A 5G Americas Briefing Paper
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EVOLVING DEVICES FOR 5G ADOPTION

Introduction

5G devices are used in a wide variety of areas, but there is no single device type which can meet all requirements needed in different use cases. In this briefing paper, we review the evolution of 5G devices from smartphones (based on enhanced Mobile Broadband eMBB) to mid-tier IoT devices with Reduced Capability (RedCap), and introduce emerging, low-cost, battery-less devices (ambient IoT) covering a wide spectrum of 5G use cases. Categorization and analysis of 5G device types are provided based on multi-dimensional device characterization, requirements, market evolution, and enabling technologies. This paper will provide an insight on how 5G is evolving from the device perspective to address various use cases through optimization and adaptation.

Device Characteristics

Device characteristics play a significant role in determining device categorization. High-level categorization can provide a glimpse into the connectivity requirements, and help map technology options. A precise taxonomy of devices is difficult to lay out, so multi-dimensional perspectives are to be considered:

- **Mobility:** Devices such as smart meters, sensors, and parking point-of-payment are immobile compared to warehouse inventory sensors and readers which tend to be relatively mobile within certain areas, such as an enterprise campus. On the other extreme, fleet management devices, tracking containers, trucks, and electric scooters are mobile and expected to travel across a broad geographical area.
- **Bandwidth requirements:** Devices drive different volumes of data both in transmitting and receiving information based on use. Security cameras transmitting round-the-clock video streams demand much higher bandwidth than a smart water meter sending low volume of data on a scheduled basis. The asymmetric aspect of connectivity needs to be considered, as well as devices with higher upload requirements.
- **Size (form factor):** Industrial applications mandate specific size requirements and physical constraints placed on devices. This can impose limitations on batteries, antennas, and general size. A tracking device attached to the collar of a farm animal will have different requirements than a shipping container tracking module or a weather monitoring station.
- **Accessibility/maintenance:** Devices, especially those deployed in uninhabited environments (such as those for wildfire monitoring or farms), are expected to perform their tasks autonomously with very limited accessibility for maintenance or management purposes. These devices have varying durability requirements.
- **Reliability:** Different use cases require different levels of reliability, which accordingly requires different reliability features for devices, e.g., URLLC (higher reliability than eMBB), NB-IoT/LTE-Cat-M/Recap/eRedcap (similar reliability as eMBB) and Ambient IoT (lower reliability than eMBB). The difference in reliability requirements provides different opportunities helping 5G address wider use cases.
- **Cost:** It ranges from a simple sensor with limited connectivity options to complex devices configured with compute, storage, and several radio modules.
- **Security requirements:** Security is particularly important when devices are deployed in uncontrolled or unprotected environments where protecting data at rest (in the device) is as important as protecting data in transit (transmitted or received).

- **Coverage:** Modern connected devices will demand a wide range of coverage options depending on their application. The supporting technology to connect as well as the network topology will include relays, proxies, or mesh networks.
- **Battery life:** Devices need at least one way to stay operational depending on mobility, location, size, and complexity.
- **Radio access technology:** Most connected will employ Bluetooth, WiFi, 4G, 5G (or a combination of multiple) to achieve their functional requirements depending on availability, coverage or bandwidth needs.

Device Landscape

Mobile phones are no longer the only consumer or enterprise connected devices available. The portfolio of devices is expected to increase in the next decade, covering a broad spectrum of general-purpose devices, as well as highly specialized ones.

On the general-purpose end of the spectrum, we see powerful devices containing high-end compute, flexible storage, and memory options with a broad range of connectivity options driven by sophisticated and customizable software operating systems.

- **Smartphones:** Smartphones continue to evolve and dominate the market with screen technology expected to provide the biggest changes with extended visual real estate such as flip and folding models.
- **Untethered immersive/extended reality (XR) glasses:** Augmented reality (AR) glasses will play a significant role in the enterprise digital transformation. By combining image recognition and artificial intelligence (AI) driven knowledge these devices will increase efficiency in warehouses, production lines, and other processes. For example, a technician wearing augmented reality glasses would be able to see specs for a container without opening it. Virtual reality headsets will also enable more use cases, such as allowing enterprises to experiment and test before investing in physical infrastructure.
- **Screenless, voice-enabled connected devices:** Advancements in active noise cancellation and voice recognition have opened the door to a new category of connected devices with limited or no visual interaction, and fully driven by voice communication. These devices are already deployed in hospital environments, and allow for handsfree, two-way communications between nurses, doctors, and other healthcare providers. Combined with powerful AI-driven, personal assistant-type applications, they prove to be powerful tools empowering consumers and workforce. These devices also serve as communication enablers for people with disabilities.
- **Untethered health, fitness tracking devices (e.g., smartwatches):** Devices like smartwatches are already a growing market segment in the consumer connected devices space. This category will continue growing its presence in the health industry by allowing remote monitoring and management for telehealth use cases. These powerful connected devices are fitted with several sensors tracking movement, oxygen levels, blood pressure, blood sugar levels, and other vitals able to monitor patients outside of expensive hospital environments.
- **Specialized devices (IoT devices):** Specialized IoT devices are driven by very stringent requirements including cost and size. They are designed to perform rather limited functions, and can be embedded in products or be part of sophisticated solutions.
- **Industrial IoT devices:** Industrial IoT devices comprise a large group of devices such as actuators, connected cameras, and specialized robots which are used to track, monitor, and control industrial equipment or automate industrial processes.
- **Asset Tracker:** These devices will have different characteristics depending on their use case. In the consumer space, luggage tracking is currently a popular application for which a small, low-powered device is embedded in the suitcase and transmits its location on a regular basis. This requires global 4G/5G connectivity with roaming enabled, and a battery that provides weeks of autonomy on a single charge. In enterprise, equipment tracking devices provide inventory management within a campus, or for fleet management with much wider geographic coverage.
- **Meters/Sensors:** Popular in smart city use cases, these are relatively small and low bandwidth devices collecting data from existing infrastructure such as electric grid, water distribution network as well as environmental analytics including temperature, humidity, etc.
- **Inventory Tag:** Inventory tracking devices are commonly used in logistics, transportation and manufacturing, and help manage assets or warehouse inventory.

Table 4 in the appendix shows how different device types have different characteristics/requirements in addressing different use cases. Corresponding spectrum of 5G device use cases (eMBB, mMTC-RedCap, mMTC-ambient IoT) were shown in the bottom of Table 4.

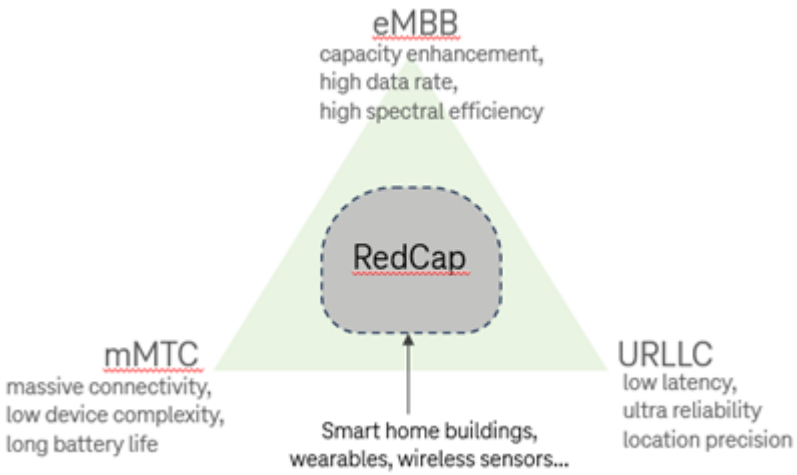
Reduced Capability Devices

When 5G New Radio (NR) technology was first defined in the 3GPP Release 15 specifications, the focus was mainly on enhanced Mobile Broadband (eMBB) application as per the ITU-2020 vision. One of the most significant developments for 5G has been the wide adoption of eMBB devices (e.g., smartphones, mobile hotspots, and home internet wireless access). The industry is also aware of the lack of specifications for the low throughput, low cost, and low battery consumption 5G applications. 3GPP defined the Reduced Capabilities (RedCap) specifications in Rel-17. RedCap has defined a new set of features allowing reduced radio technology support for such applications. The newly defined RedCap specification would enable a new device capability of up to 150 Mbps downlink peak throughput and 50 Mbps uplink peak throughput.

RedCap devices cater to use cases that are different from the three key 5G usage scenarios (eMBB, mMTC, and Ultra-reliable and low latency communications [URLLC]), as explained in Figure 1. RedCap addresses those middle-zone usage scenarios which do not require as high data rate as eMBB. The latency requirement is less stringent than the URLLC, while focusing on battery life extension and the scalability in connectivity without the intention to satisfying mMTC requirements. Because of the more relaxed requirements, the advantage of RedCap is that it provides an optimal solution for those middle-zone usage scenarios with minimal overlapping with core use cases for eMBB/URLLC/mMTC.

One major difference between eMBB and RedCap is the peak data rate, which is closely associated with the spectrum bandwidth, and ultimately leads to the difference in devices' complexity and cost. The maximum transmit/receive bandwidth in FR1 for eMBB is 100MHz, whereas RedCap devices cannot support transmit/receive bandwidth larger than 20MHz per Rel-17 specification. Additionally, eMBB can achieve higher data rate (in both download and upload) by combining multiple carriers via carrier aggregation (CA), which is not supported in RedCap. In general, eMBB use cases target peak data rate up to 20 Gbps in the Download while RedCap use cases are up to 150 Mbps in the download[1]. Because of the reduction in bandwidth support in RedCap devices and simplifications of other functionalities (such as number of antenna branches, modulation scheme and Multiple Input, Multiple Output layers supported), modem complexity is expected to be reduced resulting lower device cost for RedCap compared to eMBB. RedCap offers a path to expand 5G devices beyond smartphones/ eMBB, and extends into broadband IoT which has been served by the LTE Cat1-4 (that typically serves the mid-range segment of peak rate use cases), and supports larger data volume than Cat-M/NB-IoT.

Figure 1: RedCap address the middle-zone uses cases that cannot be best served or categorized as eMBB, URLLC, and mMTC



Many papers mention that RedCap (with relaxed requirements, reduced complexity/cost, and longer battery life) offers an exciting opportunity to expanding 5G NR ecosystem to cater use cases that currently cannot be served well by 3GPP Rel-15 and 16 specifications[2]. I is important to expand beyond smartphones efficiently with minimum impact to the network. For instance, if a RedCap device is being used for data intensive applications (such as streaming) with relaxed receiver requirements (e.g., 1 receiver instead of 4), it can decrease the network capacity which leads to higher network costs, despite the reduced device cost. From a practical perspective, low-cost devices with low capability should reflectively be low data consumption devices.

A framework to guide the Industry in efficiently adopting RedCap devices without pushing the burden from devices to networks will be crucial for driving a successful RedCap ecosystem. From data rate and bandwidth perspective, it is expected that RedCap will have similar capabilities as LTE Cat-4 devices, as shown in Table 1. Therefore, it would be a natural path for RedCap developments to address similar use cases that LTE Cat-4 (down to Cat-1) intended to address (from the user experience perspective), such as smart home system, smart watches, health monitoring devices. On the other hand, low-cost mobile broadband access hubs or data intensive extended reality applications would not be good candidates for RedCap and would be better suited in user experience, performance, and network efficiency without adopting RedCap. It can be challenging to mandate certain "framework" for the industry and developers to follow. Instead, it would be ideal to have a consensus view from the early stages considering that unleashing the full potential of RedCap relies on adopting it correctly and efficiently.

Table 1: Comparison between LTE IoT devices and RedCap

Category of devices	Cat 4 (Rel 8)	Cat 1 (Rel 8)	Cat M1 (LTE-M)	NB-IoT (Rel 13)	REDCAP (FR1)
Downlink Peak Rate	150 Mbps	10 Mbps	~300 kbps	~30 kbps	150 Mbps
Uplink Peak Rate	50 Mbps	5 Mbps	~300 kbps	~60 kbps	50 Mbps
Duplex Mode	Full duplex	Full duplex	Half duplex	Half duplex	Flexible for FDD (TDD also supported)
Maximum UE Receive Bandwidth	20 MHz	20 MHz	1.4 MHz	200 kHz	20 MHz (5 MHz minimum)
Voice Support	Yes	Yes	Limited	No	Yes

5G RedCap use cases have considerable market potential, especially for the wearable market (wrist wear, footwear, eye wear, body wear, and neck wear). These products have applications in fitness and sports, infotainment, healthcare, defense, enterprise, and industrial. The wearable market is expected to grow by USD 23.03 billion from 2020 to 2025, progressing at a compounded annual growth rate of 6.70% according to a Technavio market report[3]. The market is driven by factors such as the emergence of Micro-ElectroMechanical Systems sensors, the popularity of connected devices and IoT, the growth of the technologically literate population, and the rising prevalence of chronic diseases and obesity. For industrial applications, RedCap services can provide robust wireless connectivity and seamless mobility support through 5G networks for industrial devices, which enables cost-efficient Industry 4.0 transformation.

Chipsets for RedCap have been announced and RedCap devices are expected to be launched by 1H 2024, with both 5G NR and LTE mode (i.e., RedCap devices are multi-mode devices). This aligns with the RedCap ecosystem projection shown in Table 2.

Table 2: RedCap development expected milestones.

RedCap chipset ecosystem	Early commercial RedCap devices	Mass market RedCap devices
Starting in 2023	2024	2025+

RedCap will continue to evolve to support lower throughput, lower costs, and lower power consumption. In 3GPP Rel-18 (on-going development), enhanced RedCap (eRedCap) is being developed to reduce the data bandwidth down to 5MHz. eRedCap reduces the peak throughput down to LTE Cat-1 equivalent or below.

5G native Redcap and eRedCap provide a migration path for use cases, currently addressed by LTE Cat 1 ~ Cat 4, within 5G standalone deployment. For Cat-M and NB-IoT as 5G low-power wide-area (LPWA) technologies, there are several implementation/development challenges such as sub carrier spacing, coexistence, etc. LPWA devices (e.g., keep alive trackers/sensors or fleet management systems) may continue operate in the existing EPC core yet as part of 5G solutions with potential path to connect to 5G in standalone deployment. In below the LPWA segment, 3GPP is defining a 5G native new technology segment - Ambient IoT.

Ambient IoT

Background

Ambient IoT: Ambient IoT (A-IoT) is a new device type/segment which operates only on energy harvested from the environment. It is considered inexpensive; small form factor devices consuming very low power take the lowest segment in IoT device categories—well below NB-IoT and eMTC in terms of cost, complexity, power, etc.

Why Ambient IoT: By design, an A-IoT does not require battery replacement. This reduces or removes the effort and potential cost for maintenance. A-IoT devices benefit in use cases (such as wireless sensors for factory, farming, buildings, bridges, etc.) where frequent human access is difficult or costly. The low cost of A-IoT can allow large numbers of devices to be connected to a network. For supply chain (including manufacturing, shipping, warehouse, etc.), A-IoT devices could be attached to products or assets for inventory and tracking. The low cost and small form factor combined with no battery replacement makes the device appropriate for such use cases.

Use cases: 3GPP has identified more than 30 use cases in the following four categories: inventory, sensor, positioning, and command as shown in Table 3[4].

Table 3: Use cases identified in 3GPP SA1 study.

Inventory	smart labeling/identification in warehouse, supply chain, airport shipping, manufacturing, logistics, retail, etc.
Sensor	environment sensing in smart farm, smart city, smart home, smart grid, etc.
Positioning	location tracking and ranging in indoor/outdoor for assets, products, personal item tracking, etc.
Command	actuator, device activation/deactivation, electronic labeling, etc.

Market: A-IoT is a new business opportunity for operators, device manufacturers, and data analytics companies. The small form factor, low cost, and low intervention will enable a massive number of objects to be connected to a network, which will allow data collection, tracing, controlling, and more. According to Global System for Mobile Communications Association, low-cost IoT support is the second most important feature for network transformation5. The market size for whole cellular IoT keeps growing and is expected to grow to $25B by year 20306. The global Radio Frequency Identification (RFID) market size is expected to reach $22B by 20307.

Similar types of devices (RFID, Bluetooth): In the current market, there are already low-cost self-powered IoT devices like RFID, which is widely used for automatic identification in manufacturing, warehousing, supply chain, and retail.

Standard activities: 3GPP, IEEE, and Bluetooth started seeing the potential of low cost, low complexity, and battery-less devices, and started studying the feasibility of such types of devices in their ecosystem[8910 11].

Key Enabling Technologies

Energy harvesting is the key enabling technique for ambient IoT. Multiple energy sources including RF signal, solar, vibration, and thermal are available, but differ in terms of availability and energy density. RF signal with low energy density requires longer charging time, but it is directly controllable by a wireless network. RF signal as an energy source has a direct implication on system design and operation for ambient IoT. It should be designed such that the 5G system provides both communication and energy signals to support an ambient IoT device. Other types of energy can be harvested opportunistically depending on availability. Harvesting could be implemented with minimal impact on the 5G system design. Energy harvesting can be done by RF-Direct Current converter, photovoltaic cells, thermoelectric devices, or piezoelectric harvesters. The energy could be stored in capacitor, and size would depend on the device type.

Backscattering with active signal generation is one of the communication techniques considered to achieve low power operation of ambient IoT devices. Backscattering is a widely used technique in RFID, which allows a device to communicate with a network by simply reflecting the incident waves after modulating it with information to be carried. The device can be powered by incident RF signal or stored energy. Since the communication signal is generated without an active RF component, power consumption could be very low, but coverage is typically limited due to the nature of reflection. On the other hand, the active signal generation method uses traditional active RF component to generate signals. Because the signal is generated in an active manner, it has benefits for coverage and more complex operations that increase the chance of leveraging the existing functionality of 5G networks.

Radio Access Networks and Ambient IoT

Device type categorization: Ambient IoT devices are categorized into different device types including passive, semi-passive, and active depending on energy storage and transmission signal generation method. Passive devices do not have energy storage (e.g., capacitor) and communicate based on backscattering communication technique. Semi-passive devices have energy storage and communicate with backscattering communication techniques potentially aided by energy storage. Active devices have energy storage and communicate by actively generating a signal using an active RF component and its energy stored. Table 5 in the appendix summarizes the device characterization and metrics with qualitative comparisons.

Topologies: Following basic topologies can be considered to support A-IoT devices in indoor and outdoor scenarios (gNB to A-IoT device direct connection, gNB to intermediate node to A-IoT device connection, and connection assisted by assisting node). Figure 2 in the appendix illustrates these topologies.

Security/Privacy: Supporting security and privacy is a challenge in ambient IoT devices due to their low complexity and cost. Providing a secure tunnel between A-IoT and the system would be necessary, especially when A-IoT device is connected through intermediate node

System Challenges and Role of Operator

The overarching issue is finding the appropriate level of awareness of individual A-IoT devices by 5GS. This not only determines the need for and level of potential network infrastructure investments, but also directly impacts the complexity of IT processes (e.g., for subscription management or handling of a potentially large amount of charging records). Given that the average revenue per A-IoT device can be expected to be rather small, it is essential to find an appropriate balance to enable operators to monetize support for A-IoT scenarios. On the other hand, it also essential to limit system changes and impacts to IT processes so that ambient IoT support can become a viable business model for operators.

The following system challenges need to be addressed:

- **Subscription management:** The number of A-IoT devices are expected to be very large in certain use cases, like inventory. As a result, a key issue is to decide whether to store a subscription for each A-IoT device in 5GS, or find alternative approaches for relieving individual mobile network operators from the burden of creating and managing individual subscriptions for each A-IoT device.
- **Authentication and authorization:** It is crucial to address where to perform authentication and authorization with

subscription management. Specifically, if 5GS will need to authenticate and authorize individual tags or—based on agreements with the operator—if authentication and authorization can be performed by 3rd parties (e.g., external authentication as supported by 5GS).

- **Association between A-IoT devices and networks:** A-IoT devices could be associated with a network either by the device's network selection procedures or by the device's response to queries from different networks without prior selection of one of those networks.
- **Registration management:** For passive and semi-passive type devices, it appears challenging to support complex multi-step registration procedures as performed by traditional 3GPP UEs due to its low complexity and limited power.
- **Reachability management:** Existing 3GPP networks keep track of UEs so the network always knows the area to page a UE in case downlink data or signaling needs to be delivered. For ambient IoT devices, the challenge is to determine which reader a particular A-IoT device can be reached. The complexity of this determination depends on the use case and deployment scenario. Although this is a minor issue for inventory use cases in indoor scenarios, it may require a different approach to enable finding mobile A-IoT devices in outdoor scenarios (e.g., to read sensor data from the device).
- **Connection management:** It is crucial to determine how to provide connection between A-IoT and end users. One option is setting up an end-to-end session between an A-IoT device and a user-plane function to enable a 3rd party to communicate with the A-IoT device. Alternatively, 5GS control plane could provide API-based services for interactions with A-IoT devices without the need for any data session to a user-plane function.

Conclusion

We reviewed diverse types of 5G devices from existing smart phone to RedCap and emerging battery-less ambient IoT devices.

Firstly, based on various aspects of 5G devices such as mobility, bandwidth, cost, battery life, etc., 5G devices were categorized into general-purpose and specialized IoT devices, where the latter case refers to devices optimized for IoT use cases with lower complexity and cost in general.

Secondly, the evolution of 5G devices from eMBB to RedCap as then discussed. RedCap typically addresses the use cases that previously LTE Cat-4 (down to Cat-1) was intended for. We explained how RedCap has been developed and how critical it is for RedCap to be adopted smartly without shifting burden from devices to networks.

Lastly, emerging battery-less ambient IoT device was introduced which targets even lower complexity and cost. Target use cases, standard activities, enabling technologies, and many open issues and challenges in radio and system design aspects were discussed.

In conclusion, the new use cases and business opportunities have driven 5G device evolution from smart phone to IoT, XR, or even new device types. It is expected that current 5G devices will continue to evolve aiming to improve energy efficiency, form factor, cost, coverage, etc to better address current and emerging use cases.

Appendix

Table 4: Characteristics/Requirements for different types of 5G devices

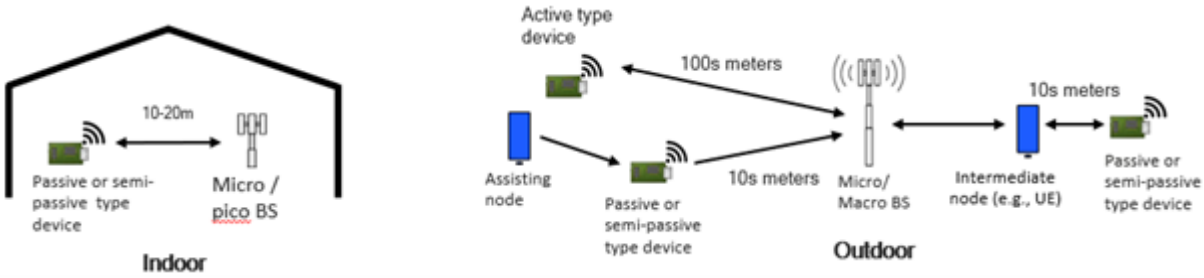
	General-purpose device				Specialized device IoT			
	Smart phones	eXtended Reality Glasses (AR/VR)	Health Tracking/ smart watch	Voice Enabled	Industrial IoT device, e.g., actuator	Asset tracker	Meter/ Sensors	Inventory tag
Mobility	Broad	Broad	Broad	Broad	Limited/ Stationary	Limited/ Stationary	Limited/ Stationary	Limited/ Stationary
Bandwidth	100s MHz	≤100MHz	≤100MHz	≤20MHz	≤20MHz	≤20 or (typically 5 MHz*)	≤20 or (typically 5 MHz*)	<1MHz
Form factor	Palm size	Glasses or Head Mount Display	Watch size	Credit card size	Credit card size	Stamp to credit card size	Stamp to credit card size	Stamp size
Accessibility/ Maintainability	High	High	High	High	High	High	Low	High
Reliability	Medium	Medium	Medium	Medium	Higher/ Medium	Medium	Medium	Lower
Cost	$$$	$$$	< $$$	$$	< $$	$	$	<$
Security	Strong	Strong	Strong	Strong	Limited ~ Strong	Limited ~ Strong	Limited ~ Strong	Limited
Coverage (w.r.t cell size)	Full	Full	Full	Full	Full	Full/Partial	Full/Partial	Partial
Battery life	1 day Battery	< 1 day Battery	1 day Battery	A few days (or plugged in)	Years (or plugged in)	<Months (or no limit with energy harvesting)	Years (or no limit with energy harvesting)	No limit (with energy harvesting)
Optimized 5G device use case	eMBB	eMBB	eMBB	eMBB	eMBB/ URLLC	eMBB		
		mMTC-RedCap	mMTC-RedCap	mMTC-RedCap	mMTC-RedCap	mMTC-RedCap or eRedCap	mMTC-RedCap or eRedCap	
						mMTC-Ambient IoT	mMTC-Ambient IoT	mMTC-Ambient IoT

*Some use cases could be addressed even lower bandwidth, e.g., 3 MHz.

Table 5: Device type comparison[12]

Device type	Device characterization			Performance metrics			Potential use cases
	Energy storage	Communication technique	Complexity	Coverage (meter)	Cost ($)	Power consumption	
Passive	No	Back-scattering	Low	Small (<10)	Low (<0.1)	Low (<10 uW)	indoor inventory
Semi-passive	Yes	Back-scattering	Medium	Medium (10s)	Medium (~0.10s)	Medium (<1mW)	Indoor/outdoor sensors, inventory
Active	Yes	Active signal generation	High	Large (100s)	High (<1)	High (<=1s mW)	Outdoor sensors/ tracking

Figure 2: Basic topologies to support ambient IoT device for indoor and outdoor scenarios



Acronyms

3GPP: Third Generation Partnership

5GS: 5th Generation System

CA: Carrier aggregation

eMBB: Enhanced Mobile BroadBand

eRedCap: Enhanced Reduced Capability

IoT: Internet of Things

LPWA: Low-power wide-area

LTE: Long Term Evolution

mMTC: massive Machine Type Communication

NB-IoT: Narrow Band Internet of Things

NR: New Radio

RedCap: Reduced Capability

RF: Radio Frequency

RFID: Radio Frequency Identification

URLLC: Ultra-reliable and low latency communications

Acknowledgments

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References

1 Ericsson White Paper, RedCap – expanding the 5G device ecosystem for consumer and industries, pg. 6, Feb 2023.

2 Qualcomm OnQ Blog, 5G NR-Light (RedCap): Revolutionizing IoT, Kiran Mukkavilli, Jul 18, 2022.

3 Wearables Market Size to grow by USD 23.03 billion by 2025, Driven by Growing Preference for Wearables Devices – Technavio, Aug 2022.

4 3GPP 22.840 Study on Ambient power-enabled Internet of Things

5 GSMA Intelligence Operators in Focus: Network Transformation Survey 2022

6 Cellular IoT Module Market Insight: Q1 2023, Counterpoint

7 https://www.vantagemarketresearch.com/industry-report/rfid-tags-market-1666

8 22.840 Study on Ambient power-enabled Internet of Things

9 38.848 Study on Ambient IoT (Internet of Things) in RAN

10 IEEE 802.11-23/0436r0, "Technical Report on support of AMP IoT devices in WLAN", March 2023.

11 https://www.bluetooth.com/2023-market-update/

12 38.848 Study on Ambient IoT (Internet of Things) in RAN