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HEAVY READING WHITE PAPER

Scaling 5G IoT with NR-Light

A Heavy Reading white paper produced for Qualcomm

Qualcomm

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SCALING 5G IOT

5G is designed to support diverse services on a common network platform. Two key objectives beyond delivering enhanced mobile broadband are to enable connected industries using machine communications and to support new Internet of Things (IoT) applications.

5G IoT to date has focused on low complexity devices, such as asset trackers, and on high performance applications, such as control of industrial equipment. There is also, however, a clear need to address mid-tier devices, such as wearables, health monitors, vehicle trackers, voice assistants, and industrial sensors. This mid-tier IoT market requires a 5G-native solution that can take advantage of new 5G system capabilities and is future-proofed as the industry migrates from 4G to 5G networks. Mid-tier 5G IoT has diverse applications in connected industries and consumer services. In the broadest sense, it will serve as a tool to instrument the physical world and digitalize workflows.

The industry solution for mid-tier 5G IoT connectivity is 5G NR-Light, also known as RedCap for "reduced capability" devices. Introduced in 3GPP Release 17, NR-Light bridges the capability and complexity gap between the high and low performance IoT solutions available in 5G today. NR-Light devices connect to 5G standalone (SA) networks and can run in all 5G frequency allocations alongside other service types in the same network.

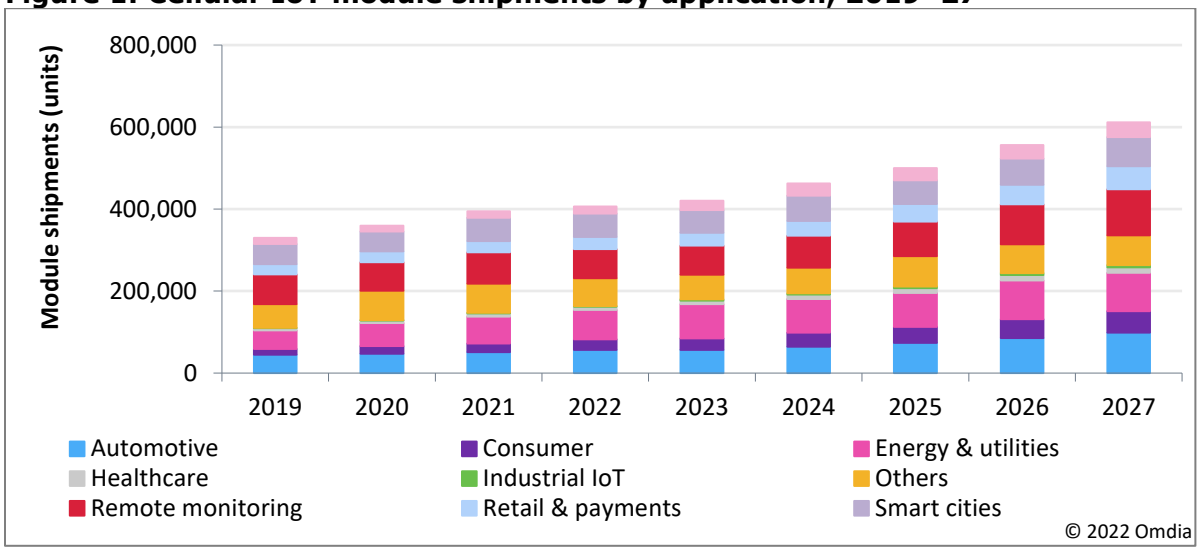
This white paper investigates progress in NR-Light standardization, discusses the critical technologies and device capabilities, and positions mid-tier IoT in the wider 5G ecosystem. Heavy Reading believes this technology can scale rapidly and will contribute to making 5G a technology platform on which diverse industries and customers can innovate.

5G IoT market context

Omdia's *Cellular IoT Market Tracker* counts over 2 billion active cellular IoT devices (versus ~6 billion phones). **Figure 1** below forecasts module unit shipments through to 2027 by application type. With 400,000 modules expected to ship in 2022 and strong growth through the forecast period, the overall base of active cellular IoT devices will more than double over the next few years. Moreover, this is broad-based growth across diverse application categories; for example, CAGRs for 2021–27 are in the range of 25% for industrial IoT, 16% for consumer, and 12% for automotive.

In 4G LTE, this market is made up primarily of narrowband IoT (NB-IoT) and enhanced machine-type communication (eMTC; a.k.a. Cat-M), which account for just over half the market (NB-IoT volumes are especially high in China). Cat-1–4 devices make up much of the remaining half. 5G is currently a very small part of the cellular IoT market but is set to scale in the coming years.

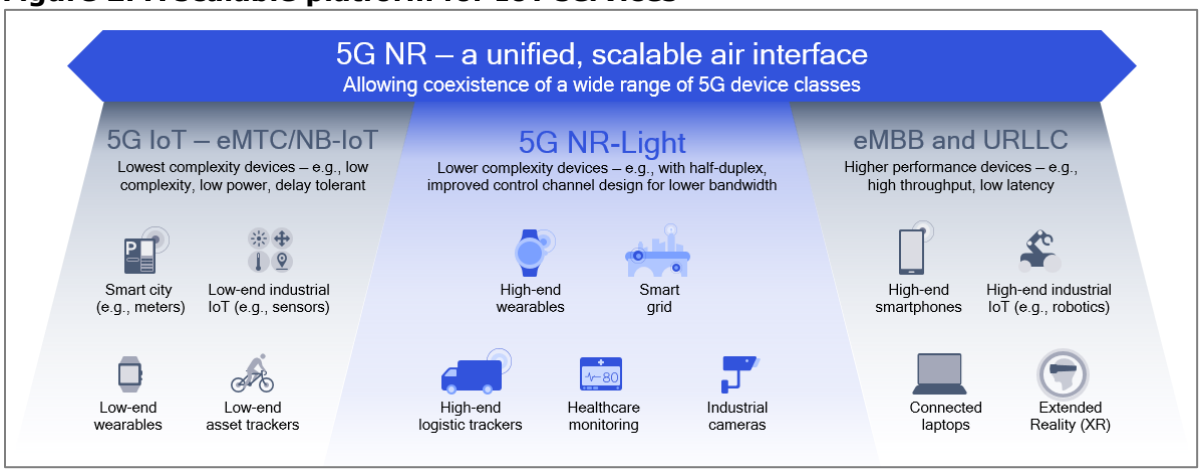
Figure 1: Cellular IoT module shipments by application, 2019–27



Source: Omdia, Cellular IoT Market Tracker – 1H22 Analysis

5G is designed to serve a full range of IoT use cases, as shown in **Figure 2**. The left of the chart shows low complexity devices. In 3GPP Release 16, NB-IoT and eMTC were enhanced to operate in-band alongside 5G NR and now qualify as 5G technologies when connected to a 5G core. To the right are high end devices enabled by 5G. Today, these are based on chipsets used in smartphones. In the future, this segment will support advanced capabilities such as ultra-reliable low latency communication (URLLC) and time-sensitive networking (TSN) for services such as high performance industrial IoT applications. NR-Light sits between these two ends of the scale.

Figure 2: A scalable platform for IoT services



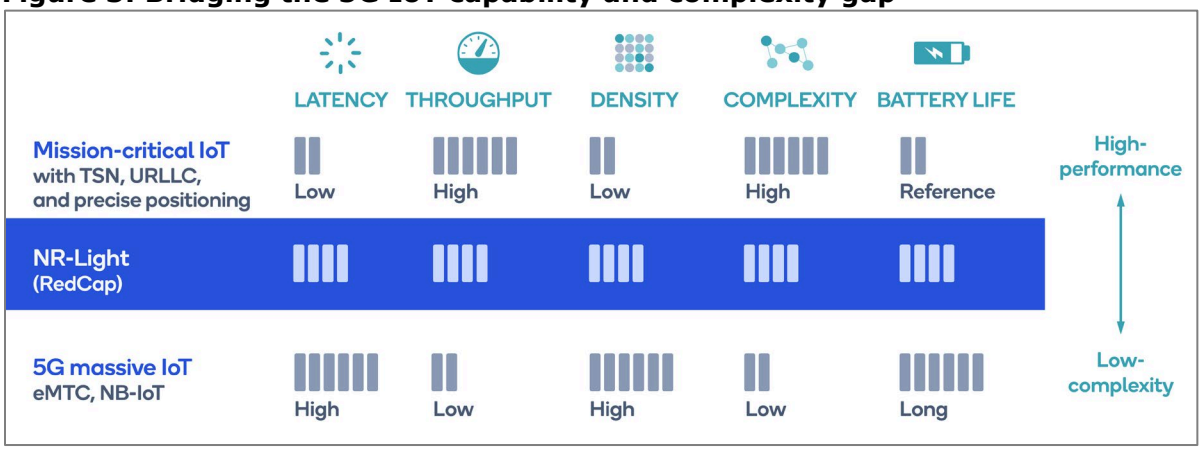
Source: Qualcomm

NR-Light technology is standardized in 3GPP Release 17. Development has been accelerated to meet the needs of connected industries, to enable a faster transition to 5G from LTE, and to enable direct to 5G IoT in public and private networks. At the time of writing, Heavy Reading expects the first 5G NR-Light hardware modules to be offered as a generally available product in late 2023 or the first half of 2024.

OPPORTUNITY FOR NR-LIGHT

The justification for work on NR-Light—to enable connected industries, wearables, and smart cities—is discussed in 3GPP document RP-202933 (December 2020). This document discusses various use cases, which are mapped to performance requirements. And these requirements generate the NR-Light technical characteristics shown in **Figure 3**.

Figure 3: Bridging the 5G IoT capability and complexity gap



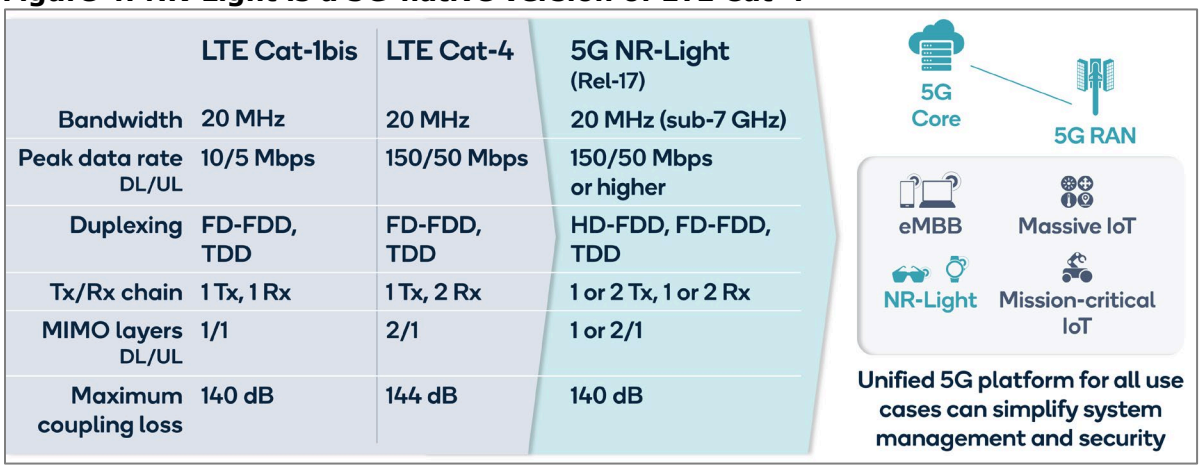
Source: Qualcomm

In terms of devices and associated services, NR-Light is very flexible. Typically, IoT connectivity is delivered as a plug-in module that is integrated by the device maker to create the end product. NR-Light devices suggested by industry participants include environmental sensors (pressure, humidity, thermometers, etc.), motion sensors, accelerometers, actuators, smart watches, cameras, wearables, health monitors, vehicle trackers, voice assistants, smart doorbells, video surveillance devices, and many more.

In its initial form, NR-Light will be suited to devices currently served by LTE Cat-4. Over time, as the technology is optimized, NR-Light will also address use cases served by LTE Cat-1bis. LTE Cat-4 is typically used in IoT applications that require relatively high throughput, such as video surveillance cameras. Cat-1bis is typically used for voice and mobile IoT applications and offers a migration path for 2G and 3G applications. LTE Cat-1bis and LTE Cat-4 can both operate on standard LTE networks and do not require network upgrades. NR-Light will continue this cellular IoT evolution path.

Figure 4 shows that the operating parameters (channel width, numbers of antennas) and performance attributes are similar between LTE Cat1bis, LTE Cat-4, and NR-Light.

Figure 4: NR-Light is a 5G-native version of LTE Cat-4



Source: Qualcomm

One strategic question for NR-Light is the extent to which it can extend into the lower end and higher end of 5G IoT. At high volumes, NR-Light could offer a power-efficient, 5G-native alternative to NB-IoT and eMTC that is reasonably cost competitive, far more capable, and future-proof. Toward the higher end, by offering a low cost solution capable of more advanced 5G services (with good enough latency, bandwidth, and positioning), NR-Light could be used in more sophisticated, high value applications. This extension of NR-Light is speculation for now and will depend on many factors, but there is potential for it to become the dominant 5G IoT technology over the longer term.

5G-native cellular IoT

Many cellular IoT use cases can be handled by Cat-1bis and Cat-4 or by NB-IoT and eMTC. Nevertheless, there are compelling reasons why a 5G-native IoT solution is needed. These include the following:

- **5G needs IoT support to become a true platform technology:** In public and private networks, a large part of the investment case for 5G is about connected devices and machine communications; yet, today, the market is dominated by smartphones. 5G-native IoT solutions will expand the market for 5G and enable 5G networks to support diverse consumer and industrial IoT use cases.
- **A long-term migration path for Cat-1bis and Cat-4 services currently operating in LTE networks:** This is important to operators seeking to refarm 2G/3G and 4G spectrum for 5G because to do this most effectively, they may also need to migrate existing services. Spectrum refarming is a long-term project for most operators but one with very significant benefits.
- **To support direct to 5G deployments:** Many organizations will want to deploy IoT directly on 5G to future-proof the investment and service lifecycle. These customers will be able to take advantage of the massive global investment in 5G technology and rapidly expanding wide-area network coverage. As a 5G-native IoT platform, NR-Light will continue to evolve beyond Release 17.

- **5G brings value to IoT:** 5G system capabilities (e.g., scalable numerology, beamforming, positioning, service exposure, QoS, slicing, energy efficiency, etc.) can be used to enable better, more efficient IoT services. 5G supports the full coexistence of NR-Light with other services, such as mobile broadband or time-critical communications, in the same network deployment.

NR-LIGHT STANDARDS AND TECHNOLOGY

NR-Light specifications have been in development by the 3GPP for some time. The 3GPP "Study on support of reduced capability NR devices" was issued as Technical Report (TR) 38.875 in March 2021. At the 3GPP Technical Steering Group (TSG) meeting in June 2022 (TSG#96), RedCap was confirmed as part of 5G Release 17. This marks the formal release of specifications that will underpin NR-Light.

NR-Light system overview

NR-Light is a 5G RAN technology that connects to a standard 5G core network. It is a 5G-native technology that can only be used in 5G SA networks. An overview of the NR-Light system is shown in **Figure 5**.

Figure 5: NR-Light system overview

	FR1		FR2	
	Baseline	NR-Light	Baseline	NR-Light
Maximum device bandwidth	100MHz	20MHz	200MHz	100MHz
Number of receive antennas	2 or 4 depending on frequency	1 for bands where baseline device has 2 antennas 2 for bands baseline device has 4 antennas	2	1
Maximum number of downlink MIMO layers	2 or 4 depending on frequency	1 or 2 according to number of receive antennas	2	1
Maximum downlink modulation	256QAM	64QAM mandatory 256QAM optional	64QAM	64QAM
Duplex operation	FD-FDD	HD-FDD, FD-FDD, TDD	TDD	TDD

Source: Ericsson, Qualcomm, Heavy Reading

The key features are focused on flexibility and performance while reducing complexity and power consumption, as follows:

- **NR-Light frequencies:** NR-Light works in all sub-7GHz (FR1) and mmWave (FR2) 5G spectrum bands specified by 3GPP. This makes it very flexible. It is the first low power cellular IoT system optimized for mmWave (which may have particular use in, for example, industrial settings). Current 2G/3G/4G IoT devices tend to work in FDD spectrum (although TDD is now specified for NB-IoT and eMTC, there are few deployments). NR-Light is specified for TDD and FDD from the start.
- **Channel bandwidth:** In sub-7GHz spectrum, NR-Light devices can operate in a maximum of 20MHz of spectrum (vs. 100MHz for a smartphone). This reduces RF frontend costs and enables greater power efficiency. Although this comes at the expense of throughput, 20MHz bandwidth is more than sufficient for most NR-Light use cases. In the future, 3GPP Release 18 will introduce a peak data rate option of 10Mbps using just 5MHz for the downlink and uplink data channels (but will retain the 20MHz channel for signaling to ensure backward combability). In FR2 spectrum, rather than a 200MHz channel width, NR-Light is limited to 100MHz.
- **Device antennas and MIMO layers:** To reduce cost and device size, NR-Light devices will be limited to two antennas. In many cases, they may use only one antenna; this limits the number of MIMO layers and receiver performance, which in turn impacts throughput and link budget. There are several techniques emerging that can enhance the performance of single-antenna devices that will help counteract some of these limitations.
- **Modulation scheme:** 256QAM has become commonplace in 5G mobile systems. In NR-Light, 64QAM modulation is mandatory (lower modulation reduces the processing requirements of the device and allows it to operate in poorer channel conditions). 256QAM is optional to implement and can be useful where higher throughput is required and where channel conditions are good.
- **Duplex operation:** Current cellular IoT solutions use full duplex FDD. NR-Light may also use half-duplex FDD to enable smaller, simpler devices. Without the need for duplex filters, manufacturers can include more bands in a device (increasing volumes and reducing product variants and logistics costs). There is also an opportunity for greater RF silicon integration relative to full duplex FDD devices, which could result in significant cost reduction over time.

Reduced cost and complexity

The NR-Light system is designed to reduce the cost and power consumption of IoT connectivity. For context, LTE Cat-1bis and LTE Cat-4 modules are widely advertised for between $30 and $50 on part distributors' websites for low volume purchases.

3GPP document TR 38.875 estimates cost reductions for devices employing one or more of the device complexity reduction techniques summarized in **Figure 5** relative to a reference NR device with high end features (multiband, multi-antenna, etc.). The results vary between TDD and FDD and between FR1 and FR2, according to the technique in question, but the reductions are substantial. For example, in FDD FR1, using 20MHz instead of 100MHz generates a saving of 33%, whereas using a single receive antenna generates a 58% cost/complexity reduction. For more details, see TR 38.875, Table 7.8.2-1 for FR1 FDD, Table 7.8.2-2 for FR1 TDD, and Table 7.8.2-3 for FR2.

Relative to a 5G smartphone connectivity module, the amount of cost and complexity reductions achievable in an IoT module is dependent on many other factors that will change over time. For example, NR-Light may use newer semiconductor manufacturing nodes or processes than earlier LTE Cat-4 chips to offer lower power consumption and a reduced physical footprint.

Power efficiency for NR-Light devices

For battery-powered devices, power consumption is critical, especially where devices are deployed in hard-to-access locations for long periods. Reducing the number of antennas and associated RF chains has the biggest impact on power use and is a key reason why single-antenna solutions are likely to be popular. However, there are several other optimizations that, in combination, will enable further substantial reductions in power consumption. These are summarized in **Figure 6**.

- Using extended discontinuous reception (eDRX), the idle period over which devices do not need to monitor paging, is extended to almost three hours. This deep sleep phase is very power efficient relative to the tens of seconds typical in smartphones.
- Static devices (e.g., utility meters) and infrequently nomadic devices (e.g., environmental sensors) need only to monitor the RAN for mobility-related signaling updates very occasionally.
- A host of other power-saving features are also included in 5G NR that can be used in NR-Light as needed according to the application or device characteristics.

Figure 6: Release 17 power-saving features for 5G NR-Light

Source: Qualcomm

Coverage and reliability without network modifications

A consequence of reduced cost, complexity, and energy consumption is a reduction in receiver and uplink performance. All things being equal, these compromises result in reduced coverage and reliability. How severe this challenge is in practice depends on the application; low bit rate, non-critical services can tolerate a poorer signal relative to services with greater reliability requirements.

The critical question is: Does the operator have to make network changes to compensate—for example, by increasing site density? The simple answer is "no"; NR-Light should work on a network deployed for mobile broadband without modification. Techniques such as transport block combining and frequency hopping within the channel (e.g., across the 20MHz specified for FR1) or the ability to resend uplink communications up to 32 times, as shown in **Figure 7**, help to address these challenges.

Figure 7: Coverage optimizations for reduced capability devices

Downlink coverage	Uplink coverage
• Transport block size (TBS) scaling • Lower modulation and coding scheme (MCS) • Higher control channel element (CCE) aggregation level	• Enhancement for uplink data channel repetition (up to 32) • Transport block processing over multi-slot uplink channel • Inter-slot frequency hopping and repetition • Dynamic indication of uplink control channel repetition • Enhancement of channel estimation with demodulation reference channel (DMRS) bundling

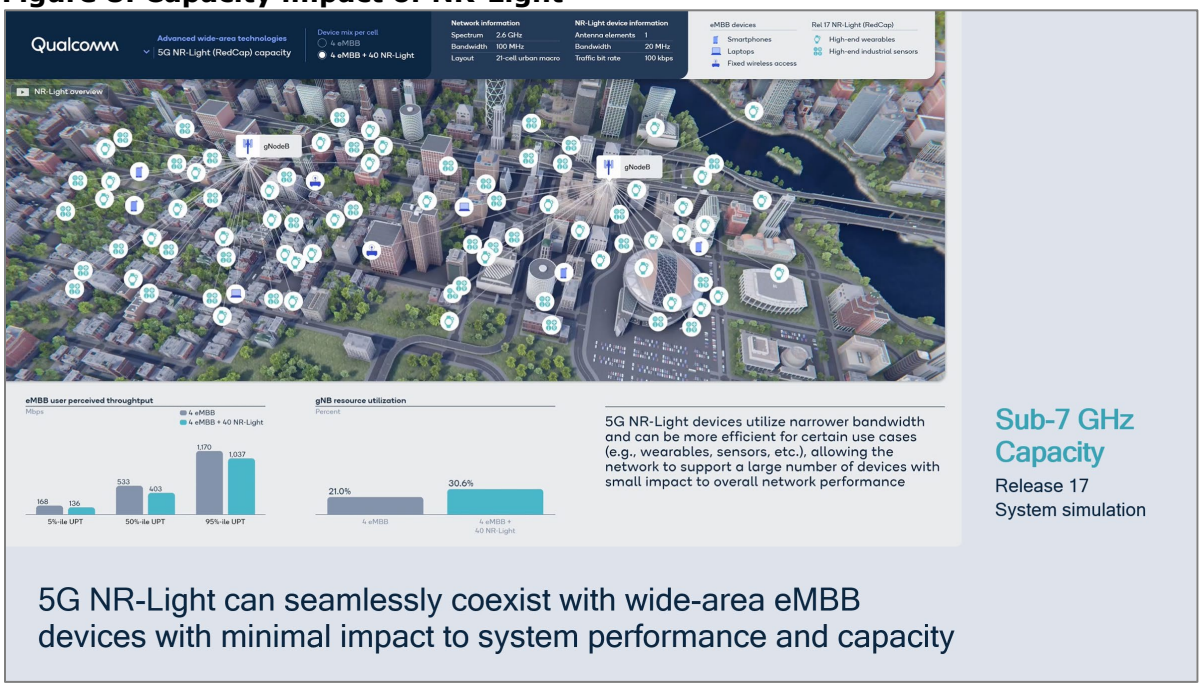
Source: Qualcomm

Coexistence with wide-area mobile broadband 5G network

NR-Light can be deployed in any spectrum specified by 3GPP for 5G and be served by the same network equipment with no, or minimal, modification alongside other services (e.g., smartphones, connected cars, or fixed wireless). 5G NR-Light devices are identified by the RAN and core network during the session setup, allowing the network to potentially apply charging differentiation, support specialized policies, or place IoT services into discrete network slices. This ability to deploy onto existing 5G networks will allow rapid scaling of NR-Light services in line with 5G RAN coverage.

An important question is: How does NR-Light affect network capacity and performance for other services, particularly where there is a high density of devices in the coverage area? **Figure 8** shows a simulation where NR-Light has only a small impact on the mobile broadband user experience. In this simulated scenario, a 21-site macro cell cluster is deployed for eMBB in 100MHz of 2.6GHz spectrum, with each cell loaded with 4 active eMBB devices and 40 NR-Light devices. The simulation shows barely any impact on eMBB performance (at the 95th percentile, users get 1Gbps downlink with and without NR-Light active) and only a small impact on capacity utilization, which rises from 21% for eMBB-only to 31% when the 40 NR-Light devices are also active.

Figure 8: Capacity impact of NR-Light



Source: Qualcomm

NR-Light requires 5G SA (and other challenges)

There are a number of challenges to the widespread adoption of NR-Light. These are generally related to the maturity of 5G technology and network deployments and therefore should be alleviated over time. The key challenges in the early phases include the following:

- LTE Cat1bis and Cat-4 already serve the mid-tier IoT market. There are additional features NR-Light can offer, but in the main, LTE is a good solution and benefits from a rapidly maturing device and module ecosystem.
- NR-Light requires a 5G SA network, which in turn depends on a 5G RAN with excellent coverage and a 5G core. This infrastructure is being deployed in many markets, but it will take some years for 5G to achieve equivalent geographic coverage to LTE. 5G core networks are in deployment, but again, they will take time to mature and scale.

- NR-Light silicon, modules, and devices are not commercially available. When they are, it will take some years for the ecosystem to mature and offer the range of device types and distribution as is currently the case with LTE.
- NR-Light is designed for battery-powered devices, but there are several further optimizations that will extend battery life considerably. For certain device categories, such as consumer wearables such as smart watches, these further optimizations are probably required.

EVOLUTION OF NR-LIGHT

3GPP Release 17 is the foundation release for NR-Light. However, work to improve and further optimize the technology, known as enhanced RedCap (eRedCap), is underway in 5G Advanced—i.e., in Release 18 and (probably) beyond. This ongoing work underlines how strategic NR-Light is to machine communications in 5G networks.

Some of the key areas being addressed are as follows:

- **Enhanced power savings:** A target for NR-Light is to support a battery life of multiple days—and perhaps as much as one to two weeks for wearables and several years for certain industrial sensor devices. This will require optimization across all areas of the technology stack and will be a constant focus of ongoing specification work and product development.
- **Accurate network positioning:** This is a useful feature for many IoT use cases and much in demand for industrial IoT in particular. Release 18 will likely set performance requirements for location accuracy and time to fix and identify potential further enhancements for Release 18+.
- **Sidelink:** This topology can be useful to extend network coverage, enhance resiliency, and save power. Release 18 is working to support unlicensed spectrum operations for sidelink, including for NR-Light devices. It could be useful, for example, to employ NR-Light to connect lightweight XR headset devices to a smartphone or hub for network connectivity. In time, sidelink could extend to multi-hop communications enabling new use cases.
- **Flexible bandwidth:** NR-Light is currently specified to use 20MHz of spectrum in FR1, which is a "sweet spot." In Release 18, eRedCap will move to a flexible bandwidth model that includes a 10Mbps peak data rate option optimized for power consumption. This will maintain support for a 20MHz for RF frontend (to allow reuse of broadcast signals from earlier releases) but will introduce a reduced bandwidth of 5MHz for downlink and uplink data channels.

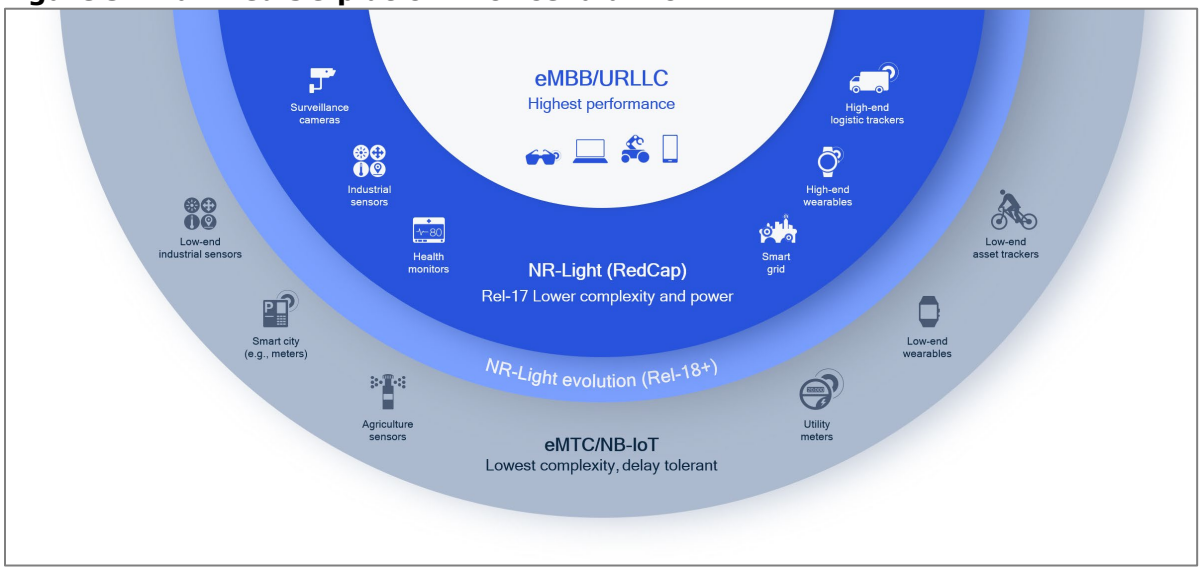
CONCLUSION: A UNIFIED PLATFORM FOR 5G IOT

NR-Light is a 5G-native IoT solution optimized for mid-tier devices. The technology can run in all 5G frequency allocations alongside other service types in the same network. The first 3GPP specifications are available, and product development is underway.

Mid-tier 5G IoT has many diverse and useful applications in connected industries and consumer services. There is an industry need for NR-Light to maximize the value of 5G networks, enable customers to evolve IoT over the long term, and bring new 5G network capabilities to IoT services.

NR-Light is part of a wider 5G capability to support IoT. **Figure 9** shows how the 5G system offers a unified air interface and network platform capable of supporting diverse IoT application types, from mission-critical services through to low complexity, delay-tolerant services. NR-Light helps complete the picture and has the potential to serve the broadest number of cellular IoT use cases.

Figure 9: A unified 5G platform for cellular IoT



Source: Qualcomm