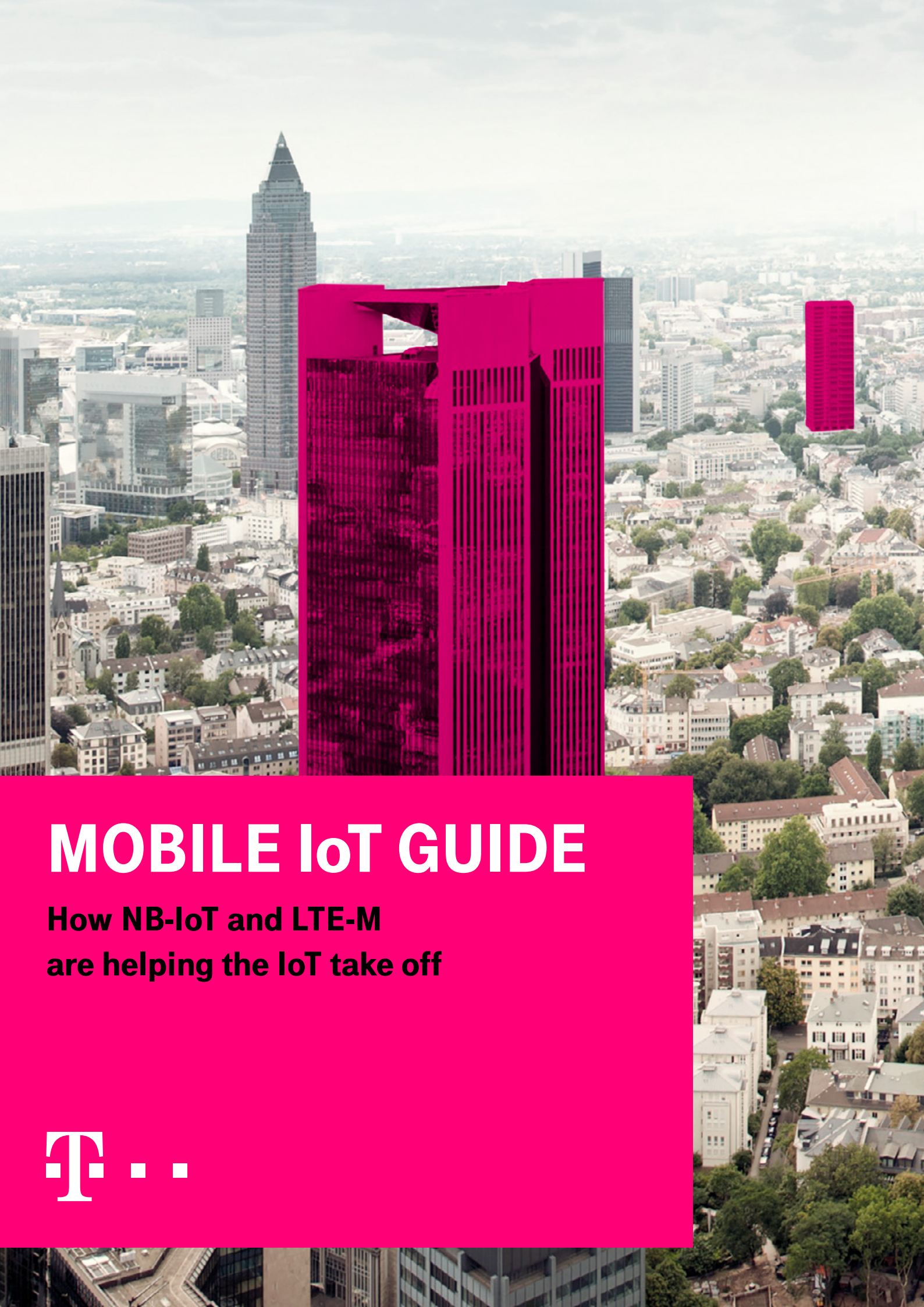


MOBILE IoT GUIDE

How NB-IoT and LTE-M are helping the IoT take off

INHOUD

INTRODUCTION

**Industries and cities are increasingly embracing the Internet of Things (IoT). According to the industry trade body GSMA, there will be 25 billion IoT connections globally by 2025.
Mobile IoT technologies such as NarrowBand IoT (NB-IoT) and LTE-M will be a key part of this growth and are hence rapidly becoming more relevant. This Mobile IoT Guide shall provide advice for companies and cities that want to explore new business opportunities around these technologies.
It covers the current state of Mobile IoT and explains why, when and how to use it. Furthermore, this document intends to give inspirations for end-to-end IoT use cases and explains why Deutsche Telekom is the right partner for realizing them.**

More and more companies and cities around the world are seizing new opportunities with the Internet of Things (IoT): They are equipping machines, vehicles, containers and buildings with software, sensors and connectivity to monitor and control them and to gain valuable data. Data with which they can build new business models, offer new services or increase their efficiency.

Since the early days of IoT, many devices have been communicating via the GSM mobile network, which guarantees a reliable connection and enables worldwide operation. But GSM, unfortunately, also has its limits.

What companies expect from IoT

In the past, the following were among the most common responses from companies as to why they had not implemented IoT solutions yet.

- "Our thousands of devices require long battery lifetime to avoid costly replacements."
- "Poor connectivity within buildings prevents us from realizing new use cases."
- "Own local networks are currently the only way to connect our devices, but require high installation and maintenance effort."
- "In my business, every cent counts and, unfortunately, the radio module and connectivity costs for IoT are currently just too high."

What companies and organizations truly need is a network optimized for exchanging very small quantities of data between devices and servers. Such a network would be optimized for the traffic profile of the vast majority of IoT devices. And while GSM and other cellular technologies offer excellent outdoor coverage, their reception deep inside buildings is often insufficient.
Furthermore, many of the usual wireless services, such as SMS, voice or high data rates, are not needed for most IoT use cases. In fact, they would simply drive up the average hardware costs. Finally, battery lifetime of several years is often just not feasible with existing technologies, simply because they were optimized for smartphones rather than for IoT devices.

Enter Mobile IoT

In 2016, the 3rd Generation Partnership Project (3GPP), a worldwide "standardization body" including Deutsche Telekom, developed a set of new cellular technologies specifically optimized for the IoT, jointly termed "Mobile IoT". One of them is NarrowBand IoT (NB-IoT/LTE Cat-NB) – this network standard is a genuine game changer for IoT solution providers, as it expands the technical possibilities to make massive IoT deployments economically feasible. The other new cellular IoT technology is LTE-M (LTE Cat-M), a standard to support IoT use cases with higher data rates and lower latency. Together, NB-IoT and LTE-M complement each other and are critical for the IoT breakthrough.

The unique advantages of Mobile IoT include lower costs, reduced power consumption and better indoor coverage. They are based on a global industry standard and are operated within licensed spectrum. NB-IoT and LTE-M address customers' needs for international operations, stability, reliability, security, cost-effectiveness and high scalability. To drive the development forward and to provide companies and cities with connectivity specifically optimized for IoT, Deutsche Telekom is rolling out NB-IoT and LTE-M networks across numerous international markets and is partnering with leading market players in the development of a strong ecosystem.

On the way to 5G

Both Mobile IoT technologies are also an integral part of 5th Generation Mobile Networks (5G). 5G will enable three main types of usage scenarios: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC) and Massive Machine Type Communications (mMTC). NB-IoT and LTE-M have been defined by ITU to meet the IMT2020 requirements for mMTC. But even right now, before wide availability of 5G networks, Mobile IoT is 5G-ready and already available to connect a rapidly growing number of IoT devices.

MOBILE IOT TECHNOLOGIES

Mobile IoT enables a very broad range of new IoT applications with its technical capabilities. The key features are long battery lifetime, deeper indoor coverage and low module cost.

Energy saving design to extend battery lifetime

Operating for many years on battery power is one of Mobile IoT's key benefits, making it suitable for those use cases where sensors and modules cannot be maintained. For example, in smart parking applications, where sensors are embedded in the ground. To enable an energy-efficient operation, Mobile IoT chipsets are optimized to focus only on relevant radio features. Moreover, signaling and overhead are reduced. Another key factor are special energy-saving features such as Power Saving Mode (PSM), long Periodic Tracking Area Update (TAU) as well as efficient data transfer over NAS (Non-Access Stratum, i.e. the signaling channel). See page 12 for more details.

Transmission techniques to enhance coverage

Wide reach and deep indoor penetration are further essential attributes of Mobile IoT, making it perfect for use cases like smart metering in basements. Devices in locations with poor coverage conditions benefit from two Coverage Enhancement (CE) techniques:

1) The transmission power density is increased by using a narrower frequency bandwidth.
2) Each message is repeatedly transmitted, allowing for proper decoding despite poor channel conditions. In contrast, proprietary technologies, operating on an unlicensed spectrum, are legally limited in their number of repetitions due to prescribed duty cycles. See page 14 for more details.

Low module costs due to reduced complexity

As Mobile IoT's lower data rates require less processing power in radio chipsets, these can be produced more cost-effectively. To further reduce complexity, a number of unnecessary LTE features have been omitted in NB-IoT and LTE-M chipsets, such as full duplex mode or inter-RAT handover. NB-IoT has been simplified even further by waiving voice support and seamless cell handover functionality. Given the fast-increasing global production volumes, the originally specified industry price target of $5 per NB-IoT module has already being reached around two years after the first commercial network launches. Moreover, Mobile IoT devices require only a single antenna, reducing their bill of materials (BoM). Going forward, the integrated SIM will help further reduce the total cost of ownership of IoT devices. See page 15 for more details.

Billions of devices
Up to 100x more devices per cell (compared to GSM)

Low data volumes
Bidirectional, infrequent transmission of low data volumes

Energy efficiency
Up to ten years of battery-powered operation[1]

Deep indoor penetration
Up to +20 dB link budget (compared to GSM)

Minimal cost
Cost-efficient radio modules, lower total cost of ownership

Plug & Play
Direct connectivity of each sensor, no installation and maintenance of local networks/gateways required

Worldwide standard
Worldwide 3GPP industry standard on operator-managed networks in licensed spectrum

High security
Proven LTE-grade SIM-based security mechanisms

Figure 1: Mobile IoT's characteristics

[1] Assuming equivalent of two AA batteries and typical traffic pattern in base coverage level (CE 0).

Mobile IoT as a global cellular standard

NB-IoT and LTE-M are based on operator-managed cellular networks, deployed in their existing LTE infrastructure via software upgrades. Using either GSM or LTE frequency spectrum, they provide reliable data connections with no geographical restrictions. A standardized SIM profile also allows international usage of NB-IoT and LTE-M on the networks of foreign mobile network operators. Both access technologies are based on LTE and therefore guarantee LTE-grade scurity (see page 19 for more details).

Mobile IoT is plug & play: Every device has a direct wide area connection, taken care of by the cellular operator. Alternatively, companies could use other technologies based on local or mesh networks, avoiding cellular connectivity charges. While this might seem appealing in the short term, it requires the installation and permanent maintenance of many peripheral gateways. This results in a high complexity for the user and usually an increased total cost of ownership in the long run.

DIFFERENT NETWORKS FOR DIFFERENT PURPOSES

To serve the requirements of the numerous and diverse use cases in the IoT sector, different technologies are needed.

NB-IoT is the choice for extremely or highly cost-sensitive applications with low performance needs, termed "Massive IoT". In contrast, regular LTE is needed for high-end applications with maximum performance requirements such as high data rates and very low latency. This other end of the spectrum is referred to as "Critical IoT". LTE-M bridges the gap between these two extremes. It has distinct benefits because, although higher bandwidth and data rates are required when compared to NB-IoT, it delivers on the promise of longer battery lifetimes and better indoor penetration. Most importantly, it is considered the key substitute technology for 2G (GPRS) and 3G (UMTS) technology. Eventually, together with NB-IoT, LTE-M will displace the other two as the long-term option for all related Mobile IoT use cases.

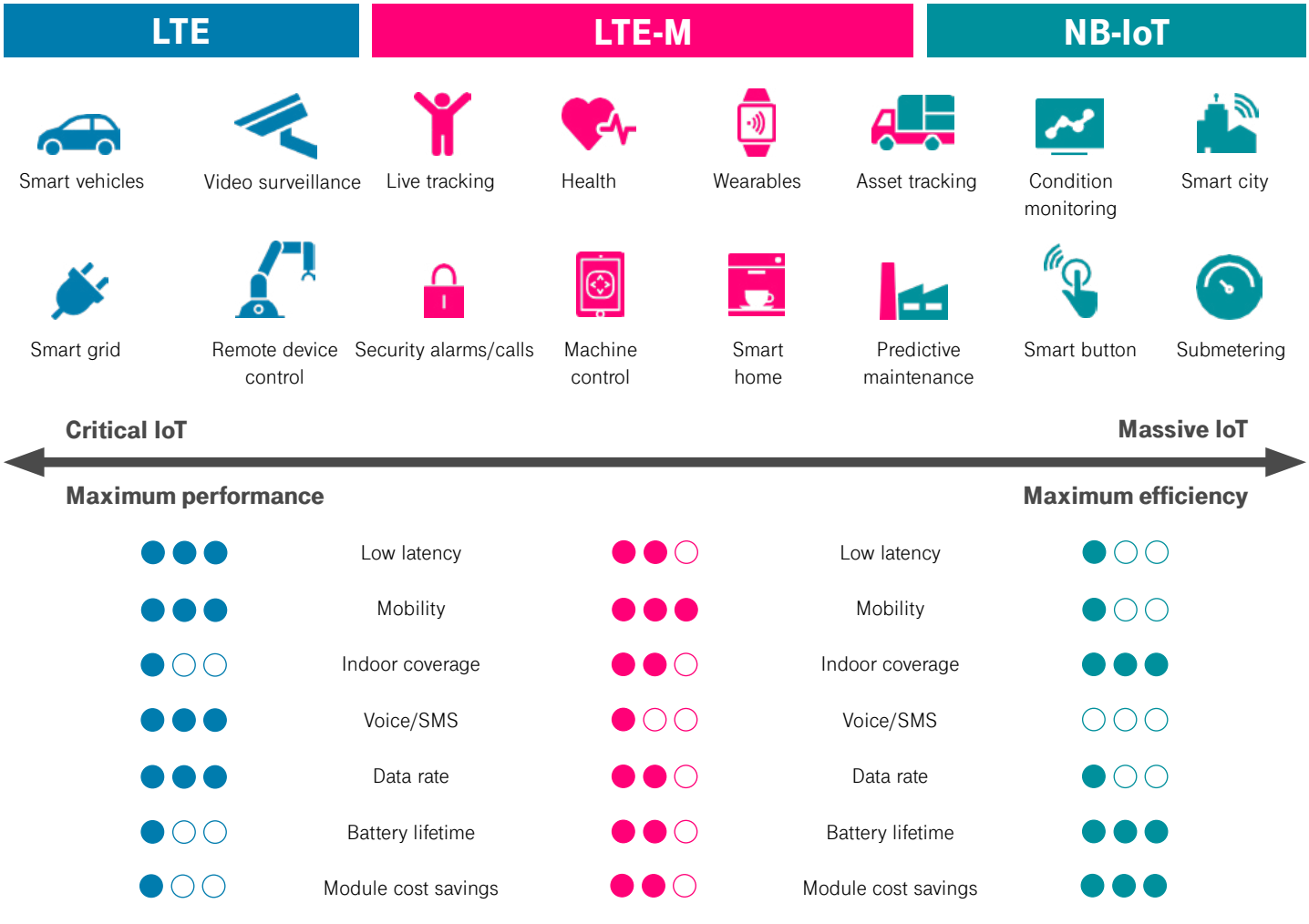


Figure 2: Features and use cases of cellular IoT technologies

COMPARISON TO ALTERNATIVE LPWA TECHNOLOGIES

As previously mentioned, NB-IoT and LTE-M use the existing assets of cellular network operators such as sites, base stations, antennas, backhaul and their licensed spectrum. In contrast, the specifications of other Low Power Wide Area (LPWA) technologies such as Sigfox and LoRa differ in a variety of ways, most notably in terms of required infrastructure, spectrum use and standardization.

Non-cellular technologies need dedicated base station or gateway hardware, operated by individual companies across countries and even urban regions. Many of them have only recently become operators and do not as yet have a long-term track record. Since their networks utilize unlicensed spectrum bands when the number of connected devices increases, data transmission becomes more likely to deteriorate due to interference as well as the legally defined duty cycle limitations. Therefore, these providers cannot guarantee Service Level Agreements (SLAs) in the same way as cellular Mobile Network Operators (MNOs).

With Mobile IoT, MNOs manage their own spectrum and can enforce policies to ensure smooth operations (see page 17 for more details). These frequency bands can handle a massive number of devices while remaining stable and avoiding interference, ensuring reliable data transmission. Having proven longterm practical experience in running nationwide telecommunication networks,

	LTE[6]	LTE-M[4]	NB-IoT[5]	LoRa	Sigfox
Spectrum	Licensed	Licensed	Licensed	Unlicensed	Unlicensed
Bandwidth	20 MHz	1.4 MHz	180 kHz	125-500 kHz	200 kHz
Bidirection Data Transfer	Full duplex	Half & Full duplex	Half duplex	Half duplex	Half duplex
Peak Data Rate	10 Mbps (DL) 5 Mbps (UL)	1 Mbps (DL)[2] 1 Mbps (UL)[2]	250 Kbps (DL)[3] 230 Kbps (UL)[3]	50 Kbps (DL) 50 Kbps (UL)	0,6 Kbps (DL) 0,1 Kbps (UL)
Typical Downlink Daily Throughput	Limited only by battery power, radio signaling condition and commercial terms (e.g. monthly data volume, amount of messages/size per period)			~200 B	~24 B
Typical Uplink Daily Throughput				~ 200 kB	~1,64 kB
Max. Coupling Loss (vs. GSM)	144 dB (0 dB)	156 dB (+12 dB)	164 dB (+20 dB)	157 dB (+13 dB)	153 dB (+9 dB)
Expected Module Cost	> $ 10	< $ 10	< $ 5	< $ 7	< $ 3
Expected Max. Battery Lifetime[1]	3 - 5 years	5 - 10 years	10+ years	10+ years	10+ years

Table 1: Overview of IoT transmission technologies

[1] Assuming typical traffic pattern and battery size.

[2] These values relate to full duplex mode. Currently observed mean rates, based on half duplex transmissions, are around 350 kbps (DL/UL).

[3] These values relate to overall cell capacity. Currently observed mean rates, based on single tone transmission, are around 20 kbps (DL/UL).

[4] Relates to 3GPP Cat-M1 specification Rel. 13.

[5] Relates to 3GPP Cat-NB1 specification Rel. 13.

[6] Values relate to LTE-Cat 1 category.

MNOs are thus best suited to operate reliable and secure networks and platforms for IoT applications, fulfilling data security and high capacity requirements.
NB-IoT and LTE-M networks also include proven LTE security mechanisms on SIM and network level, being continuously refined by a large community of companies and developers worldwide (see page 19 for more details). Sigfox and LoRa networks, however, can only utilize security protocols on the application level, which in turn are also limited by the low payloads that can be effectively transmitted, particularly in downlink.

Another notable advantage of cellular networks is their innate ability to interoperate. NB-IoT and LTE-M multimode radio modules can easily switch to other bearers including 2G and 3G. This allows global operation even in countries that do not yet have Mobile IoT networks and enables the use of different technologies for different purposes, e.g. NB-IoT for status reporting and LTE-M for large software updates.

Overall, the global industry standards of NB-IoT and LTE-M benefit not only from the wide cellular operator support, but also from a large ecosystem of chipset and device manufacturers. This ultimately reduces the risk of vendor lock-in, a problem frequently becoming apparent for companies that have deployed proprietary technologies. Mobile IoT as a global standard is therefore a safe choice as opposed to other proprietary technologies dominated by single companies or private consortia.

COMMON MYTHS ABOUT NB-IOT

NB-IoT has already proven its unique set of features for many different applications. Nevertheless, there are some persistent myths about this technology that we would like to dispel.

1. NB-IoT does not need a SIM card

NB-IoT always uses a SIM, because the technology operates within the licensed LTE band of the operator's cellular network. This also means NB-IoT has a security benefit – compared to technologies working in an unlicensed spectrum – thanks to LTE's high security standards. However, classic plastic SIMs are not necessarily required: The form factor can vary from 2FF to 4FF, conventional soldered SIMs (MFF) to even eUICCs. There now is also an option of having just a profile without separate SIM hardware – an integrated SIM (see page 15 for more details).

2. NB-IoT is only suitable for fixed-location use cases

NB-IoT as an access technology can be widely used for mobile use cases. While it is true that NB-IoT does not support seamless cell handovers, applications based on NB-IoT do not use streaming or voice calls and therefore handovers of continuous data streams are not necessary. As soon as a device has changed the camping cell, it can perform a cell reselection and immediately thereafter start sending and receiving data again seamlessly. It should be noted, however, that the extra signaling traffic associated with cell reselection requires additional power consumption of the device.

3. NB-IoT applications are TCP/IP-based
Common protocols like TCP/IP, UDP/IP or Non-IP are all supported by NB-IoT. Depending on the capabilities of modules and applications, users are free to choose any of these – however, TCP/IP is not recommended due to a resulting higher data volume. UDP/IP is the preferred and recommended transfer protocol for NB-IoT.

4. NB-IoT always provides a ten-year battery lifetime
It is important to note that ten years is by no means the default battery lifetime for any device using NB-IoT. Battery lifetime depends primarily on the use case requirements, i.e. the frequency of transmission and reception, the use of power-saving features or the Coverage Enhancement (CE) level – and, of course, battery capacity. So, provided the optimum parameters are met, an NB-IoT module could run up to ten years on one battery charge.

5. Firmware updates are not supported
Since NB-IoT has a reliable downlink channel, firmware over-the-air (FOTA) is possible. Deutsche Telekom strongly recommends making devices capable of FOTA to receive future security updates. But again, the associated energy consumption should be factored in.

SUITABLE APPLICATIONS

- Low data rates
- Infrequent data transmission
- Latency is uncritical
- No external wake-up function needed
- Deep indoor penetration
- Low power consumption/long battery lifetime
- Cost-sensitive use case

NOT SUITABLE APPLICATIONS

- High data rates
- Frequent messages
- Latency-critical, real-time information required
- Wake-up function needed
- Voice or SMS needed
- Safety-critical applications (i.e. real-time alarming)

UNDERSTANDING AND OPTIMIZING ENERGY CONSUMPTION

Key 3GPP-defined features such as Power Saving Mode (PSM) put modules into a sleep mode with very low energy consumption while sending occasional Tracking Area Update (TAU) messages to keep them registered at the network, avoiding the need for re-registration upon wake-up. The Long Periodic TAU feature allows modules to extend the duration between these tracking messages up to several weeks, hence expanding sleep intervals and thus additionally saving power. The extended Discontinuous Reception (eDRX) feature offers a longer low-power paging mode to allow the devices to receive downlink data from the server, while no uplink data is being sent. Generally, any Mobile IoT device can request and control PSM, long periodic TAU and eDRX to optimize its energy consumption according to its use.

Investigating energy consumption

How much energy do devices actually consume? As part of certifying the world's largest portfolio of Mobile IoT modules, Deutsche Telekom assessed the power consumption of over two dozen NB-IoT products. Figure 3 illustrates the broad range of power consumption measured across several 3GPP-standardized chipsets on our networks. These measurements were broken down to isolate the power consumption of basic radio chipset routines, such as attaching to the network or uploading data. The measurement results indicate that NB-IoT is exceptionally power-efficient in Coverage Enhancement levels 0 and 1.

Coverage Enhancement level 2 (for deep indoor and remote outdoor areas), however, is optimized to ensure that application data from deployed IoT devices can still reach the server at the expense of higher power consumption.

The IoT Solution Optimizer

Designing, testing and optimizing IoT devices and applications is a long and costly process. Building a vertical IoT solution from scratch typically requires several iterations of prototyping and analysing energy consumption of the device, taking weeks to months. This is why Deutsche Telekom has developed the IoT Solution Optimizer to drastically improve time-to-market, help to identify risks early on, ensure proper integration of feature support and weigh out design choices. It is a cloud-based service that digitizes and scales up IoT technical consultancy for onboarding enterprises. Within minutes, users can compose their own design by selecting hardware components and characterizing their application's intended behavior, including the use of specific network features. After users finish configuring the deployment scenario for their product, the IoT Solution Optimizer models device performance, delivering reliable results and multiple optimization opportunities. This includes energy consumption breakdowns to predict battery lifetime.

Deutsche Telekom is rapidly extending this unique offering by partnering with leading companies in the IoT industry including suppliers of network components, chipsets, modules and batteries. **For more information, please visit Deutsche Telekom's IoT website: iot.telekom.com**

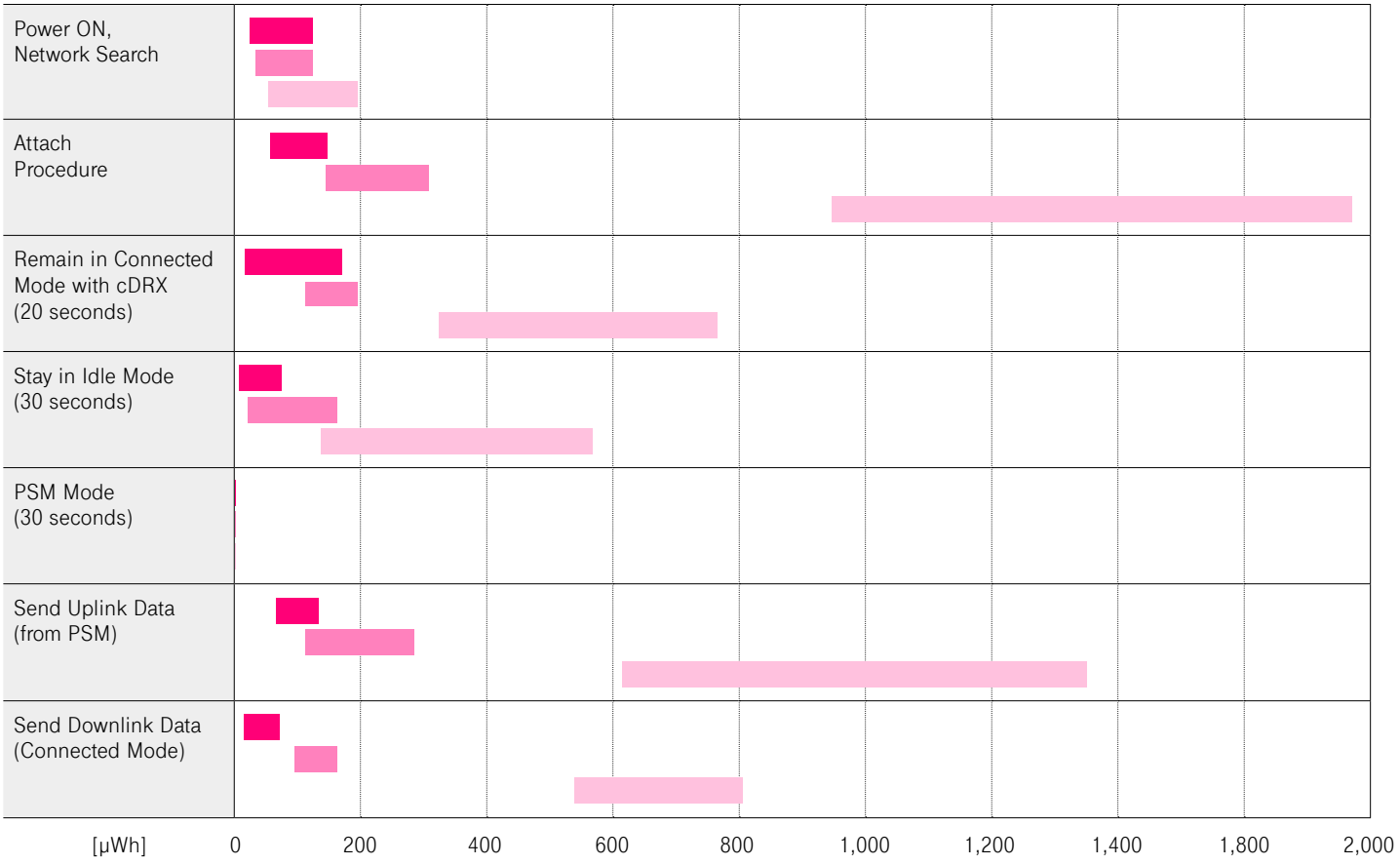


Figure 3: Power consumption of common radio chipset routines

EXCELLENT INDOOR COVERAGE: TESTED AND PROVEN

One of NB-IoT's unique features is its great indoor coverage. This makes the technology predestined for use cases where conventional mobile radio usually has its limits – for example, when it comes to smart submetering. At least that was the theory. But how does it work under real-life conditions?

To prove the capability of a live NB-IoT network inside buildings, Deutsche Telekom initiated the largest NB-IoT measurement campaign known so far. It was conducted in cooperation with ista International GmbH, which provided access to the measurement locations. The measurements themselves were independently performed by P3 communications GmbH at about 500 positions outside of and inside 60 apartments.

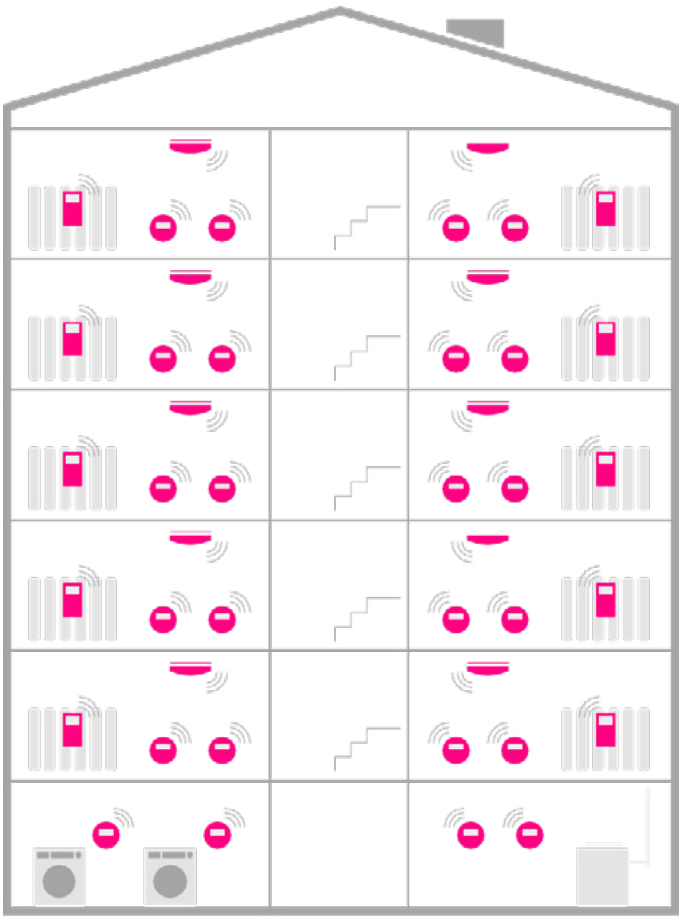


Figure 4: Measurements were done on several levels above ground and in basements

Very high indoor coverage proven

The results were more than satisfying: On ground floor or higher, a perfect attach rate of 100 % was observed as well as a 95 % attach rate in basements (see *figure 5*). When attached, data transmission was possible for almost all measurements (99.75 %). This fulfills and exceeds the expectations on NB-IoT in terms of performance when compared to existing technologies such as 2G/3G/4G.

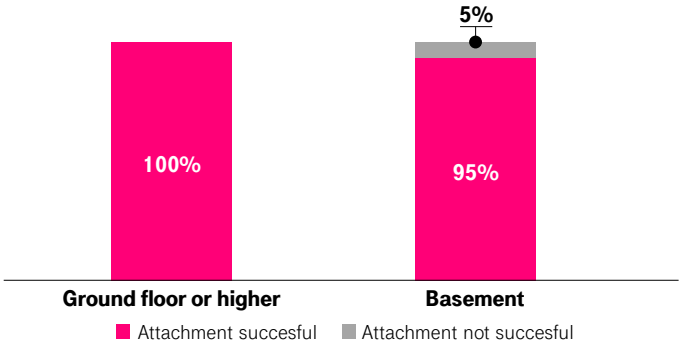


Figure 5: Indoor attach rate above and below ground

A main feature of NB-IoT is Coverage Enhancement(CE) which supports a base level (CE level 0) and two coverage enhancement levels (CE 1 and CE 2). Outside of buildings, practically no coverage enhancement was required. Indoors on ground floor or higher, for 93 % of measurements still the base coverage level sufficed. When measuring indoors in the basement, however, CE level 1 was used 27 % of the time and CE level 2 was used 19 % of the time.

For more information on the results of the measurement campaign, please refer to the white paper "NarrowBand IoT Delivers – insights from the largest NB-IoT indoor measurement campaign", available for download at **iot.telekom.com**.

NEXT-GENERATION INTEGRATED SIM

Low cost is one of the main promises of NB-IoT. But while the prices for NB-IoT radio modules have dropped significantly since the first network launches, the total cost of ownership (TCO) for a classic SIM card or an eSIM/eUICC has not declined in the same way. Obviously, a new approach is required: The integrated SIM moves the SIM function into the chipset to substantially reduce complexity and hence device costs.

The nuSIM solution

To bring affordable connectivity to the IoT market, Deutsche Telekom brought together leading industry partners and developed nuSIM. nuSIM is an integrated SIM, particularly tailored to the constraints of NB-IoT while maintaining LTE-grade security. The advantages are manifold:

COST EFFICIENCY

- No separate SIM hardware
- No related logistics, stock keeping and handling efforts

FOOTPRINT

- Reduced hardware and software requirements
- Optimized internal functions and interfaces
- No outside contacts and circuit paths
- Less total area consumption on printed circuit board

POWER EFFICIENCY

- Energy-saving design
- Longer battery lifetime

OVERALL SIMPLICITY

- Operator data loaded at module or device stage
- Network connectivity included in the device, ready for operation

nuSIM use cases

nuSIM provides the necessary network access for NB-IoT applications where cost efficiency and power consumption are crucial elements. Typical nuSIM devices are cheap and simple sensors deployed in use cases such as smart metering, service buttons, smart parking or building maintenance.

	Classic SIM	eSIM/eUICC	nuSIM (integrated SIM)
Vormfactor	Separate component (mounted)	Separate component (soldered)	Integrated in radio chipset
Cost (TCO)	Medium	High	Low
Stroomverbruik	High	Medium	Low
Profile Handling	Single	Multiple	Single
Use Cases	Existing IoT devices not intended for redesign, or not price-sensitive	High-end devices, e.g. smartphones, tablets, smartwatches	Simple low-cost devices, e.g. heat meters, smart buttons

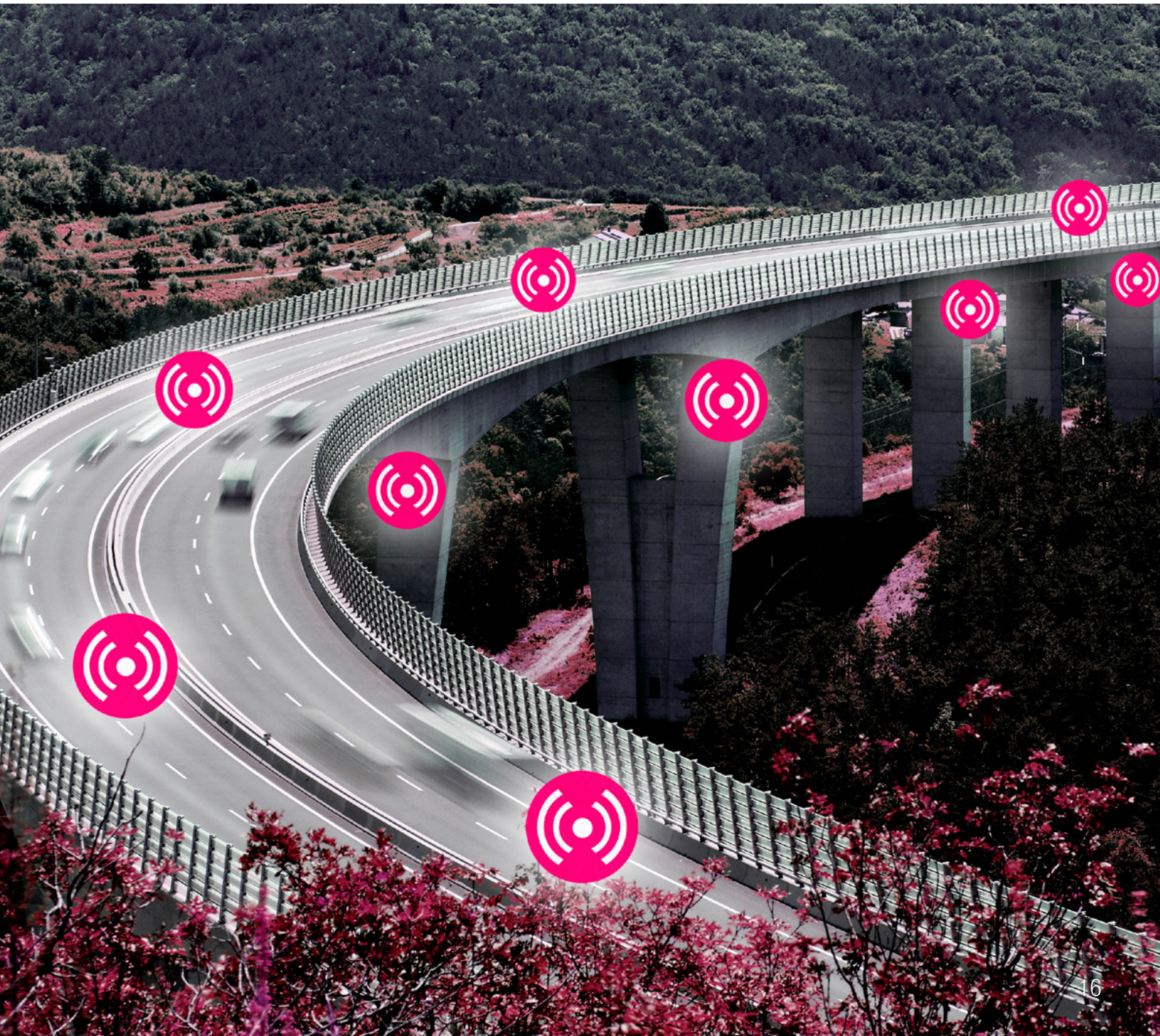
Table 2: SIM characteristics

The nuSIM ecosystem

What makes nuSIM really powerful is its open and interoperable ecosystem which can easily be joined by other operators, chipset vendors, module suppliers and providers of digital security.

As of February 2019, 12 partners contribute to making nuSIM a de-facto standard for the IoT market. nuSIM products from these partners will become available in the second half of 2019.

- Altair Semiconductor
- CommSolid/Goodix
- Giesecke+Devrient
- Mobile Security
- HiSilicon
- Nordic Semiconductor
- Qualcomm
- Technologies Inc.
- Quectel Wireless Solutions
- Samsung Electronics
- Sequans Communications
- Sierra Wireless
- Telit
- u-blox



PROTECTING THE NETWORK

NB-IoT and LTE-M are novel technologies not only offering new business opportunities, but also requiring new expertise to be properly utilized. To ensure that our networks can optimally serve the growing number of IoT applications, Deutsche Telekom enforces a comprehensive "No Harm to network" policy. This includes an extensive certification program for Mobile IoT chipsets and modules.

Module and chipset certification

Since the commercial launch of NB-IoT, Deutsche Telekom has certified the world's largest portfolio of Mobile IoT radio chipsets and modules. We qualify 3GPP-compliant chipsets and modules to ensure their seamless interoperability with our networks and to deliver the highest-quality connectivity experience possible. By integrating industry partners from across the globe, we offer the widest range of implementation options for Mobile IoT modems. Using Deutsche Telekom-certified products, our customers can reduce their implementation costs and minimize risks. Our teams can provide expert advice and guidance on each solution, based on its features, configurations and best-practice handling. Our current certification lists include numerous single-mode (NB-IoT) and multi-mode (NB-IoT, LTE-M, 2G) solutions – from gateways to routers, trackers, modules and chipsets – from suppliers worldwide.

Radio Policy Manager

Deutsche Telekom's "No Harm to network policy" comprises the implementation and activation of a Radio Policy Manager (RPM), an element of the GSMA's IoT device connection

POTENTIAL IOT RISKS AND CHALLENGES

- The lack of standardized operating systems for IoT devices gives way to poorly designed applications which could harm the network.
- Device applications may disregard the IoT-specific characteristics for which NB-IoT and LTE-M were designed, thus draining batteries faster, congesting the network and degrading network service quality.
- Developers may lack sufficient 3GPP knowledge to understand how to properly handle back-off, communication or connectivity requests by the Mobile IoT network.
- Poor antenna design may compromise transmission performance and may cause excessive signaling load in the network.
- Applications may not have defined and tagged their data priority, hence not have scheduled data transmissions accordingly.
- Multi-mode IoT devices may camp on a wrong radio access technology (RAT) such as 2G/3G or may not proactively switch whenever the service quality or the use case requires it.
- Fragmentation of supplier landscape complicates device management, leading to an inability to reach all IoT devices, e.g. to push firmware updates.

efficiency guidelines. RPM helps protecting the mobile operator network from the signaling overload caused by improperly designed IoT applications. To date, RPM is the sole industry solution deployed worldwide that controls how IoT devices communicate.
Deutsche Telekom works closely with radio chipset suppliers to integrate this feature into the chipset protocol stack for NB-IoT and LTE-M devices.

Deutsche Telecom's “no harm to network” policy
Deutsche Telekom attributes a high importance to service quality and network availability. In order to secure Service Level Agreements (SLAs), it must be ensured that no harm to networks is done by IoT devices. The risks are quite high – from unrecoverable devices out in the field to signaling storms threatening our radio and core networks, backends and clouds. Deutsche Telekom addresses all of these aspects by actively encouraging the adoption and observance of the GSMA guidelines among our customer base.

PROTECTING DEVICES AND DATA

Mobile IoT is a worldwide standardized technology featuring 3GPP LTE security mechanisms, offering a high level of security for its applications. It provides higher security than proprietary technologies, as its protection measures cover all aspects from the SIM card (also known as universal integrated circuit card, UICC) in the device to the application servers. It is all about integrity, authentication, confidentiality and availability.

Integrity and authentication
When accessing the Mobile IoT network, the identities of both the subscriber/device and the network are verified. This so-called mutual authentication of the infrastructure is done via the SIM card, on which sensitive credentials and subscriber data are stored and protected against unauthorized access. Integrity of the transmitted data is ensured by means of a specially generated key, independent of the encryption function.

Compared to other technologies, Mobile IoT uses longer encryption keys (typically 128bits) to increase security. A manipulation of the data is reliably detectable by the device and the network. For the nuSIM, the authentication is performed directly on the chipset.

Confidentiality
User data is encrypted between the Mobile IoT modem and the core network using a separately generated key and algorithm. Between the core network and the application server, data traffic can be protected via an IPsec tunnel, so the device cannot be reached from the Internet. Furthermore, the user can choose to encrypt or hash the data end-to-end from the client application on the device up to the server.

Availability
Deutsche Telekom's Mobile IoT network is operated and managed alongside existing LTE networks. It therefore benefits from a proven infrastructure and many years of operating experience. Its European core network is

IP OR NON-IP

There are two possibilities for data transmission between Mobile IoT devices and the respective application server:

IP (Internet Protocol): Depending on the capabilities of the radio module and the operator, IPv4 and/or IPv6 can be used. For IoT applications using NB-IoT UDP is the common and recommended transport protocol. On the air interface, TCP is, in principle, supported for NB-IoT (and specified in the 3GPP standard), but is not recommended due to the resulting higher data volume.
Likewise, HTTP and HTTPS over the air interface cannot be reasonably implemented because they rely on TCP and demand additional data volume for their overhead.

Non-IP: If possible, a non-IP based data transmission is recommended for NB-IoT, as it further reduces the transmitted data volume over the air interface (since IP overhead is saved). The device data is then forwarded by the core network to the application via IP. Data can only be sent to one target IP address (server), further increasing the security of the device by reducing the risk of fraud.

geo-redundant and thus highly available. For a further enhancement of availability levels, redundant connections from the core network to the application server are also possible. Being a global industry standard, NB-IoT and LTE-M (just like LTE) benefit from a large international ecosystem of vendors as well as other experts to constantly review and enhance security functions and algorithms as new threats arise. As part of its corporate ethos, Deutsche Telekom strives to protect its customers and its assets to the greatest extent possible.

MOBILE IOT AT DEUTSCHE TELEKOM

In 2015, Deutsche Telekom started investing in Mobile IoT technologies. Since then, the company has been building up expertise in this area while shaping the market. It sculpted the related global 3GPP standard, being one of the key contributors to Release 13 published in 2016. Furthermore, Deutsche Telekom lead the rollout of NB-IoT networks in many countries and established itself as one of the global leaders of Mobile IoT networks when it comes to number of deployments.

Network rollouts

In nine European countries as well as in the US, Deutsche Telekom became the first network operator to set up NB-IoT networks. By the end of 2019, countrywide coverage will be available in most of them. In the Netherlands, the world's first nationwide NB-IoT network was already completed in May 2017.
To complement its Mobile IoT portfolio, Deutsche Telekom is also preparing its networks for LTE-M. Already in late 2018, base stations in the Netherlands, Poland, Austria, Croatia and Germany were equipped with LTE-M technology to enable first proofs of concept with customers. First commercial offers are planned to go live in mid-2019.

NB-IoT prototyping programs

Prior to the first commercial launches, in late 2016, Deutsche Telekom started one of the world's first NB-IoT prototyping programs run by its incubator hub:raum. Various innovative start-up companies and established solution providers have since then developed and tested NB-IoT prototypes at our IoT labs in Bonn, Berlin and Krakow, contributing to an early boost to the market. In these programs, all solution partners were offered access to new access technologies and technical support, helping them to accelerate product development, prototyping and market implementation. These activities laid the foundation for several successful partnerships with vertical industry specialists (see pages 24–30 for more details).

In addition, Deutsche Telekom's European Smart Solutions Center based in Budapest and T-System's Smart City business unit have adopted some of the hub:raum partner solutions and are on-boarding them into their respective portfolios. Many of the developed smart city solutions use NB-IoT or LTE-M as their network access technology and more will follow.

Telekom open IoT labs

In 2017, Deutsche Telekom joined forces with the Fraunhofer Institute for Material Floiot.w and Logistics (IML) to found the Telekom Open IoT Labs. In a joint working space in Dortmund, expert teams are developing tailor-made end-to-end IoT prototypes together with our customers. Telekom Open IoT Labs combines hardware, software and connectivity expertise to test practical forward-looking innovations today. For connectivity, most projects use Telekom's NB-IoT networks. One of the first developments is the IoT Service Button. The intelligent retrofit solution can, with just one click, order replacement parts, retrieve full containers or report technical malfunctions. Another good example of this successful collaboration is the Low Cost Tracker. This tracker can be embedded into pallets to remotely monitor movements of goods in a supply chain. Both solutions use the NB-IoT network to send and receive data.

Hub:raum LTE-M prototyping

Given the positive feedback and results of the NB-IoT prototyping activities, Deutsche Telekom initiated an LTE-M prototyping program in the second half of 2018 to jointly explore this new technology with partners. Almost 150 start-up and IoT specialist companies across Europe and the US submitted proposals.
18 solution partners from 12 different countries were selected for further cooperation in prototyping LTE-M use cases. With Deutsche Telekom's support, they implemented LTE-M connectivity into their prototypes and operated them

FIVE EXAMPLES OF INNOVATION LEADERSHIP

- At the Mobile World Congress in 2016, Deutsche Telekom was among the first to present NB-IoT prototypes.

- In November 2016, Deutsche Telekom demonstrated in Cosmote's headquarters in Athens one of the first end-to-end IoT solutions based on NB-IoT, a smart parking system.

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- In May 2018, Deutsche Telekom, together with VodafoneGroup, successfully completed the first international NB-IoT roaming trial in Europe, proving the interoperability of devices and network features across national borders.

- In the summer of 2018, Deutsche Telekom, together with ista International and P3 communications GmbH, conducted the largest NB-IoT indoor measurement campaign by that time, proving the impressive reliability and indoor penetration of this technology (see page 14 for more details).

- At the Mobile World Congress 2019, Deutsche Telekom presented its version of integrated SIM for IoT (see page 15 for more details). The nuSIM is specifically designed for the low cost IoT segment. Its partner ecosystem of leading IoT market players is the largest of any integrated SIM solution to date.

in local LTE-M test networks in Krakow, Berlin, Reutlingen, Rotterdam or Vienna. The innovative solutions that emerged from the prototyping program span several industries, including smart city, wearables, e-health and smart tracking.

Working with us

To immediately start using our IoT networks, we at Deutsche Telekom offer trial packages to develop own solutions and directly pilot them in several markets. In addition to an online forum to help with technical questions, starter workshops and Installfests allow interested parties to identify the right mix of protocols, devices and access technologies for their business. Further, we provide the IoT Solution Optimizer, a cloud-based service that digitalizes and scales up IoT technical consultancy for onboarding enterprises.

Our networks are designed to simplify device onboarding and enable IoT applications to more effectively manage and communicate with device fleets. Besides connectivity, we provide an environment in which companies can rapidly develop their own applications using the proven IoT platforms such as Cloud of Things and Connected Things Hub. For selected use cases like asset tracking or smart metering we even offer end-to-end bundles that combine hardware and connectivity with specialized applications.

As of February 2019, more than 1,000 companies worldwide are already using our NB-IoT networks to realize their innovative IoT applications. If you would like to become part of this ecosystem, please contact your local Telekom or T-Mobile representative.

NB-IOT AVAILABILITY IN DEUTSCHE TELEKOM'S FOOTPRINT

Live networks available in ten markets:
(*Nationwide roll-out completed; as of February 2019.)


AUSTRIA*


CROATIA


CZECH REPUBLIC


GERMANY


GREECE


HUNGARY


NETHERLANDS*


POLAND


SLOVAKIA*


USA*

INFINITE USE CASE POSSIBILITIES – NB-IOT

Efficient waste management

Waste disposal companies empty trash containers at fixed intervals – regardless of whether they are actually full. That is why the international disposal and recycling company **Saubermacher** has started a pilot project in several Austrian regions, equipping its garbage bins with sensors. These transmit the bin location and the fill level to a central platform. This provides Saubermacher with valuable information for optimizing its emptying routes, so the garbage trucks would only drive to full bins. Additionally, Saubermacher wants to develop new and more individual services, based on the experiences made in the project. But the sensors were inefficient and quickly drained the battery. The project has become successful thanks to new sensor technologies – and the low energy consumption of T-Mobile Austria's NB-IoT network. The safety of the customers has also been increased with the new sensors. They can detect unusual increases in temperature or even fires and report them immediately. In the future, private customers can even order special emptying via an app – if, for example, the birthday party on the weekend produced more than the usual amount of garbage.

Benefits:

- Citizens, businesses and the communities benefitting from more efficient emptying routes
- Optimized logistics reducing traffic, noise pollution, fuel consumption and CO2, and thus protecting the environment
- Very high building penetration of NB-IoT, also reaching garbage bins in basements
- Long runtime of batteries installed in the sensors

Remote cattle monitoring

In livestock farming, monitoring the physiological functions of cows is key for efficient operation and production. Deploying different monitoring devices means operating in an unstable network and having high costs for gateways, relays and cabling to achieve coverage. This is challenging for larger and outdoor farms. **T-Systems Hungary, Magyar Telekom** and their solution partner **Moonsyst Inc.** found the perfect solution: They equip a smart rumen bolus monitoring device with an NB-IoT SIM card. Now, thanks to NB-IoT's deep coverage features, the device has a stable connection and reports the pH level and the temperature of the rumen every ten minutes. Whenever the values reach a critical level, the farmer is alerted via a push message, giving him the ability to adjust conditions accordingly. Further, the smart rumen bolus is equipped with a gyro sensor. This allows activity tracking, such as general movement and heat detection.

Benefits:

- Best-in-class solution from a farmer's point of view
- Maintenance-free monitoring
- Reliable connection via NB-IoT
- Lower cost for monitoring the animal welfare

Remote water metering

The Western Slovakia Water Company (ZsVS) supplies households, industry, agriculture and other consumers with drinking water from public pipes. They also drain and purify waste water that is discharged into the public sewerage system. ZsVS needs a large staff to regularly drive out to the measuring points, control the water quality and perform water pipe diagnostics. To do the job remotely, **Slovak Telekom** provides ZsVS with a complete water metering solution for over 2,300 metering points, based on NB-IoT. The access technology's deep penetration capability guarantees radio coverage even inside pipes and enables the staff to remotely read water meters.

Benefits:

- Reduced time and manual labor
- Reduced maintenance effort since water supply site is accessed less
- Easy-to-read and well-documented detailed water consumption data
- Stable connection in difficult environments thanks to NB-IoT

Paperless goods labeling and tracking

To transport components and parts between locations, **car manufacturers** make use of small load carriers. These are currently equipped with paper labels (e.g. receipts, delivery number, component name, etc.) that get updates, or are exchanged several times during the transport process. This can result in up to 100,000 labels being used at a single location on a daily basis. Deutsche Telekom's IoT solution optimizes this process by helping to avoid waste and errors. The paper labels are replaced by an ePaper display that is connected to the cloud eLabel solution via NB-IoT networks. The car manufacturer can now manage its devices with a web-based monitoring tool. From deep inside production halls to basements – all data is reliably transmitted via NB-IoT to an integrated IoT cloud solution for condition monitoring.

Benefits:

- Remote labeling and re-labeling: no need for paper labels and manual replacement, no cleaning expenses All relevant information shown in real-time
- Localization via Cell-ID and reliable indoor coverage via NB-IoT
- Additional sensors providing further information about box condition (e.g. crash detection, temperature, humidity, pressure)
- Configurable screen making the label easily adjustable for other use cases in logistics, production, transport

NB-IoT™

Smart parking

The search for free parking in cities is tiresome. It takes time, uses fuel and causes traffic jams. **Hrvatski Telekom** and **Mobilisis** demonstrate how IoT technology can shorten the search: Together, they deployed a smart parking solution based on NB-IoT in the Croatian city of Split. About 80 sensors were installed in the city center, enabling parking spaces to reliably report and even forecast their occupancy. A smartphone app allows drivers to then navigate to available spots. The app is especially welcomed by Split's disabled community, increasing their quality of life.
After Split, more Croatian cities want to follow: The city of Krk is starting its own smart parking pilot, envisioning soon to cover the whole city.

The German city of Hamburg also relies on NB-IoT to connect public parking lots – for a good reason. NB-IoT sensors require low energy and offer wide reach. They even transmit data from inside buildings, such as car parks and underground garages, and report in real time if a parking space is available. The Park and Joy app navigates drivers to a free parking lot near their destination. They can also save themselves a trip to the ticket machine and book the space online by creating a virtual parking ticket with only two clicks. Drivers can pay for the parking duration per minute using all common payment procedures and extend their parking time remotely.

Benefits:

- Reduction of traffic jams, fuel consumption and harmful emissions
- Valuable data for cities to increase the profitability and the capacity utilization of parking spaces
- Convenient for drivers – less time searching for a spot, billing to the minute and no need to go to a vending machine
- NB-IoT allows for cost-effective upgrade of parking spaces and reliable data transmission

Remote groundwater monitoring

Constantly monitoring the level and quality of groundwater is important for cities: to protect construction areas, industries, people and drinking water. But water management is often done manually, using on-site manpower to collect data with long periods between measurements. The Dutch measurement experts from **Munisense** offer real-time water management, using wireless water level loggers and water quality meters.
T-Mobile Netherlands was closely involved in the integration of NB-IoT into the company's online platform. The NB-IoT communication protocol is ideal for monitoring groundwater as it provides much better accessibility in places that are difficult to reach by radio. NB-IoT equipment can deal with lower signal strength compared to GPRS equipment. And thanks to the energy-saving characteristics of NB-IoT, the water meters can work maintenance-free for weeks, months or even years on their internal batteries.

Benefits:

- Quick and easy installation of devices
- Immediate wireless data communication for water networks
- Years of operation on a single battery thanks to NB-IoT
- Measurement intervals from seconds to days
- Adjustable alarms

Concrete structure warning system

More than 80 % of all infrastructure buildings in the world are made of concrete – roads, bridges, tunnels, dams and power stations. Even though concrete is a very strong substance, the reinforced steel inside can lose its protectiveness under the influence of time, water, salt or humidity. When this happens, the structure starts to die from the inside out. The first small areas of damage are not easily noticeable. If left alone, they can cause serious damage to the structure. That is why **Deutsche Telekom, T-Systems** and their German partner **BS2 Sicherheitssysteme** have developed a smart early-warning system for concrete structures. Batteryless RFID sensors are directly installed into the concrete, e.g. harbor walls or edge beams of a bridge. From there, they monitor humidity, temperature and corrosion. The captured data is transmitted via Deutsche Telekom's NB-IoT network to a backend for further analysis. This system can identify early indications of damage long before they can be seen. It makes concrete structures safer and more sustainable.

Benefits:

- Reduced inspection, repair work and maintenance costs
- Early monitoring and detecting of potential damage to concrete structures
- Increased sustainability and durability of structures
- Suitable for newly built, renovated or retrofitted constructions
- Increased longevity of equipment through NB-IoT

Digital wine quality tracker

When it comes to wine, consumers – perhaps even more so than with any other beverages – pay particular attention to quality. Millennials are now drinking more wine than beer and will pay more money for ecofriendly, vegan or more sustainable wine. To ensure a consistent quality of wine bottles throughout the entire supply chain, our Greek partner **Istmos**, together with Deutsche Telekom Group's Greek operator **Cosmote**, developed a unique end-to-end logistics solution. The system monitors each individual bottle while it is stored in the winery to ensure optimal quality and tracks it during transport to its final destination, be it a restaurant or liquor store. Sensors keep an eye on temperature, humidity and luminosity. The data is transmitted via Cosmote's NB-IoT network to a cloud platform. The results – the consistence of quality – can be checked by the consumer via an app that reads the QR code on each bottle. Life is too short to drink bad wine!

Benefits:

- Supply chain transparency
- Better monitoring and quality compliance
- Information always available online
- Low-cost tracking solution
- Enhanced coverage even in wine cellars

NB-IoT™

Building energy management

The climatization of buildings consumes enormous amounts of energy. The currently used heating and cooling systems are often complex and hard to maintain. That is why our Italian partner Enerbrain uses sensors to control heating, cooling and ventilation in buildings. With their IoT solution, Enerbrain saves over 30 % of energy, reducing CO2 emission and improving comfort. The solution is scalable with plug & play sensors and actuators. Buildings with a wasteful energy profile, such as supermarkets, airports, hospitals, schools or offices, can thus be easily retrofitted. The sensors measure temperature, humidity and CO2 emission. Enerbrain has set up a trial with T-Mobile Austria in one of their

Benefits:

- Installable on any existing HVAC system
- Helping to reduce carbon emissions
- Improving indoor air quality
- Reducing energy consumption for heating and cooling
- Reliable indoor coverage thanks to NB-IoT

NB-IoT™

INFINITE USE CASE POSSIBILITIES – LTE-M

Remote infant health monitoring

Continuously monitoring baby health requires a device with special features: It has to be mobile, very small and include a long-lasting battery. The London start-up **Daatrics** has developed the first wearable IoT device, called **Neebo**, that is small enough to be placed on the limited area of a newborn‘s wrist, to monitor all relevant parameters about the little one. The wearable remotely provides potentially life-saving information about newborns, such as the child’s heart rate, thermal state and oxygen level.
The solution uses **Daatrics** software algorithms and in the future the unique capabilities offered by Deutsche Telekom’s LTE-M network. It enables low device cost and a very long battery lifetime thanks to its energy-efficient operation mode.

Benefits:

- Continuous child monitoring
- Medical-quality measurements
- The smallest wearable device for newborns
- Low energy consumption thanks to LTE-M

Single use shipment tracking

When using common tracking devices to monitor shipments, these trackers usually need to be located and picked up upon delivery due to their high device cost, which is a labour-intense process. That is why the US start-up **Luma** invented a single use, disposable and recyclable solution that offers real-time shipment monitoring at a low cost. Location and sensor data of valuables in transit are provided by a cheap, simple and easy to use one-button tracker. The data is sent via LTE-M to a cloud platform, using the innovative technology’s full mobility feature and the low energy consumption enabling long battery life. Luma’s current focus is on tracking shipments by providing real-time shipment data or historical evidences of shipments. Their system includes low energy and efficient hardware, software and a web-based dashboard.

Benefits:

- Low-cost, recyclable tracker
- Preventing loss of valuables or damage to sensitive items
- Providing real-time shipment data via LTE-M or historical evidences of shipments

LTE-M

Rail goods management

When transporting goods by train across national borders, continuous monitoring is advisable – especially when it comes to dangerous goods. But managing mobile assets is a challenge. Our Dutch partner **Dual Inventive** offers a solar-powered tracking device with a huge battery pack and low-power LTE-M technology. Using global navigation satellite systems, the tracking device can determine the location of the asset, the distance it covered and the route it took. In addition, sensors detect accelerations, vibration, tilt and collisions. In case an important event is raised, such as a collision, an alarm is triggered and immediate action can be taken.

Benefits:

- Long battery lifetime (1,5 yrs.+)
- Hub to wirelessly attach other sensors, such as cargo condition
- Power harvesting via solar panel for autonomous operations
- Extensive LTE-M coverage in rural areas
- Near real-time asset insights via cloud platform

Bike locating

A big issue for any cyclist is to track down their bike when stolen or when they simply forgot where they left it. A trackable sensor attached to the bike could be the solution. But a fancy-looking device would probably just lead to the thieves removing it before taking the bike. The German start-up Velocate created a solution that looks just like an average tail light on a bike – but with a hidden GPS sensor inside. The tracking system also has an integrated SIM card currently using 2G, but in the future LTE-M technology to send its location data to a tracking platform. Users then just need a mobile app to find their bike. LTE-M enables a longer battery life and supports a deeper in-house coverage. The current 2G version is already successful in the market and has already returned many bicycles to their owners.

Benefits:

- Perfectly hidden in a normal tail light
- Automatic charging by dynamo or pedelec battery
- Bluetooth + GPS for near/long-range tracking

LTE-M

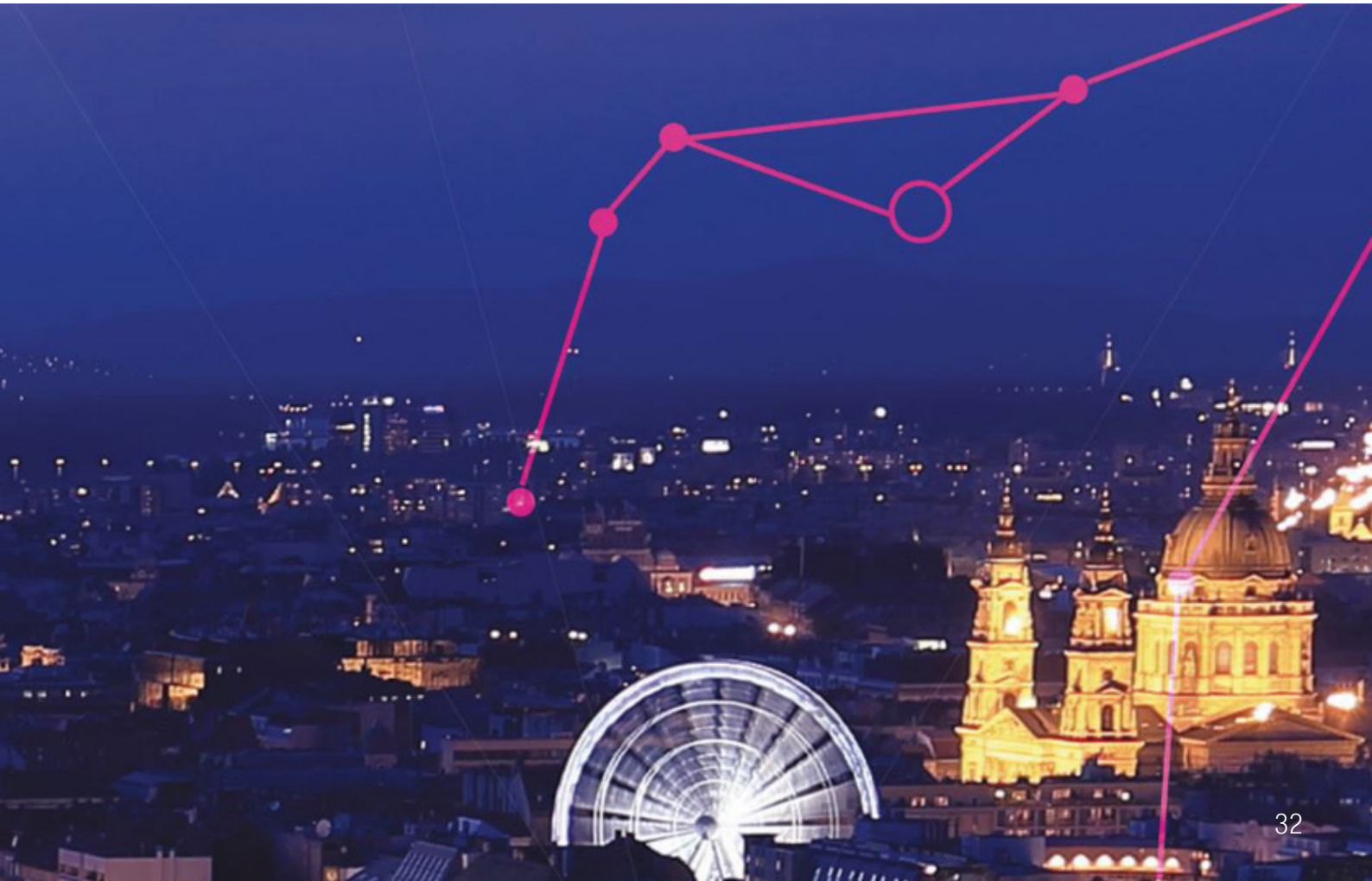
OUTLOOK

Introducing two completely new IoT technologies nationwide and across Europe has been a challenging, continuous task. And we as Deutsche Telekom are constantly working to improve our NB-IoT networks and roll out LTE-M.

On the one hand, it is about quality. We will continue optimizing our NB-IoT network to further enhance coverage – especially in buildings and basements – and, of course, to further reduce device energy consumption.
On the other hand, it is about the cost of devices. NB-IoT modules will become even more cost-effective than today, given their fast increasing production scale. Advanced power saving features as well as new power classes for devices lead to a longer battery lifetime, saving battery cost and extending device life cycles. The introduction of integrated SIMs (nuSIM) will further minimize the total cost of ownership for IoT devices. Moreover, we are also working on network-based localization techniques such as Enhanced Cell-ID and triangulation, so devices will not need a GPS module or additional processing power anymore to determine their position. Finally, the operator community is planning to provide roaming for NB-IoT in the near future to enable seamless mobility for cross-national use cases.
The introduction of LTE-M into the footprint of Deutsche Telekom will be another big step towards 5G. With NB-IoT widely available and LTE-M soon to come, all prerequisites are in place to comprehensively serve Massive IoT use cases of the 5G world today and in the near future. The 3GPP initiative has agreed that both Mobile IoT technologies will continue evolving as part of the 5G specifications, meaning that Deutsche Telekom's customers can leverage investments made today and continue working on them as part of the 5G evolution. Mobile IoT is here to stay.

GLOSSARY

2G/3G/4G/5G	3GPP mobile telecommunication standard generations
3GPP	3rd Generation Partnership Project
4FF	Fourth Form Factor (Nano SIM)
BOM	Bill of Materials
CE	Coverage Enhancement
dB	Decibel
eDRX	Extended Discontinuous Reception
eSIM	Embedded Subscriber Identity Module
eUICC	Embedded Universal Integrated Circuit Card
FOTA	Firmware Over-the-Air
GPS	Global Positioning System
GSM	Global system for Mobile Communications (2G)
GSMA	GSM Alliance
HTTP(S)	Hypertext Transfer Protocol (Secure)
HVAC	Heating, Ventilation and Air Conditioning
IoT	Internet of Things
IP	Internet Protocol
IPv4/IPv6	IP version 4/6
IPSec	Internet Protocol Security
LoRa	short for LoRaWAN (Long Range Wide Area Network)
LPWA	Low Power Wide Area
LTE	Long Term Evolution
LTE-M	LTE for Machine-Type Communications (LTE Cat-M)
MNO	Mobile Network Operator
NB-IoT	NarrowBand Internet of Things (LTE Cat-NB)
OS	Operating System
PSM	Power Saving Mode
RAT	Radio Access Technology
RFID	Radio Frequency Identification
RPM	Radio Policy Manager
SIM	Subscriber Identity Module
SLA	Service Level Agreement
TAU	Tracking Area Update
TCO	Total Cost of Ownership
TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UICC	Universal Integrated Circuit Card
UMTS	Universal Mobile Telecommunications System



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