LIFE IS FOR SHARING.

NARROWBAND IOT
THE GAME CHANGER FOR THE INTERNET OF THINGS

Whitepaper, October 2017

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Picture 1: **NB-IoT's core benefits**

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

Low data volume
Bidirectional, infrequent transmission of low data volumes. Data rates 600 b/s – 250 kbit/s[1]

Low energy consumption
Up to 10 years of battery-powered operation[2]

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

[1] Dependent on network utilization and signal strength

[2] Assuming equivalent of 2 AA batteries and typical traffic pattern

INTRODUCTION

The Internet of Things (IoT) is changing our world. Companies and cities all over the world are equipping physical objects with software, sensors and connectivity to merge them into a global network, the IoT. As things are becoming able to collect and exchange data, they emerge into new ecosystems across processes, industries and countries, enabling new services or whole new business models. Well-known IoT use cases include smart metering, goods tracking and equipment monitoring.

UNLIKE ANY OTHERS

But why use NarrowBand IoT (NB-IoT)? It is ideal for Low Power Wide Area (LPWA) systems, which is where many other technologies fail. Although there are existing mobile communications networks, these are not optimized for applications sending and receiving very small quantities of data. But that is exactly what many IoT devices do: infrequently exchange data with back-end systems. And while other technologies offer excellent outdoor coverage, their reception deep within buildings is often limited. Furthermore, commercially available wireless communication modules connecting to GSM, 3G or LTE mobile networks support a wide range of services. As many of them are not required for IoT use cases, they would just drive up the average hardware cost. Finally, a battery life of several years is often not feasible with such technologies, as neither the network nor the devices are designed to offer the necessary energy-saving mechanisms.

So, companies regularly deal with a myriad of challenges during their IoT deployments: high power consumption leads to frequent and costly maintenance routines for battery exchange or recharging.

Insufficient coverage inside buildings limits the possibilities to develop new use cases. Sensors incapable of wide area communication require the setup of local gateways and a permanent maintenance of peripheral networks. The 3rd Generation Partnership Project (3GPP) – a worldwide alliance including Deutsche Telekom that focuses on standardizing mobile communications – vowed to tackle these challenges. In mid-2016, as part of its Release 13, it published a series of innovative cellular technologies optimized for the IoT. NarrowBand IoT (or LTE Cat-NB1) is one of these 3GPP-defined standards. It is a genuine game changer for IoT solution providers, as it expands the technical possibilities to make massive IoT deployments economically feasible.

THE NB-IOT DNA

Which qualities does NB-IoT actually possess? Catering to the low bandwidth requirements of many IoT use cases in industrial, public and consumer domains, its unique advantages include lower costs, reduced power consumption and deeper indoor coverage. Based on a global industry standard and operated within licensed spectrum, NarrowBand IoT addresses users' needs for international operations, stability, reliability, security, cost-effectiveness and high scalability. To drive and be a part of this exciting development, Deutsche Telekom is in the process of rolling out NB-IoT across numerous international markets and is involved in the development of related applications.

Low cost
Radio module < 5 $ (industry target), lower total cost of ownership

Plug & Play
Direct connectivity of the 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-like SIM-based security mechanisms

LPWA: DIFFERENT NETWORKS FOR DIFFERENT PURPOSES

NB-IoT is not the only 3GPP-defined LPWA standard. Another example is Long Term Evolution for Machines (LTE-M), also referred to as LTE Cat-M1 or eMTC. Just like NB-IoT it serves as an extension of the current LTE standard and can transmit higher data rates than NB-IoT, but requires significantly more spectrum bandwidth and more complex hence more costly radio modules. The two technologies complement each other by meeting the needs of different IoT use cases.

Some other LPWA technologies have specifications that differ from NarrowBand IoT in a variety of ways, most notably standardization, required infrastructure and spectrum use. NB-IoT is using existing assets of LTE network operators such as sites, base stations, antennas, backhaul and their licensed spectrum. These licensed bands can handle a massive number of devices while remaining stable and avoiding interferences. They have high capacities and are thus highly reliable in their data transmission, hence contributing substantially to the attractiveness of NB-IoT. In contrast, if the number of connected devices increases, data transmission on unlicensed bands is likely to deteriorate (e.g. by interference). Moreover, as a global industry standard, NB-IoT benefits from a large ecosystem of chipset and device manufacturers, which ultimately reduces the risk of vendor lock-in, a problem which can occur with proprietary technologies.

Which technologies can enable a massive deployment of IoT applications? This is the question most users ask when choosing a network.

SCALABILITY IS KEY

Scalability is one of the notable features of cellular networks, in which mobile network operators (MNOs) can manage their own capacities alongside existing LTE networks. In contrast, proprietary technologies like e.g. LoRa and Sigfox need dedicated gateways and networks, operated by different companies across countries and urban regions. Arguably, MNOs are better suited to operate reliable and secure networks and platforms for IoT applications fulfilling the need for data security and high capacities. As an industry standard currently being rolled out all over the world including the US and the Chinese market, where all three mobile operators are rapidly expanding their networks, NB-IoT benefits from decreasing module costs thanks to increasing production scale.

Table 1: **Overview of IoT transmission technologies**

	LTE Cat-1	LTE-M	NB-IoT	LoRa	Sigfox
Spectrum	Licensed	Licensed	Licensed	Unlicensed	Unlicensed
Bandwidth	20 MHz	1.4 MHz	180 kHz	125 – 500 kHz	200 kHz
Bidirectional Data Transfer	Full duplex	Half duplex & full duplex	Half duplex	Half duplex	Half duplex
Peak Data Rate	10 Mbps (DL) 5 Mbps (UL)	1 Mbps (DL) 1 Mbps (UL)	250 kbps (DL) 230 kbps (UL)	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

[1] Assuming typical traffic pattern and battery size

NB-IOT – THE TECHNOLOGY

Apart from the bandwidth it uses, there is nothing narrow about NarrowBand IoT. In fact, this new Low Power Wide Area technology enables a very broad range of new IoT applications. But which of its technical capabilities make this possible?

PERFORMANCE BENEFITS

NB-IoT is based on the LTE technology, whereas some features of its specification deemed unnecessary for LPWA needs have been stripped out. Due to this, NB-IoT is able to provide unique advantages that other technologies like 2G, 3G or LTE cannot achieve or could only do so at great cost. So, how exactly does NB-IoT gain its capability of long battery lifetime, deeper indoor coverage and low module cost?

Operating for many years on batteries is one of NB-IoT's biggest benefits. To enable this, NB-IoT chipsets are optimized to focus only on radio features relevant to the devices used. Signaling and overhead is reduced so that data can be transferred more efficiently directly over the control plane – a feature referred to Data over Non-Access Stratum (DoNAS). Moreover, key 3GPP features such as Power Saving Mode (PSM) put modules into a sleep mode with very low energy consumption (consuming only a very low current of a few µA) while sending occasional tracking area update (TAU) messages to keep them registered at the network to avoid 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 increasing the sleep intervals. 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 device is able to request and control PSM, long periodic TAU and eDRX to optimize its energy consumption according to its use.

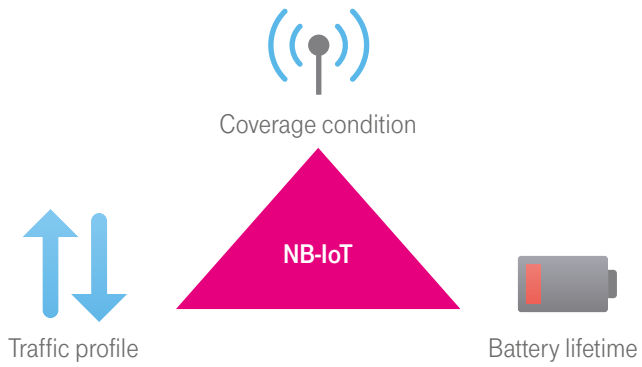
Deep indoor coverage is another great NB-IoT benefit. This is achieved by a higher power density, as radio transmissions are concentrated into a narrower carrier bandwidth of just 180 kHz. The Coverage Enhancement (CE) feature additionally offers the capability to repeat the transmission of a message if needed due to poor coverage conditions however, at the expense of a lower data rate. Proprietary technologies operating on unlicensed spectrum, in contrast, are legally limited in the number of repetitions (due to prescribed duty cycles), which impede effective indoor coverage.

A cost of less than 5 US dollars per NB-IoT module is the specified industry target and expected to be reached within the next years. To ensure this, a range of unnecessary LTE features has been eliminated to its bill of materials (BoM). By waiving carrier aggregation, voice support, multi-stream transmissions for both downlink and uplink, parallel processing, connected mode mobility measurements, turbo decoders and inter- and intra-RAT handovers, the modules can be produced more cost-effectively than regular LTE, 3G or GSM modules.

THE THREE PILLARS OF PERFORMANCE

The technical performance of an NB-IoT device is influenced by three factors: battery lifetime, traffic profile and coverage condition.

Picture 2: **The three pillars of performance**



To determine the effectiveness of a NarrowBand IoT application, the following questions apply:

- Coverage condition: Where is the device located, e.g. deep within a building? The answer indicates whether CE level 0, 1, or 2 is required to establish connectivity.
- Traffic profile: How often should the IoT device send data to the server (uplink traffic)? How large is the average traffic payload? What about downlink traffic (e.g. commands for IoT devices, firmware updates)?
- Battery lifetime: How long should the battery be able to power the IoT device? What type of battery is required?

These factors are interdependent and therefore require a trade-off. Depending on which of them is the most important for an application, users have to accept concessions on the others. For example, an IoT device located deep within the basement of a building (assuming CE level 2 is needed), sending numerous messages an hour will typically not reach a 10-year battery life.

THE NB-IOT NETWORK

NB-IoT is based on LTE, therefore it can also be easily integrated into existing LTE infrastructure. Most of the time, operators can deploy it in their LTE radio access network by simple software upgrades. In addition to these, a few components specified by the 3GPP for NB-IoT need to be set up, e.g. core network elements such as the C-SGN.

As NB-IoT can be deployed both in the GSM or the LTE spectrum, no additional spectrum licenses are needed. It supports different spectral operation modes, making its deployment flexible and adaptable to different regional network implementations, e.g. stand-alone, guard band or in-band operation.

Any device using NB-IoT requires a specific NB-IoT radio module or chipset as well as a SIM card to benefit from LTE-like security. A standardized SIM profile also allows international usage of NB-IoT on the networks of foreign mobile network operators. Many different form factors are supported, including the M2M Form Factor (MFF). However, several providers like Deutsche Telekom do currently not support eSIM (eUICC) due to its high costs, which would not fit in with NB-IoT's low-cost business model.

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

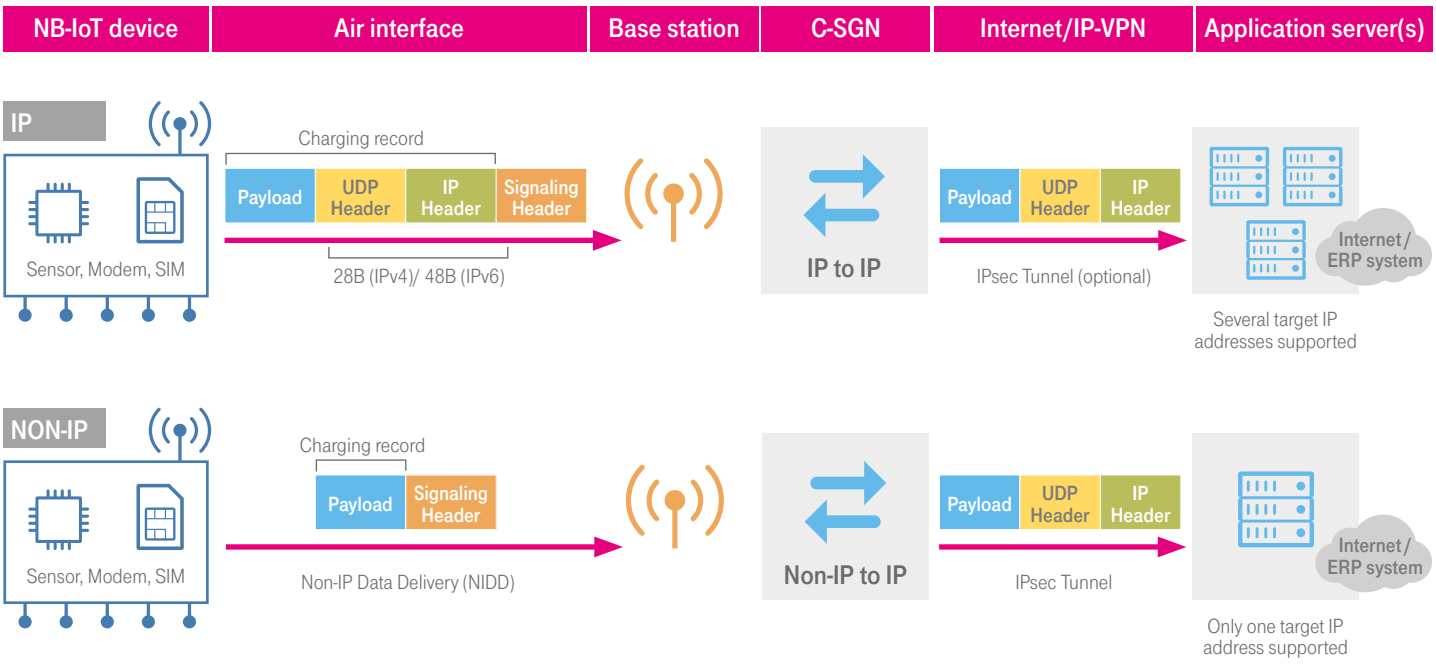
1. **IP:** Depending on the capabilities of the radio module and the operator, IPv4 and IPv6 are supported. Here, UDP is the common and recommended transport protocol. On the air interface, TCP is in principle supported for NB-IoT (and specified in the 3GPP standard), but not recommended due to the resulting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

2. **Non-IP:** If possible, a non-IP based data transmission is recommended for NB-IoT because it reduces the transmitted data volume (since overhead is saved). The data of the device is then forwarded by the 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.

In all cases, application protocols like MQTT, MQTT-SN, COAP and oneM2M can be used.

In general, operator-managed networks allow reliable data connections with no geographical restrictions, as every device has a direct wide area connection. In comparison: For technologies using local or mesh networks, many peripheral gateways must be managed. This can increase the total cost of ownership.

Picture 3: **Data transmission on an NB-IoT network**



SECURE ON ALL LEVELS

NB-IoT is a worldwide standardized technology featuring 3GPP LTE security mechanisms, offering a high security level for its applications.

- **Integrity and authentication:** When accessing the NB-IoT network, the identities of both the subscriber or 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, NB-IoT uses longer encryption keys (128 to 256 bits) to increase the security level. A manipulation of the data is reliably detectable by the device and the C-SGN.

- **Confidentiality:** User data is encrypted between the NB-IoT modem and the core network using a separately generated key and algorithm. Between the core network (C-SGN) and the application server, data traffic is 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 or ERP system.

- **Availability:** Deutsche Telekom's NB-IoT network is operated alongside existing LTE networks. Therefore it benefits from a proven infrastructure and long year operating experience. Its European C-SGN is geo-redundant and therefore highly available. For a further enhancement of availability levels, redundant connections from the core network to the application server are also possible.

Overall, NarrowBand IoT provides a higher security than proprietary technologies, as its protection measures cover all aspects from the UICC in the device to the application servers. Being a global industry standard, NB-IoT (just like LTE) benefits from a large international ecosystem of vendors and other experts to constantly review and enhance security functions and algorithms as new threats arise. As part of its corporate identity, Deutsche Telekom seeks to protect its customers and its assets to the greatest extent possible.

NB-IOT IS NOW

Deutsche Telekom became the first network operator to launch NB-IoT in Germany, where services on live networks are currently available. In the Netherlands, the world's first NB-IoT network with countrywide coverage has already been achieved in May 2017. NB-IoT rollout has also started in several further European countries. In the US, T-Mobile expects to launch the continent's first commercial NB-IoT network in Las Vegas this autumn and plans to establish countrywide coverage by mid-2018.

Deutsche Telekom enables customers, partners and other interested parties to easily start using the new network by offering entry packages to prototype NB-IoT solutions and pilot them in their markets. For this purpose Deutsche Telekom has started its NB-IoT Prototyping Hub already in 2016. Together with its incubator hub:raum, innovative start-ups and established solution providers have developed and tested prototypes in IoT labs in Bonn, Berlin and Krakow, contributing to an early stimulation of the market. Additionally, the WARP NB-IoT Program by hub:raum Krakow and Deutsche Telekom provides an industry ecosystem, enabling start-ups, B2B partners and customers to develop NB-IoT applications and solutions at an early stage.

Deutsche Telekom is also eager to share its best practices in NB-IoT solution design. IoT Solution Guidelines, available to customers and partners, provide insights regarding the network's parameterization, tricks that can be used for power optimization in NB-IoT enabled hardware and device application design. These guidelines also cover security requirements for embedded devices and IoT solutions.

At the time of the first commercial launches, radio modules were only available from a few vendors. In an active exchange with further vendors, Deutsche Telekom was pushing the development of modules and chipsets from the very beginning, so the first modules are expected to be fully certified by the end of 2017.

Deutsche Telekom has also been one of the key driving companies in extending the Global Certification Forum's (GCF) certification scheme to NB-IoT. GCF certification now includes simulator-based conformance testing with 3GPP NB-IoT test cases and live network testing based on GSMA specifications. One missing piece of the puzzle so far was the availability of live networks for GCF NB-IoT field validation. This gap has now been closed with Deutsche Telekom's declaration of NB-IoT field validation availability.

NB-IOT USE CASES

There are many use cases perfectly suited for NB-IoT, as the network supports a very wide range of applications. Notable examples can be found in utilities, logistics, industrial manufacturing, consumer and agriculture, as well as in the smart city and smart building field. By offering low costs, low power consumption and deep indoor coverage, NB-IoT addresses use cases and applications that previously could not be served efficiently by available networks and technologies. Now, enterprises will not only be able to increase the efficiency of existing IoT applications, but also tap into new markets and develop entirely new products and services.

SMART PARKING

According to estimates, up to 30 % of traffic in cities is caused by drivers searching for a parking space. Smart Parking solutions like Deutsche Telekom's Park and Joy help drivers to save time and also enable municipalities to tackle the challenges of providing their inhabitants with enough parking spaces, which increases revenue and reduces traffic. Find – book – park – pay: According to this motto, Park and Joy supports drivers during the whole parking process. The IoT solution collects occupancy information while sensor fusion enables a reliable parking forecast of parking spaces in the city. Drivers can obtain this information through a Smartphone app. The first city to offer Park and Joy is Hamburg, where NB-IoT sensors will be installed throughout the city over the next years.

SUPPLY CHAIN MONITORING

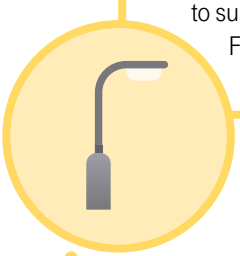
Every year smugglers traffic hundreds of tons of narcotics into the EU and US by sneaking them into third-party shipping containers. To stop this, Dutch start-up Babbler developed a next-generation seal, aiming to fix the flawed security that allows this type of smuggling to happen. The solution provides early warning of integrity incidents, allowing for better risk analysis by customs and carriers. NB-IoT is well-suited for the difficult environments in harbors and on ships, where traditional technologies such as Wi-Fi or GSM fail due to power or connectivity constraints. In addition, global roaming will allow integrity data to be collected from any port or supply chain hub.

SMART SUBMETERING

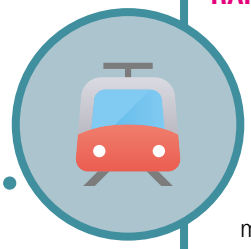
The remote reading of meters and submeters (heat, gas, water and electricity) creates greater convenience for property managers and households in residential buildings. The deep indoor coverage of NB-IoT allows the direct connection of the (sub-)meters without having to install and maintain local gateways. ista International GmbH, a German company providing intelligent submetering services, considers NB-IoT as a potential future technology to facilitate remote submeter reading in residential and commercial properties. The requirements towards intelligent submeter reading perfectly matches with NB-IoT's capabilities, as its low power consumption guarantees a maintenance-free operation for many years, submeters can be reliably connected even deep indoors and the expected overall cost per device is very low. On the contrary, low data rates are acceptable and mobility (as of seamless cell handover) is not needed.

SMART STREET LIGHTING

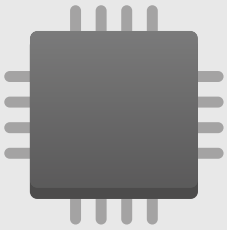
Connecting street lights to the NB-IoT network helps municipalities as well as highway authorities or operators of large shopping centers to increase the energy efficiency and to optimize the maintenance of their lighting network. In-depth grid management gives an accurate real-time feedback of any change occurring along the grid, reduces energy loss and offers advanced maintenance optimization tools. The IoT solution adapts to the existing street lighting infrastructure and uses an array of sensors and add-ons to suit the particular needs of every area. For example, inteliLIGHT, a solution by Romanian company Flashnet, ensures that the right amount of light is provided where and when needed. The solution can yield up to 35 % in energy savings and up to 80 % in reduced maintenance costs.



RAIL ASSET MANAGEMENT

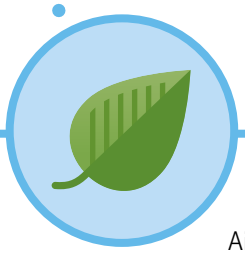


The development of rail asset management systems is being driven by the constantly increasing need for data. On the basis of the NB-IoT network, Dutch company Dual Inventive developed a value-for-money critical rail temperature monitor to help infrastructure managers to guarantee safe passage of trains. With this IoT solution, temperature data is captured and uploaded to a cloud platform. Railway managers can access this data via a mobile app to analyze data and configure alarms to enhance their maintenance processes. These improvements, in turn, help to achieve greater reliability on the railway network.



SMART WASTE MANAGEMENT

Most cities provide waste disposal – regardless of whether it is private or commercial waste – on a fixed schedule. Intelligent waste management is, however, geared to the principle of emptying garbage bins whenever they are full. Sensors measure the fill level of each garbage bin and send this data via NB-IoT to a cloud server for data analysis and calculation of the most efficient route. Collection route optimization helps to significantly reduce logistics costs for garbage trucks and fuel. For business customers in particular, the model also pays dividends: they can pay based on the accumulated garbage and no longer have an overflowing garbage bin. The model also encourages a greater environmental awareness. Eco Mobile from Zagreb, Croatia, specializes in the development, production and implementation of advanced IoT solutions for innovative waste management.



AIR QUALITY MONITORING

Air pollution is a ubiquitous and complex exposure affecting our environment as well as populations all over the world. To understand and prevent air pollution, preserving health and contributing to the fight against climate change, it is essential to monitor air quality not only in the industrial sector but also in public. This enables early detection of pollutants and consequently timely planning of appropriate measures, thus increasing the quality of life in urban areas. Using the NB-IoT network, RadGreen, an Israeli company participating at the Deutsche Telekom NB-IoT Prototyping Hub, has successfully implemented their system in the city of Patras, Greece. Besides air quality it also measures noise and radiation, making it a perfect example of the advanced use of environmental data for the effective monitoring and control of cities and buildings.

OUTLOOK

The commercial introduction of new, standardized and cost-effective NB-IoT services comes on the heels of Deutsche Telekom's NB-IoT network expansion across its markets. Moreover, only one year after its standardization in 2016, ready-to-use NB-IoT devices are currently being developed and tested. This includes both existing devices based on other LPWA technologies now being adapted to NB-IoT, as well as new hardware products for novel use cases and business models.

Moreover, a new release of the 3GPP specification (Release 14) has been published in June 2017. Most notably, it supports single-cell multicast, enhanced device positioning, reduced latency and improved power consumption (14 dBm output power reduction to enable further module cost savings), among other technical enhancements. The technical specifications of Release 14 will be gradually integrated into network components, chipsets and modules according to their usual development cycles, which will further improve the NB-IoT technology. Going forward, 2018's Release 15 will include enhancements for further battery consumption minimization. To support and drive the NB-IoT evolution, which will also include international roaming, Deutsche Telekom is in intensive exchange with suppliers and customers and is working alongside standardization bodies such as 3GPP and GSMA.

Looking further into the future, NB-IoT can be regarded as a precursor for 5G and will be an important part of the 5G technologies. With its virtualized core networks already implemented at Deutsche Telekom, it is reality today. Specifically for massive IoT applications NB-IoT is a crucial technological innovation that unlocks the door for the next generation of IoT architectures and services, and already provides meaningful indications for future value creation opportunities.

GLOSSARY

2G/3G/4G/5G	3GPP mobile telecommunication standard generations
3GPP	3rd Generation Partnership Project
B2B	Business-to-Business
BoM	Bill of Materials
CE	Coverage Enhancement
COAP	Constrained Application Protocol
C-SGN	Cellular Serving Gateway Node (combined 3GPP core network, especially for NB-IoT)
dB(m)	Decibel (milliwatt)
DoNAS	Data over Non-Access Stratum
eDRX	extended Discontinuous Reception
eMTC	Enhanced Machine-Type Communications
ERP	Enterprise Resource Planning
eSIM	Embedded Subscriber Identity Module
eUICC	embedded Universal Integrated Curcuit Card (SIM)
GCF	Global Certification Forum
GSM	Global System for Mobile Communications (2G)
GSMA	GSM Alliance, of which Deutsche Telekom is a member
HTTP(S)	Hypertext Transfer Protocol (Secure)
IMSI	International Mobile Subscriber Identity
intra-RAT	intra Radio Access Technology
IoT	Internet of Things
IP/IPv4/IPv6	Internet Protocol / Internet Protocol version 4 / Internet Protocol version 6
IPsec	Internet Protocol Security
LPWA	Low Power Wide Area
LTE	Long Term Evolution (4G)
LTE-M	LTE for Machine-Type Communications (LTE Cat-M1, eMTC)
M2M	Machine-to-Machine
MFF	M2M Form Factor
MNO	Mobile Network Operator
MQTT(-SN)	Message Queue Telemetry Transport (-Sensor Networks)
NB-IoT	NarrowBand Internet of Things (LTE Cat-NB1)
NIDD	Non-IP Data Delivery
PSM	Power Saving Mode
SIM	Subscriber Identity Module
TAU	Tracking Area Update
TCP	Transmission Control Protocol
UDP	User Data Protocol

LIFE IS FOR SHARING.

IMPRINT

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