# The Promise of Narrowband IoT

The Internet of Things (IoT) is expected to drive the next technological revolution that will change how we live and work. IoT will enable billions of devices with intelligent sensors and machine learning capabilities that will communicate, sense, and interact with internal or external systems, all without human intervention.

This phenomenon will cause a significant increase in the volumes of real-time data and the associated signaling traffic. Machina Research (August 2016) estimates that 27 billion connected devices will be deployed by 2025.[1] The same research also indicates that 11% of connections will use Low-Power Wide-Area (LPWA) networks. The massive IoT market segment includes several applications widely used in industries and societies, as shown in Figure 1 below.


Figure 1. MTC industry segments

Current cellular technology is not very well optimized for this massive machine-type communication (MTC). LPWA solutions and services have been around for many years, but are fragmented and non-standardized. There are therefore certain shortcomings like poor reliability, poor security, and complex deployment, as well as high operational and maintenance costs.

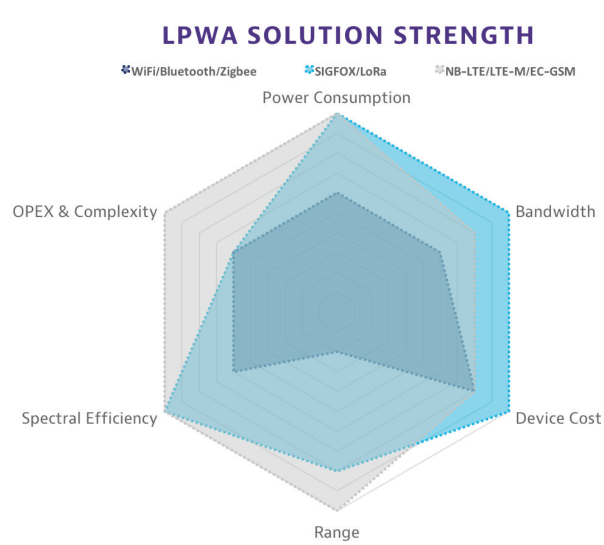


Figure 2. LPWA solution offering

## LPWA Solution

| | SIGFOX | LoRa | NB-LTE | LTE-M | EC-GSM |
|---|---|---|---|---|---|
| Range (outdoor) | <13km | <11km | <15km | <11km | <15km |
| MCL | 106dB | 157dB | 164dB | 156dB | 164dB |
| Spectrum | Unlicensed | Unlicensed | Licensed | Licensed | Licensed |
| Bandwidth | 100Hz | <500Hz | 180kHz | 1.4MHz | 200kHz |
| Data Rate | <100bps | <10kbps | <150kbps | <1Mbps | 10kbps |
| Battery Life | >10 yrs | >10 yrs | >10 yrs | >10 yrs | >10 yrs |
| Cost of Device | ~2 USD | ~2 USD | <5 USD | <5 USD | <5 USD |
| Timeline | Today | Today | 2016-17 | 2016-17 | 2016-17 |

To overcome these challenges, industry standards group 3rd Generation Partnership Project, or 3GPP, started working on standardization of the requirements for new cellular-based narrowband technology targeted for the Internet of Things. The first version of the NB-IoT standard was released in June 2016, as a part of Release 13 of the global 3GPP standard. In parallel, a pure LTE-based solution, LTE-M, was also brought into 3GPP, continuing the optimizations already done in Release 12 with the introduction of a new device category cat-M1. However, deployment flexibility and other optimizations offered by NB-IoT may make it a better solution for efficient utilization of spectrum and other network resources.

Some of the key requirements for cellular IoT to enable the above-mentioned services and to efficiently compete with non-cellular technologies can be summarized as follows:

- Long battery life – more than 10 years, as many IoT devices will be battery-powered, and often the cost of replacing batteries in the field is not viable.
- Low device cost – sub 5 USD per module, for a positive business case when billions of devices need to be integrated this is a must have.
- Low deployment cost – plug and play to reduce OpEx.
- Extended coverage – 164 dB maximum coupling loss (MCL), 20dB better than General Packet Radio Service (GPRS), typically NB-IoT devices tend to be placed in signal-challenged location like basements and remote rural areas.
- Support for a massive number of devices – 40 devices per house hold or 50K per cell.

Although NB-IoT is integrated into the LTE standard, it can be considered as a new air interface and thus not fully backward compatible with existing 3GPP devices. However, it is designed to achieve excellent co-existence performance with legacy GSM, GPRS, and LTE technologies.

NB-IoT requires 180 kHz minimum system bandwidth for both downlink and uplink, respectively. The choice of minimum system bandwidth enables several deployment options for NB-IoT as shown in figure 3 below.

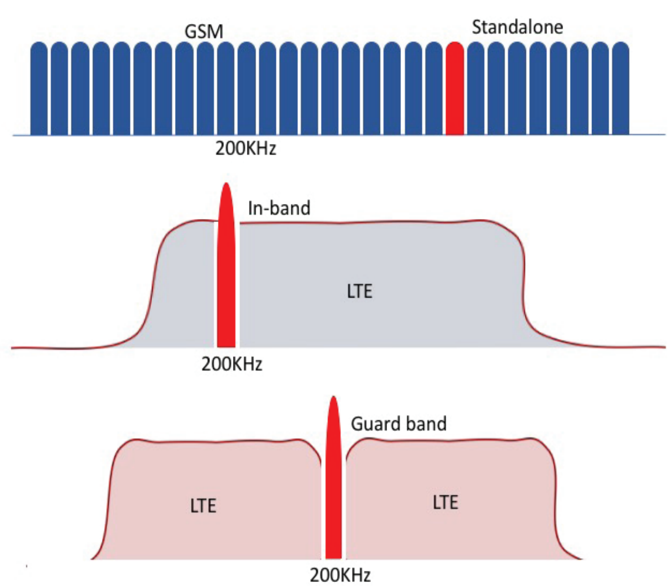


Figure 3. Deployment options for NB-IoT

### Deployment option for NB-IoT Standalone – replacing a GSM carrier with an NB-IoT carrier

GSM is still the dominant mobile technology in many markets, and the significant majority of cellular M2M applications today use GPRS/EDGE for connectivity. By reframing one or more of the GSM carriers to carry NB-IoT traffic, GSM operators can ensure a smooth transition to LTE for massive MTC in the future. This approach will also accelerate IoT time-to-market, maximizes the benefits of a global-scale infrastructure and guarantees future-proofing of IoT investments.

### In-band –flexible use of part of an LTE carrier

The LTE in-band option provides the most spectrum- and cost-efficient deployment of NB-IoT for service providers with LTE service. The in-band option sets NB-IoT apart from any other LPWA technology. The NB-IoT carrier is a self-contained network element that uses a single physical resource block (PRB). If there is no IoT traffic, a Physical Resource Block (PRB), available for an NB-IoT carrier, may be used instead for other purposes, as the infrastructure and spectrum usage of LTE and NB-IoT are fully integrated. The base station scheduler multiplexes NB-IoT and LTE traffic onto the same spectrum, which minimizes the total cost of operation for MTC, which essentially scales with the volume of MTC traffic.

In the in-band operation, certain resource blocks are allowed for NB-IoT They are restricted to the following values:

| LTE System Bandwidth | 3 MHz | 5 MHz | 10 MHz | 15 MHz | 20 MHz |
|---|---|---|---|---|---|
| LTE PRB indices for NB-IoT synchronization | 2, 12 | 2, 7, 17, 22 | 4, 9, 14, 19, 30, 35, 40, 45 | 2, 7, 12, 17, 22, 27, 32, 42, 47, 52, 57, 62, 67, 72 | 4, 9, 14, 19, 24, 29, 34, 39, 44, 55, 60, 65, 70, 75, 80, 85, 90, 95 |

### Guard Band – Applies to both WCDMA or LTE

A third alternative is to deploy NB-IoT in a guard band, which allows NB-IoT to operate without causing interference. In contrast to other LPWA technologies, the physical NB-IoT layers have been designed with the requirements of in-LTE-guard-band coexistence specifically taken into consideration.

Again, like LTE, NB-IoT uses OFDMA in the downlink and SC-FDMA in the uplink. The design of NB-IoT has fully adopted LTE numerology, using 15kHz subcarriers in the uplink and downlink, with an additional option for 3.75kHz subcarriers in the uplink to provide capacity in signal-strength-limited scenarios.

### NB-IoT Enhancements

Device affordability and battery life are the key to successful deployment of massive MTC. Low data rates and relatively relaxed latency requirements for NB-IoT devices offer an opportunity to reduce solution complexity – and cost. Some of the needed changes for NB-IoT to get to a simpler and cost reduced device are:

- Reduced peak physical layer data rates: in the range of 100–200kbps or significantly lower for single-tone devices.
- FDD only and half-duplex User Equipment (UE) supported. For half-duplex support, every switch from UL to DL or vice versa there is at least one guard subframe (SF) in between, where the UE has time to switch its transmitter and receiver chain.
- To facilitate low-complexity decoding in devices, turbo codes are replaced with convolutional codes for downlink transmissions.
- Coverage extension is achieved by trading off data rate through increasing the number of repetitions. Coverage enhancement is ensured also by introducing single subcarrier Narrowband Physical Uplink Shared Channel (NPUSCH) transmission and π/2-BPSK modulation to maintain close to 0 dB PAPR, thereby reducing the unrealized coverage potential due to power amplifier (PA) backoff.
- Preamble based Random Access on 3.75 kHz
- NPUSCH provides two subcarrier spacing options: 15 kHz and 3.75 kHz. The additional option of using 3.75 kHz provides deeper coverage to reach challenging locations, such as deep inside buildings, where there is limited signal strength.
- The data subcarriers are modulated using binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) with a phase rotation of π/2 and π /4 respectively.
- Both single tone and multi-tone transmission is supported.
- Maximum transport block size (TBS) 680 bits in downlink, 1000 bits in uplink is supported.
- Narrow band physical downlink channels of 180 kHz equivalent to 1 PRB of LTE. Benefit of a narrowband technology lies in the reduced complexity of analog-to-digital (A/D) and digital-to-analog (D/A) conversion, buffering, and channel estimation – all of which bring benefits in terms of power consumption.

- A single receiver antenna is used, enabling radio and baseband demodulator parts to be only a single receiver chain.
- Design changed in terms of the placement of the device's power amplifier (PA). Integrating this element directly onto the chip, instead of it being an external component, enables single-chip modem implementations – reducing device cost.
- Single-process, adaptive and asynchronous HARQ for both UL and DL is supported.
- Maximum PDCP SDU size of 1600 bytes is supported.
- Extended Idle mode DRX with up to 3-hour cycle, connected mode DRX with up to 10.24 s cycle, allows battery longevity.
- Offers same authentication and core network signaling security as in normal LTE.
- Data transfer over Non-access stratum (NAS) signaling is also supported, which enables the usage of other delivery protocols than IP as well
- Access stratum (AS) optimization called RRC suspend/resume to minimize the signaling needed to suspend/resume user plane connection.
- No support for circuit switched services
- No support Inter-RAT mobility, intra-RAT mobility will be managed by cell reselection.

**Performance of NB-IoT:**

Even though the NB-IoT applications have reduced performance requirements, they reuse the same LTE design extensively, including the numerologies, downlink orthogonal frequency-division multiple-access (OFDMA), uplink single-carrier frequency-division multiple-access (SC-FDMA), channel coding, rate matching, interleaving, etc. This approach significantly reduces the time required to develop full specifications and helps in better integration with existing LTE infrastructure. However, NB-IoT is considered as a new 3GPP radio-access technology (RAT). Several changes are still required to both uplink and downlink channels to ensure required efficiencies are delivered.

NB-IoT RB power dynamic range, or NB-IoT power boosting, is defined as the difference between the power of the NB-IoT carrier, which occupies a PRB of the LTE carrier in-band, or 180kHz in the guard band, and the average power for the overall carrier including LTE and NB-IoT. For both in-band and guard band operations, the NB-IoT dynamic range should be equal to or greater than 6dB. Validating downlink power linearity by measuring inter-RB distortion can ensure NB-IoT performance. Viavi's CellAdvisorTM has a NB-IoT signal analysis feature that can help quickly validate performance of NB-IoT networks as shown in figure 4.

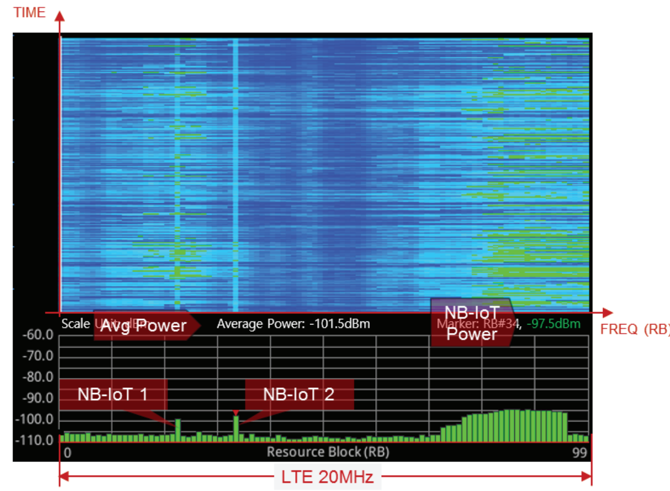


Figure 4. LTE and NB-IoT in-band downlink signal analysis

New RAT offers some challenges because of the diverse frequencies and the potential to interfere with other LTE traffic. Validation of the new physical channels and signals introduced in the downlink and uplink are necessary to ensure NB-IoT is not causing interference to the existing LTE network and vice versa. Viavi's CellAdvisorTM can help analyze the signal in terms of constellation, data channel, control channel, subframes etc.

Another challenge could be the deployment strategy for in-band NB-IoT. As NB-IoT is a new RAT, sites with older equipment may require hardware upgrades, whereas sites with newer equipment can quickly support NB-IoT via software upgrade. In such a scenario, operators may decide to phase in the deployment of NB-IoT, where sites requiring hardware upgrades may offer NB-IoT solutions at a later point. Phased roll-out can allow for faster deployment of NB-IoT without the need to upgrade the hardware on all sites. But this deployment option may create some problems. NB-IoT devices may not be able to attach to the best cell if that cell does not yet support NB-IoT. In this case, the path loss can be very high. In addition, they would also suffer from high interference coming from surrounding non-NB-IoT cells. In situations like this, OTA RF testing may be required; using a spectrum analyzer solution such as CellAdvisor Base Station Analyzer can help operators take proactive steps to optimize cell coverage areas.

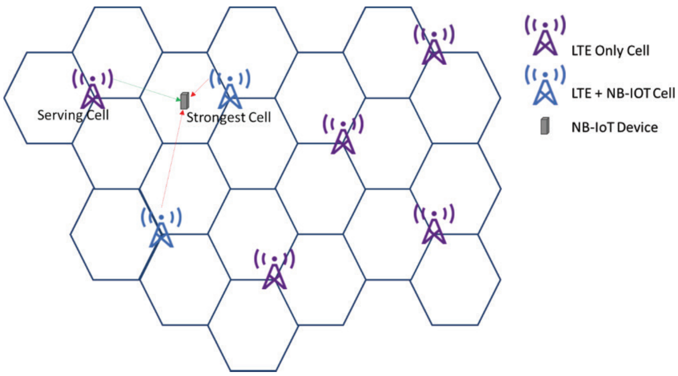


Figure 5. Non-uniform in-band deployment for NB-IoT[2]

## Summary for NB-IoT

| NB-IoT | |
|---|---|
| Deployment | In-band & Guard-band LTE, standalone |
| Coverage (MCL) 164 dB | In-band & Guard-band LTE, standalone |
| Downlink | OFDMA, 15 KHz tone spacing, TBCC, 1 Rx |
| Uplink Single tone | 15 KHz and 3.75 KHz spacing, SC-FDMA: 15 KHz tone spacing, Turbo-code |
| Bandwidth | 180 KHz |
| Highest modulation | QPSK |
| Duplexing | Half Duplex FDD |
| Duty cycle | Up to 100%, no channel access restrictions |
| MTU | Max. PDCP SDU size 1600 B |
| Power saving | PSM, extended Idle mode DRX with up to 3 h cycle, Connected mode DRX with up to 10.24 s cycle |
| UE Power | 23 dBm and 20dBm |

### Conclusion

Current IoT communication solutions on cellular systems are an overkill in terms of power and cost for many of IoT's applications. LTE-M and NB-IoT both offer lower cost and lower power consumption for a more efficient network. Operation in licensed spectrum ensures that capacity and coverage performance targets can be guaranteed for the lifetime of a device, in contrast to technologies that use unlicensed spectrum like SigFox and LoRa etc., which run the risk of uncontrolled interference emerging even years after deployment, potentially knocking out large populations of MTC devices.

Work continues for NB-IoT (and eMTC) in the 3GPP Forum. Future plans for NB-IoT include positioning methods, multicast/broadcast services support (for software updates or for messages concerning a whole group), lower power class (e.g. 14dBm), mobility enhancements for service continuity, and improved data rates.

### Viavi RF Test Solution

As LTE continues to evolve so is Viavi. Viavi Solutions has been working closely with service providers to offer a wide range of test and measurement solutions that will help them quickly deploy, maintain, and optimize new technologies as they are deployed. Our CellAdvisor Base Station Analyzer is a comprehensive solution that covers coaxial transmission sweep testing, fiber inspection, RFoCPRI/RFoOBSAI analysis, and signal quality analysis. CellAdvisor also fully supports NB-IoT testing.

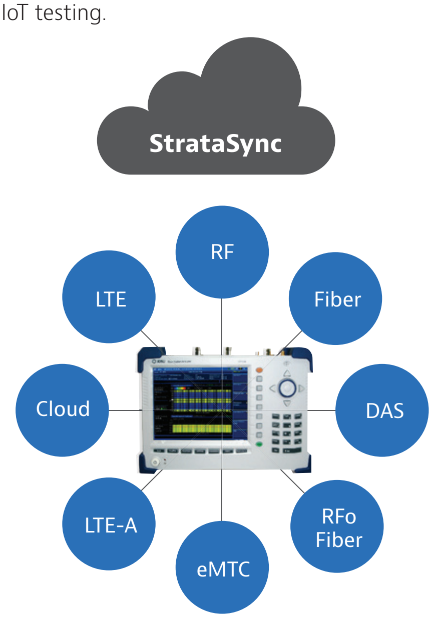


Figure 6. CellAdvisor RF test solution

[1] https://machinaresearch.com/news/press-release-global-internet-of-things-market-to-grow-to-27-billion-devices-generating-usd3-trillion-revenue-in-2025/

[2] http://ieeexplore.ieee.org/document/7794567


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