Narrowband Internet of Things

NB-IoT presentation

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Introduction

The Narrowband Internet Of Things (NB-IoT), also called LTE-M2, is a mobile network technology intended for connected objects communication. It enables low-power, low-cost, and low-data-rate communication and aims to support massive machine-type communication. The NB-IoT technology aims, through LTE optimization, to meet this demand (more than 50 thousand devices) with low data rates in delay-tolerant applications.
The purpose of this report is to gather information about this technology. First, we will talk about the physical layer of NB-IoT and all the specifications associated (frequency, modulation, bandwidth…). Then we will discuss the MAC layer of this technology. Finally, we will try to characterise the power consumption this technology uses.

Frequency Range	NB - IoT (LTE) FDD Bands: 1, 2, 3, 5, 8, 11, 12, 13, 17, 18, 19, 20, 25, 26, 28, 66, 70 MHz
Duplex Mode	FDD Half Duplex Type B
Multiple Access	Downlink: OFDMA - Uplink: SC-FDMA
Modulation Scheme	Downlink: QPSK - Uplink: π/4-QPSK, π/2-BPSK, QPSK
Link Budget	Up to 164 dB (20dB GPRS)
Data Rate	~25 kbps in Download and ~64 kbps in UL
Latency	< 10 seconds
Low Power	eDRX, Power saving mode
Features Supported	HARQ , Uplink Power Control

Key Parameters of NB-IoT

Source: [MAC Layer Protocols for Internet of Things: A Survey]

Physical layer

Frequency

Frequencies are specific according to regions. Here is an example of Narrowband IoT frequencies :

- **North America:** B4 (1700MHz), B12(700Mhz), B66 (1700MHz), B71 (600MHz), B26 (850MHz)
- **Europe:** B3 (1800MHz), B8 (900MHz) and B20 (800MHz)

- **Asia Pacific:** B1 (2100MHz), B3(1800MHz), B5(850MHz), B8(900MHz), B18(850MHz), B20(800MHz), B26(850MHz), B28(700MHz)

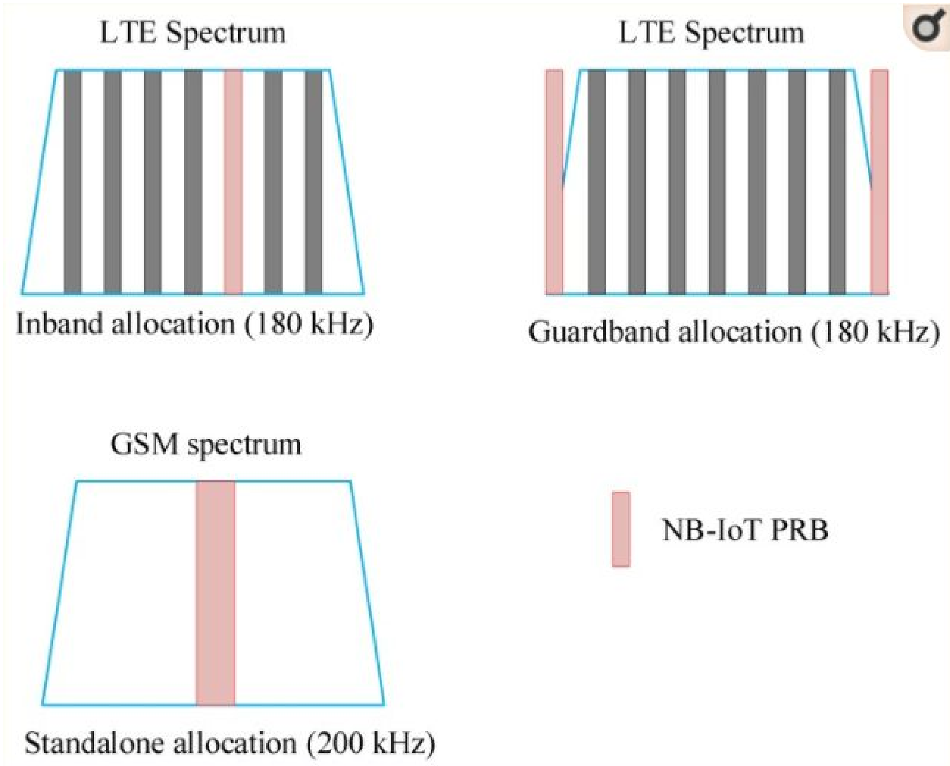
The following table is an extract of band details:

NB Band	Uplink (UL) Operating Band BS Receive / UE Transmit F_{UL_low} – F_{UL_high}	Downlink (DL) Operating Band BS Transmit / UE Receive F_{DL_low} – F_{DL_high}
B1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz
B3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz
B4	1710 MHz – 1755 MHz	2110 MHz – 2155 MHz
B5	824 MHz – 849 MHz	869 MHz – 894 MHz
B8	880 MHz – 915 MHz	925 MHz – 960 MHz
B12	699 MHz – 716 MHz	729 MHz – 746 MHz
B18	815 MHz – 830 MHz	860 MHz -875 MHz
B20	832 MHz – 862 MHz	791 MHz -821 MHz
B26	814 MHz – 849 MHz	859 MHz – 894 MHz
B28	703 MHz – 748 MHz	758 MHz – 803 MHz
B66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz
B71	663 MHz – 698 MHz	617 MHz – 783 MHz

Source:
NB-IoT Frequency Bands (As per 3GPP Rel. 13, 14 and 15)

Bandwidth

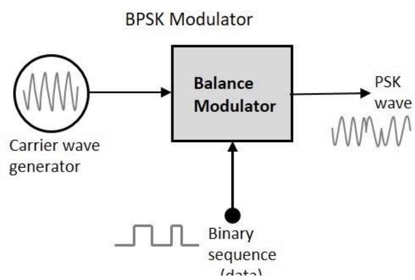
There are three different deployment modes for NB-IoT based on the following image. Inband and guarband allow a downlink and uplink bandwidth of 180KHz. Standalone mode allows a bandwidth of 200KHz. These different modes allow more flexibility for integration with LTE or GSM systems.



Source:
[Narrowband Internet of Things (NB-IoT): From Physical (PHY) and Media Access Control (MAC) Layers Perspectives]()

Modulation

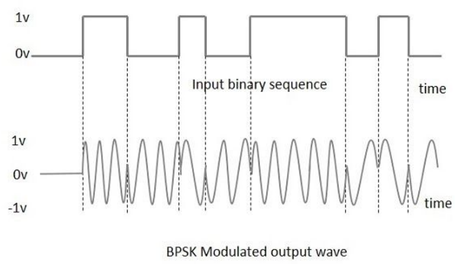
It should be relevant to remind ourselves what is the modulation, and what purpose it serves. To wirelessly transfer data, the connected object has to use a carrier wave. This carrier wave has to be modulated by a signal : this signal represents the information needed to be transfered, and is a binary sequence. This section discusses the modulation method used by NB-IOT.
This Wireless Sensor Network will use BPSK and QPSK modulation : these are phase modulations (opposed to amplitude and frequency modulations).



- **BPSK (Binary Phase Shift Key) modulator:**

The block diagram of Binary Phase Shift Keying consists of the balance modulator which has the carrier sine wave as one input and the binary sequence as the other input.

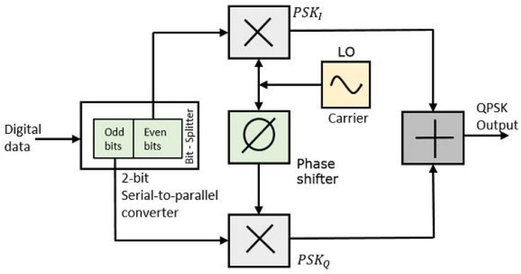
The modulation of BPSK is done through a balance modulator, multiplying the two signals given as inputs. For a zero binary input, the phase will be 0° and for a one input, the phase reversal is of 180°.



The output sine wave of the modulator will be either the direct input carrier or the inverted 180°phase shifted input carrier, which is a function of the data signal.

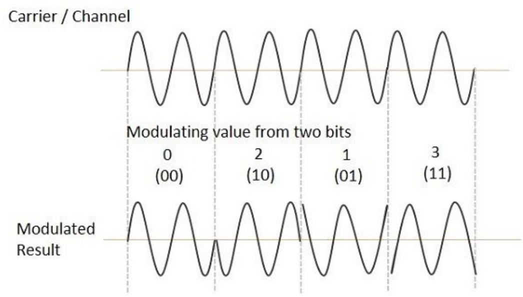
- **QPSK (Quadrature Phase Shift Key):**

The Quadrature Phase Shift Keying (QPSK) is a variation of BPSK which sends two bits of digital information at a time, called as bigits.
Rather than convert digital bits into a series of digital streams, it converts them to bit pairs. This reduces the bitare by half, which means more space for other users.



The QPSK Modulator uses a summer circuit, a bit-splitter, a 2-bit serial to parallel converter and two multipliers with a local oscillator (see block diagram on the left).

At the input of the modulator, the message signal's even bits (i.e. the 2*n-th bit) and odd bits (i.e. the (2+1)*n-th bits) are split by the bits splitter, and multiplied by the same carrier to generate two signals: odd BPSK (called PSKI) and even BPSK (called PSKQ). The PSKQ signal is then phase shifted by 90° before being modulated.
On the diagram to the right, we can see the QPSK waveform for two-bits input, showing the result of various binary inputs being modulated.



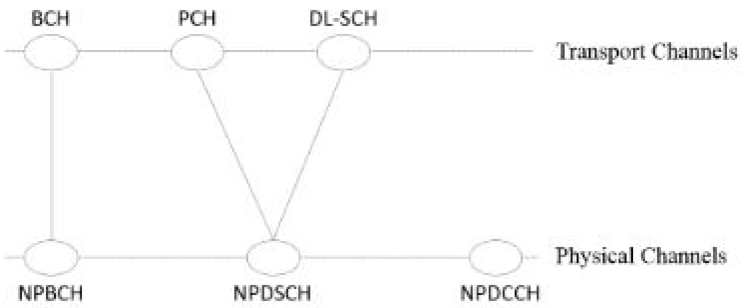
- BPSK can transmit one bit per symbol, while QPSK transmits two bits per symbol. We can use QPSK to double the data rate while keeping the same bandwidth, or halving the bandwidth to keep the same data rate.
- With the same energy per symbol, there's less chance for a BPSK symbol to be wrongly decoded compared to a QPSK symbol.
- Just like for LTE, NB-IoT link adaptation requires adaptive coding and modulation schemes, and adaptive power allocation. To reduce complexity and therefore power consumption, the modulation schemes are limited to QPSK.

Source:
[Narrowband Internet of Things (NB-IoT): From Physical (PHY) and Media Access Control (MAC) Layers Perspectives]

MAC layer

NB-IoT uses multiple physical channels and logical channels. These are the physical channels shows in the following figure:

- Narrowband Physical Broadcast Channel (NPBCH)
- Narrowband Physical Downlink Shared Channel (NPDSCH)
- Narrowband Physical Downlink Control Channel (NPDCCH)



NB-IoT Channels representation

The standard also uses different signals:

- Narrowband Reference Signal (NRS)
- Narrowband Primary Synchronization Signal (NPSS)
- Narrowband Secondary Synchronization Signal (NSSS)

NSSS and NPSS are used for cell detection as well as time and frequency synchronization. NRS is used to provide a phase reference during the demodulation of downlink channels.

These resources in the NB-IoT protocol are time multiplexed, sub frames of the whole frame structure are provided for different channels and physical signals. These sub frames contain a resource block in the frequency domain and 1ms in the time domain.

NPBCH is used to transmit the NB-IoT Master Information Block (MIB), which contains essential data for the NB-IoT User Equipment (UE) to operate in the overall NBèIoT network, and is therefore sent in each sub-frame 0 of the frame.

NPDCCH carries information relative to the scheduling of the downlink and uplink data channels.

NPDSCH carries higher layer data as well as paging message, system info and random access response message.
NPDSCH carries higher layer data, the random access response message, system info and the paging message.

NPRACH, a new random access channel, and NPUSCH, a channel for sending data, are physical uplink channels in NB-IoT.

We can find two types of transmission in NB-IoT, multi-tone and single-tone.
Multi-tone is based on SC-FDMA, it uses 15 kHz sub-carrier spacing, 0.5 ms slots and 1 ms subframes.

There are two kinds of single-tone transmissions, 15 kHz and 3.75 kHz. The 15 kHz is identical to LTE and achieves the best coexistence performance with LTE in the uplink.
The 3.75 kHz single-tone uses 2 ms slot duration.

Sub-carrier spacing	No of tones	No of SC-FDMA symbols	Transmission time
15 KHz	12	14	1 ms
15 KHz	6	28	2 ms
15 KHz	3	56	4 ms
15 KHz	1	112	8 ms
3.75 KHz	1	112	32 ms

NB-IoT Specifications

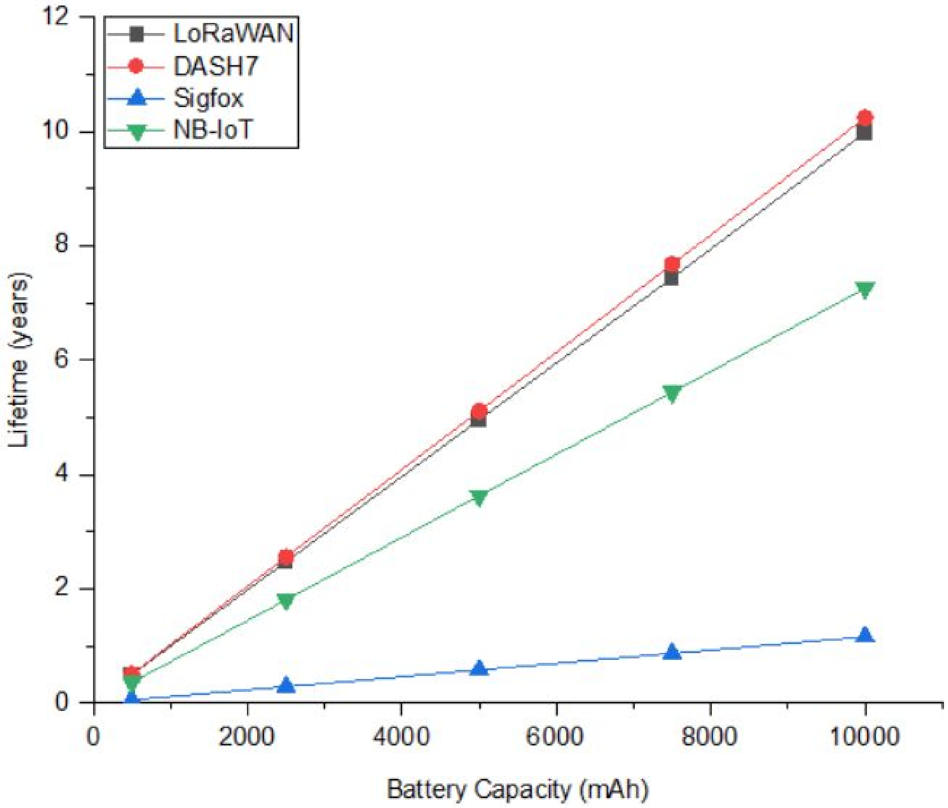
Sources:

- LTE MAC Layer – Medium Access Control
- MAC layer-based evaluation of IoT technologies: LoRa, SigFox and NB-IoT
- Random Access Preamble Design and Detection for3GPP Narrowband IoT Systems

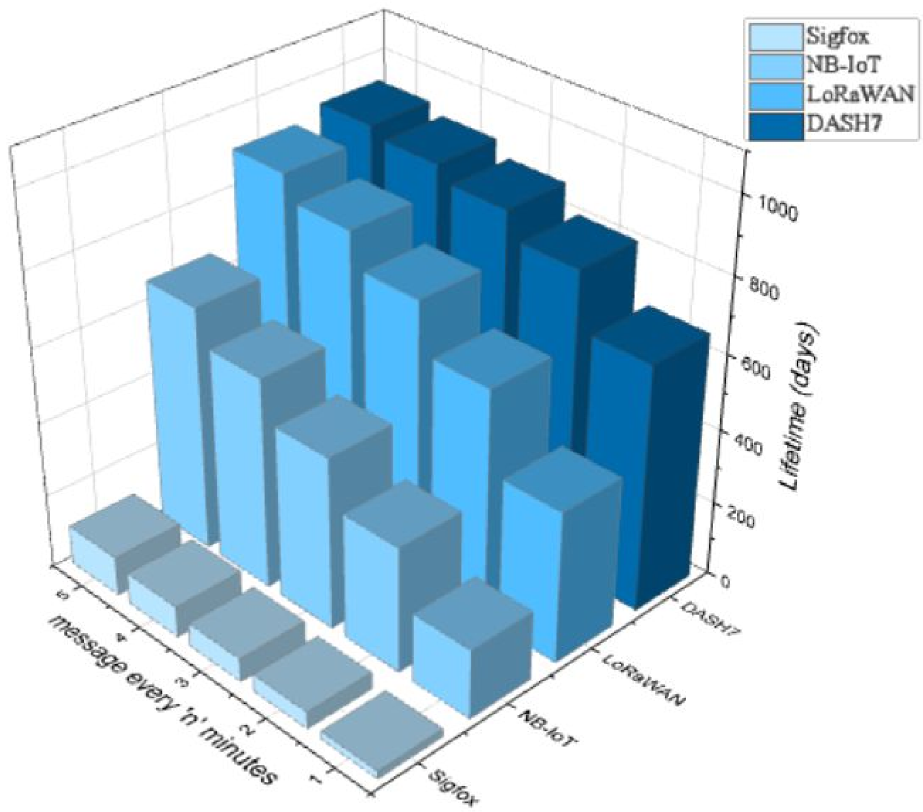
Energy consumption

The NB-IoT protocol offers two battery saving modes: eDRX (Extended Discontinuous Reception Mode) and PSM (Power Saving Mode).
The system switches to a connected mode after registering on the network. The eDRX mode starts right after for a maximum of 186 minutes where it can listen to the downlink control channel.
The system can thenswitch to the PSM mode for a maximum of 413.3 days. The system keeps the network registration settings but completely turns off its radio.

While we initially set out to calculate the power consumption of NB-IoT per transmited bit, we instead used figures showing the power consumption of the standard compared to its direct competitors, to have a better idea of how it fares compared to similar technologies.



Lifetime estimation for different LPWAN technologies and different battery capacities



Lifetime estimation for different LPWAN technologies and different transmission frequencies on 2500 mAh battery based on the frequency of emission

Source:

[Energy Consumption Analysis of LPWANTechnologies and Lifetime Estimation forIoT Application]

In *An Empirical NB-IoT Power Consumption Model for Battery Lifetime Estimation*, the authors set to illustrate the NB-IoT power measurement. They set the experiment with NB-IoT transmission consuming 716 mW when at 23 dBm with a power efficiency of 37%. Download control and data signals consume 213 mW, idle-mode-eDRx and PSM consumes 21 mW and 13 μW, respectively. According to their measurements, the power consumption is 10% around lower than the 3GPP estimates. Many parameters were taken into account for these tests, such as PSM, I-eDRx and time domain reptition. Their results showed that the subcarrier spacing has no effect on the NB-IoT device's power consumption. However, the total ON time of the devices often matters for the overall battery life. The data rates do not directly impact the power consumption, but it has a major indirect impact because it defines the overall device ON time. If the transmitting interval is 1h, the device achieves only 2.5 weeks of battery life. Increasing the duration to 24h, the lifetime of the device increases to 12.8 years in PSM.

In *Prediction-Based Energy Saving Mechanism in 3GPP NB-IoT Networks Sensors*, the authors used a prediction-based energy-saving mechanism to reduce energy consumption by decreasing the number of scheduling request procedures. Their proposed scheme showed that it could reduce the NB-IoT active time from 5% to 16% for the medium and bad channel quality and achieve from 10% to 34% battery saving in different scenarios as compared to 3GPP consumption simulation specifications.

In conclusion, while it seems like NB-IoT consumes more power than its biggest competitor LoRa, it's a tradeoff made for a higher payload size and better deployment flexibility.

Source:

[Narrowband Internet of Things (NB-IoT): From Physical (PHY) and Media Access Control (MAC) Layers Perspectives]

Conclusion

As a relatively new protocol, finding practical information about NB-IoT isn't easy. While a lot of research papers are published on the subject, the proprietary nature of this standard developped by 3GPP makes it hard to get started with the technology.

As a direct alternative to LoRa and Sigfox, NB-IoT offers advantages and drawbacks: the coverage is very good, since it relies on 4G and 5G coverage, and around 50 000 objects can be connected to a single antenna. It also has a shorter reponse time, and larger payload sizes. However, it consumes slightly more power than its alternatives, and doesn't really allow you to set up and manage your own network.

All in all, NB-IoT is great for large scale networks of primarily static objects, in an area with 4G or 5G coverage and sensors sending large packets of data.