GPP RAN document TR 38.848 outlines nine aspects and requirements that need to be considered in the design of 5G Ambient IoT devices. The document categorizes devices into three types: Type A, which has no energy storage and no independent signal generation/amplification, i.e., backscattering; Type B, which has energy storage, no independent signal generation, and can include amplification for reflected signals using stored energy; and Type C, which has energy storage and has independent signal generation, i.e., active RF components for transmission. The common and specific requirements for each type of Ambient IoT device are as follows.

	Type A	Type B	Type C
Power consumption	≤ 1 µW or ≤ 10 µW	Type A < Type B < Type C	≤ 1 mW to ≤ 10 mW
Complexity	Comparable to UHF RFID ISO18000-6C (EPC C1G2)	Type A < Type B < Type C	Orders of magnitude lower than NB-IoT
Coverage	Maximum distance of 10–50 m for indoor, maximum distance of 50–500 m for outdoor		
User experienced data rate	Maximum not less than 5 kbps, and minimum not less than 0.1 kbps		
Maximum message size	1000 bits		
Latency	1–10 s		
Positioning accuracy	Cellular network: 1–3 meters @ 90% indoor location, several tens of meters @ 90% outdoor location Device: 1–3 meters @ 90% indoor and outdoor location		
Connection/device density	150 devices per 100 m^2 for indoor scenarios, 20 devices per 100 m^2 for outdoor scenarios		
Moving speed of device	10 km/h		

Table 3. Ambient IoT device design targets and requirements

In 3GPP, the performance requirements for each service and device type are being discussed to provide Ambient IoT services. However, for 5G Advanced, the focus is Ambient IoT with limited device types in specific scenarios. The standardization of Ambient IoT capable of supporting the functions and use cases mentioned above will only be achievable with 6G. Furthermore, 6G is expected to enhance device density, service area dimension, positioning accuracy, and device speed compared to 5G performance service requirements.

4. Key Technologies for Ambient IoT

This chapter outlines the necessary technologies to implement Ambient IoT from an operator's perspective. In the current standard, design targets have been discussed, but specific technologies have not yet been detailed. Ambient IoT essentially uses the radio protocol of RFID, but as it is based on mobile communication, it differs from RFID in several ways. This is the first time 3GPP supports devices that do not use a UICC, requiring the consideration of various aspects, from radio protocols to management and authentication. Considering use cases and design targets, this white paper examines the technologies required for implementation from six aspects: device management, interference control, positioning, mobility, spectrum, and authentication. Each aspect describes the necessary improvements and technologies needed based on the current situation.

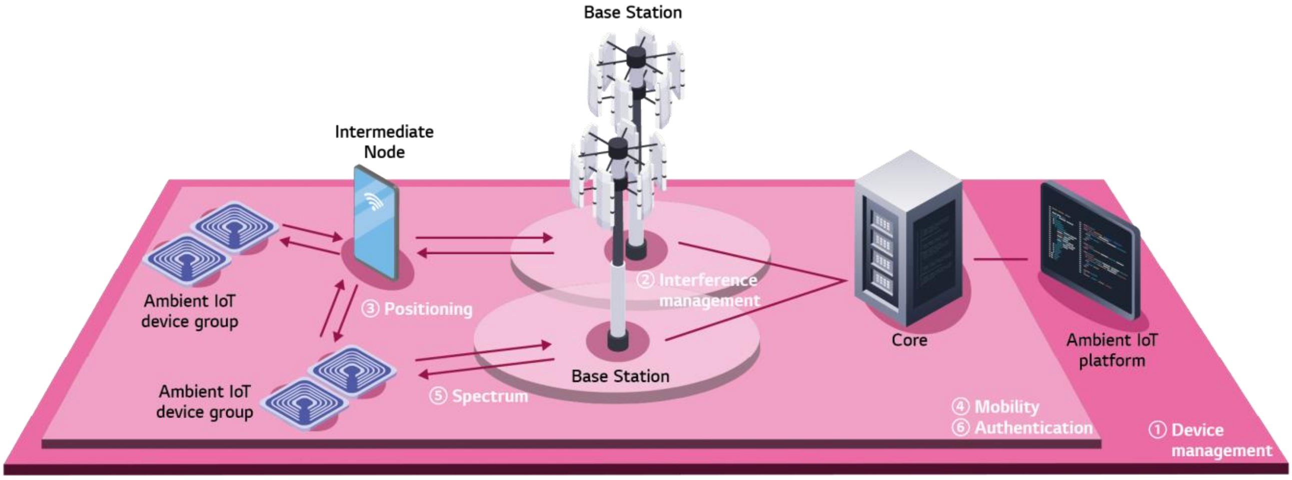

Figure 6. Architecture of key technologies

4.1 Device management technology

Ambient IoT devices are often attached to multiple items, such as for inventory management, leading to a huge number of devices communicating with a single base station. In RFID systems, only one device can communicate at a time, which limits the ability to select specific devices for communication. Moreover, even though the number of devices increases, there is no efficient way to manage communication conflicts, resulting in extended communication times.

Two key features must be considered to communicate efficiently with many devices. The first feature is group-based paging. The ID of an Ambient IoT device is expected to consist of several fields, such as the operator ID, manufacturer ID, and device ID. When a base station attempts to communicate with Ambient IoT devices, it can set a condition to determine if the value of a specific field of the device ID matches, allowing communication with only the necessary devices instead of all devices.

The second feature involves transmitting multiple device IDs at once when the base station sends the device IDs it receives to the core network. This approach addresses the problem of high signaling load in the core network caused by transmitting individual device IDs separately. The conditions for transmitting the device ID to the core network can be based on all IDs of a specific group being collected, when the timer has expired, or when a certain amount of data is collected.

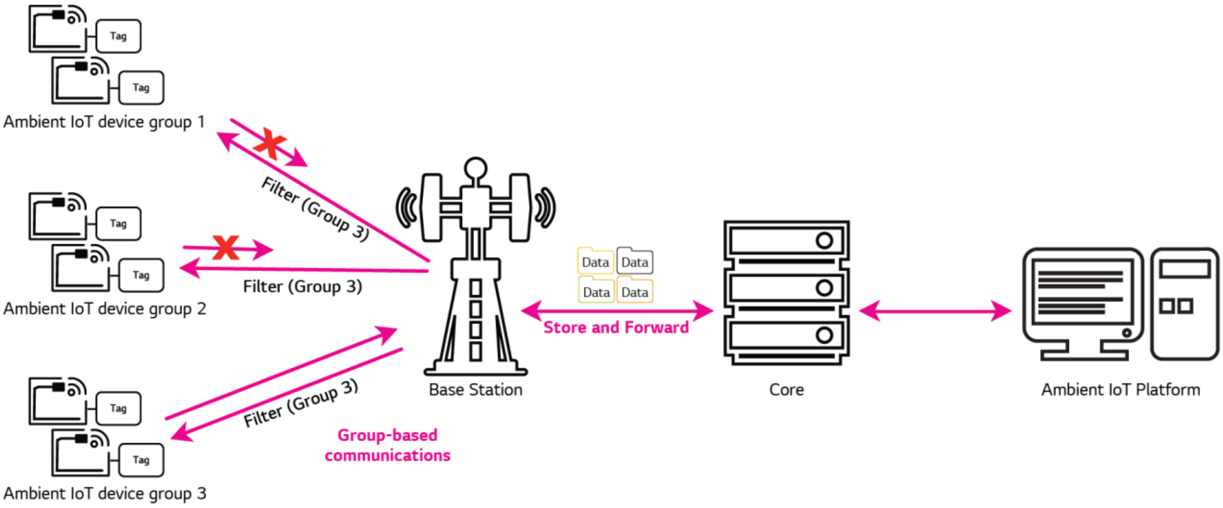

Figure 7. Device management architecture

4.2 RF signal interference control technology

In mobile communications, base stations are deployed densely to handle the high traffic from many users, resulting in overlapping RF signals from multiple base stations in an area.

In this case, a normal mobile device can measure the RF signal quality as instructed by the base station and select the most suitable one for communication. However, an Ambient IoT device may struggle to communicate normally when it receives downlink commands from multiple base stations. The main issue is that downlink commands lack cell ID information, making it difficult for the Ambient IoT device to identify which base station the command is coming from.

To address this problem, two techniques can be considered. The first is to apply a Time Division Multiplexing (TDM) that operates sequentially over time in areas where the coverage of base station downlink commands is expected to overlap, allowing only one base station to operate at any given time. This allows the Ambient IoT device to receive a single command.

The other technique is to adjust the transmission power of the base station's downlink signals. On the operations, administration, and maintenance (OAM) side, the transmission power can be adjusted to prevent coverage overlap between base stations, considering the location of each base station and usage scenario. At the time, overall optimization should be considered by taking into account the entire target area to ensure that there are no coverage holes and that only the power of a specific Physical Resource Block (PRB) is adjusted to avoid affecting other services.

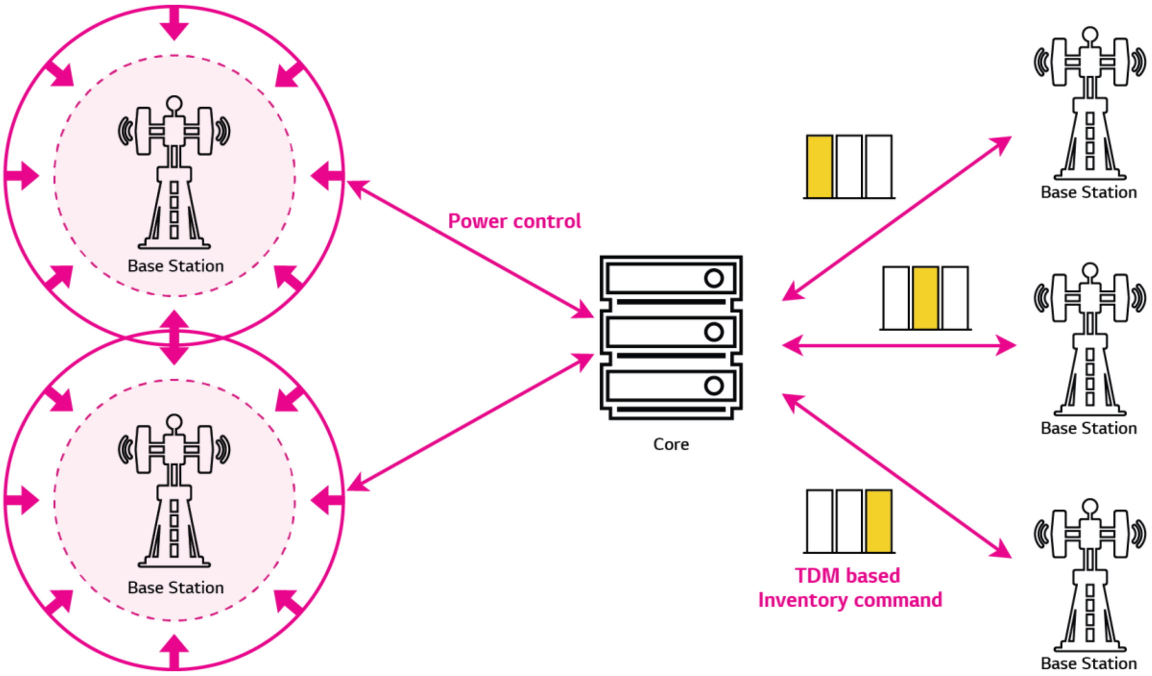

Figure 8. RF signal interference control technology architecture

4.3 Positioning technology

One of the primary use cases for Ambient IoT is tracking, which was not feasible with RFID. RFID is a technology that only focuses on collecting device IDs, so it is difficult to know the location of a device. However, the Ambient IoT standard considers positioning capability, and the 3GPP standard requires an accuracy of approximately several meters, depending on the situation.

Positioning in 3GPP can be divided into the base station Cell-ID method and the triangulation method. The Cell-ID method is easy to implement but lacks high accuracy. On the other hand, the triangulation method, which measures signal strength or time delay when a device communicates with three or more base stations, provides much more accurate location data. However, the ultralow-cost and ultralight design of Ambient IoT devices makes it impossible to measure signal strength or time delay, making it difficult to apply the triangulation method.

To address this challenge, a positioning method that minimizes device involvement needs to be developed. In this evolved method, a base station would perform the delay time measurement (traditionally handled by devices) and collect/calculate this data in the positioning server to estimate the device's location. While the accuracy of this data might decrease because of the lack of device involvement, accuracy can be improved by combining results from multiple positioning attempts on the server instead of relying on a single attempt. Multiple positioning attempts can be conducted at the same base station or by combining positioning data from each base station and the intermediate nodes.

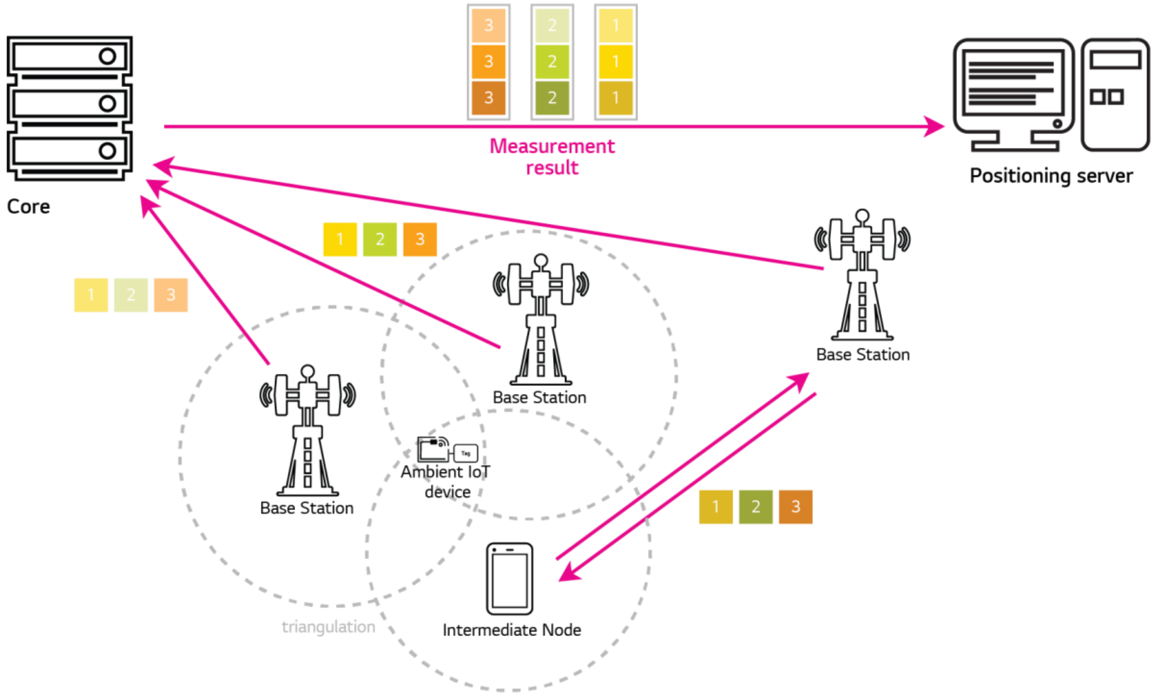

Figure 9. Positioning technology architecture

4.4 Spectrum efficiency improvement technology

Ambient IoT requires support for multiple access techniques and new frequency bands to improve spectrum efficiency. Currently, Ambient IoT primarily uses the Time Division Multiple Access (TDMA), which accommodates a large number of devices by adjusting communication times based on the number of devices. However, this technique has limitations. Introducing Frequency Division Multiple Access (FDMA) as an alternative can enable simultaneous communication with multiple devices, thus accommodating more devices. Moreover, increasing the power density of FDMA transmission signals while reducing the bandwidth used can enhance coverage.

However, implementing FDMA can raise complexity because Ambient IoT devices should continuously change their frequency. If a separate frequency shifter is required in a device to change frequencies, this increases manufacturing costs and complexity, making it unsuitable for ultralow-cost devices. One way to implement FDMA without a separate frequency shifter is by adjusting the chip rate of line coding. As the frequency can be changed depending on the chip rate, this technique can effectively implement FDMA while reducing the complexity of a device.

Due to their low cost and low complexity, Ambient IoT devices are limited in the frequency bands they can support because of their low cost / low complexity, which results in poor time accuracy. 3GPP supports two duplex modes, Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD), but Ambient IoT supports only Half-Duplex FDD (HD-FDD), which can operate with some time errors. Supporting TDD requires minimal time error because downlink and uplink are used separately based on time, and fast switching between downlink and uplink should be supported. Currently, Ambient IoT devices cannot support this because of their limitations. However, starting from 5G, TDD has become the primary technique for the efficient use of spectrum, and this trend is expected to increase in 6G. Therefore, by overcoming implementation limitations, it is believed that 6G will require support for multiple frequency bands, including TDD.

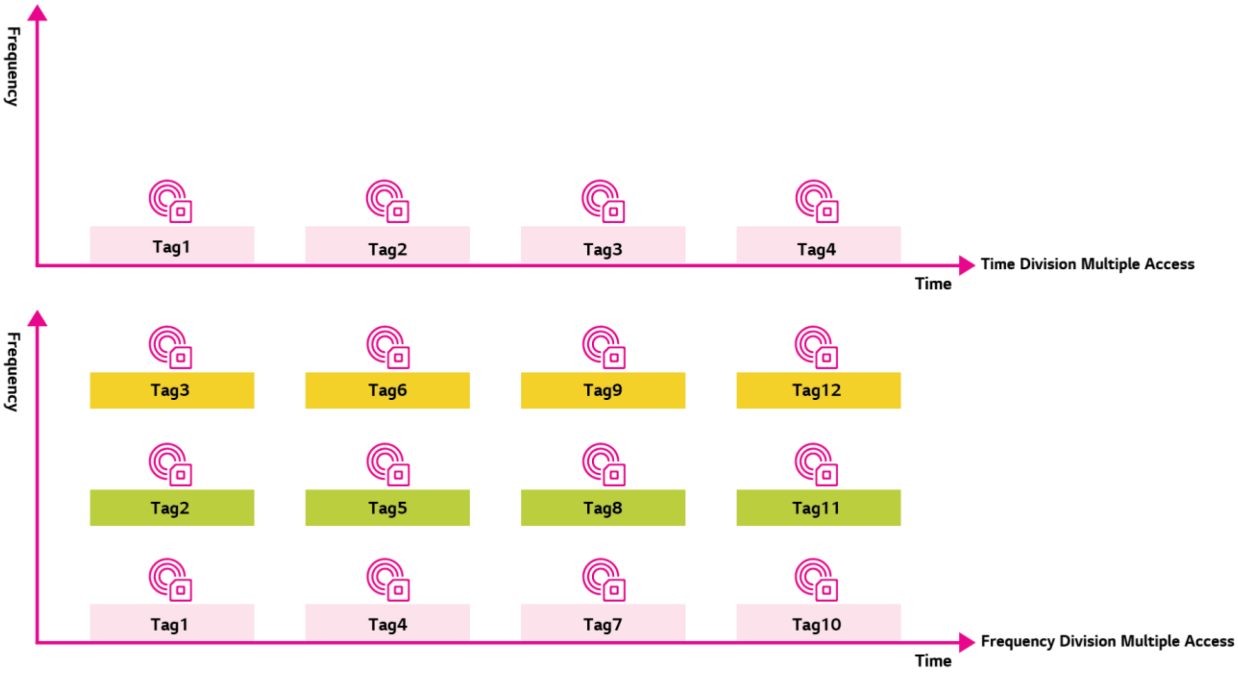

Figure 10. Example of FDMA

4.5 Mobility support technology

In tracking scenarios, mobility support for Ambient IoT devices is crucial in addition to positioning. In mobile communications, device locations can be identified by tracking area when a device is in an idle state and by cell when a device is in a connected state. However, because Ambient IoT devices that do not have UICC do not register their location, the tracking area is not considered, making it difficult for the server to detect changes in the device's location as it does in traditional mobile communications. Tracking the mobility of Ambient IoT devices can only be done manually by the server, but considering that one Ambient IoT server manages at least tens of thousands of devices, this imposes a significant load on the server.

One concept under consideration in the current standards is an inventory area. However, this is meant to distinguish specific areas where inventory operations are performed and does not support mobility. While indoor mobility support may not be essential, it is likely to be required for use cases such as tracking. To achieve this, it is necessary to implement a function that allows a device to update the location information on the server by responding to a paging-like command sent by a base station with the ID. Paging-like commands for Ambient IoT are primarily for inventory operations, so a device is not specified, but it can respond periodically when the inventory session timer expires or conditionally when the inventory area changes. This would allow for service scenarios that require continuous tracking.

4.6 Certification technology

To prevent external threats such as fake kill commands, fake data writing, and fake tags, RFID uses password or encryption-based authentication, while 3GPP uses key-based device authentication.

Ambient IoT also requires an authentication process to prevent external threats. Among the three types of devices considered in Ambient IoT, mid-priced and high-priced devices are expected to support existing RFID technologies. However, for low-cost devices, supporting the existing authentication method may be difficult because of price and complexity issues. Therefore, new authentication methods for low-cost devices need to be developed. In addition, base stations need to have technologies that can recover from or avoid attacks, considering the possibility that low-cost devices could be attacked.

5. **Conclusion**

As shown above, the use cases of Ambient IoT and the technologies needed to implement it indicate a shift in the market's expectations for mobile communication networks. Previously, mobile networks were designed to maximize the functionalities of mobile phones. In the future, however, they will need to accommodate hundreds or thousands of Ambient IoT devices that provide highly simplified functions, facilitating efficient communication even with limited information. This development is vital for achieving a network that connects people, objects, and sensors anytime and anywhere, fulfilling a long-held vision.

Realizing this vision, however, presents significant challenges. Managing the mobility of Ambient IoT devices, which cannot register their location because of the absence of a UICC, and providing the diverse service scenarios we desire will require the 6G network to be much more advanced and flexible than the 5G system. It should also be user-friendly and capable of organically exchanging data with numerous devices that offer limited functions. Ultimately, when networks evolve into an open system that enables users to easily register and manage their devices, truly ubiquitous networks will be realized using 3GPP mobile communication technology. This transformation is crucial for creating a network where everything is seamlessly connected.

Moreover, establishing ubiquitous networks based on Ambient IoT technology is essential not only from a functional perspective but also for industrial sustainability. To protect the environment and enhance our quality of life, it is impractical to depend on the continual installation of batteries in countless IoT devices, which not only consume significant power but also require frequent replacement. Ambient IoT technology, which can operate almost indefinitely using recycled energy, offers a sustainable and eco-friendly solution for ubiquitous networks.

By incorporating Ambient IoT technology into 3GPP, 6G will transform into an integrated platform that combines other wireless technologies, such as RFID. This scalable network can easily expand to support next-generation services like autonomous driving and satellite communication, serving as a key indicator of the limits and potential advancements in mobile communication technology.

Abbreviations

B2B	Business to Business
B2C	Business to Customer
NB-IoT	Narrow Band-Internet of Things
PDA	Personal Digital Assistant
PMP	Portable Media Player
RFID	Radio Frequency Identification
UICC	Universal Integrated Circuit Card
3GPP	3rd Generation Partnership Project
eMTC	enhanced Machine Type Communication
Redcap	Reduced Capability
LPWA	Low Power Wide Area
LTE-M	Long-Term Evolution Machine Type Communication
IoT	Internet of Things
eMBB	enhanced Mobile BroadBand
TSG	Technical Specification Group
RAN	Radio Access Network
SI	Study Item
WG	Working Group
SA	System and service Aspects
SA1	System and service Aspects working group 1
NPN	Non-Public Network
E2E	End-to-End
TS	Technical Specification
TR	Technical Report
ID	Identifier
OAM	Operations, Administration and Management
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
FDMA	Frequency Division Multiple Access
RRC	Radio Resource Control
PRB	Physical Resource Block
FDD	Frequency Division Multiplexing
TDD	Time Division Multiplexing
HD-FDD	Half Duplex FDD