INNOVATIVE SMART SYSTEMS

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES TOULOUSE

Introduction for NB-IoT

Wireless communication protocols

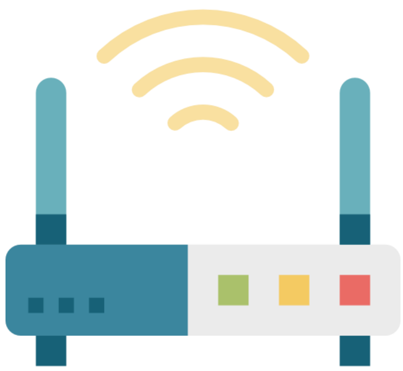

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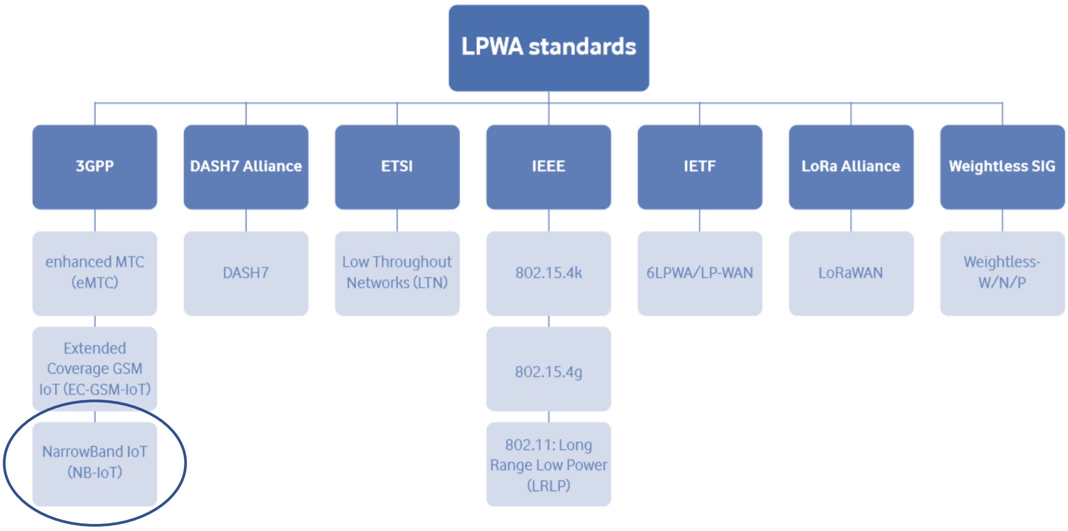
TABLE DES MATIERES

INTRODUCTION

Narrowband IoT (NB-IoT) is a Low Power Wide Area Network (**LPWAN**) radio technology standard developed by 3GPP to enable a wide range of cellular devices and services. The specification was frozen in **3GPP** Release 13 (LTE Advanced Pro), in **June 2016**.



NB-IoT focuses specifically on indoor/outdoor coverage, low cost, long battery life, and high connection density. NB-IoT is based on already existing structures and promoted by mobile phones sellers such as Huawei and Vodafone leading. It enters directly in competition with networks like **LoRa** and **Sigfox**, but not as a private initiative.

This technology wants to meet several domains, represented in the ***Figure 1*** below, and which are the IoT challenges of tomorrow, completed with the coming 5G network. .

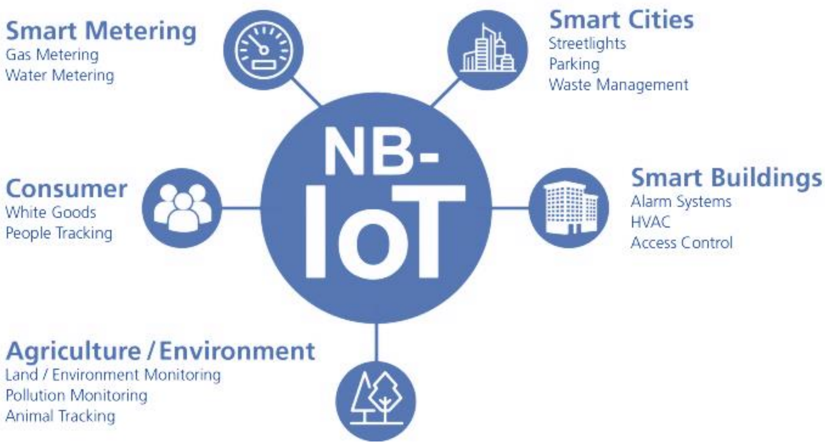


Figure 1: NB-IoT challenges

1. PHYSICAL LAYER: FREQUENCY, BW, MODULATION…

1.1. Operation modes & frequencies

NB-IoT technology uses a frequency band of **180 kHz** bandwidth (versus 1 to 18 MHz for today cellular technologies). Data rate for transmission is limited at 250 Kbits/s, which corresponds to one resource block in LTE transmission. The following operation modes are possible:

- ***Stand-alone operation***: Utilization of current GSM frequencies (there is still an interval of 10 kHz remaining on both sides of the 200kHz bandwidth).
- ***Guard band operation***: Utilization of the unused resource blocks within an LTE carrier's guard-band.
- ***In-band operation**:* Utilization of resource blocks within an LTE carrier (the assignment of resources between LTE and NB-IoT is not fixed, nevertheless, not all frequencies are allowed).

The ***Figure 2*** below shows a representation of each possible mode:

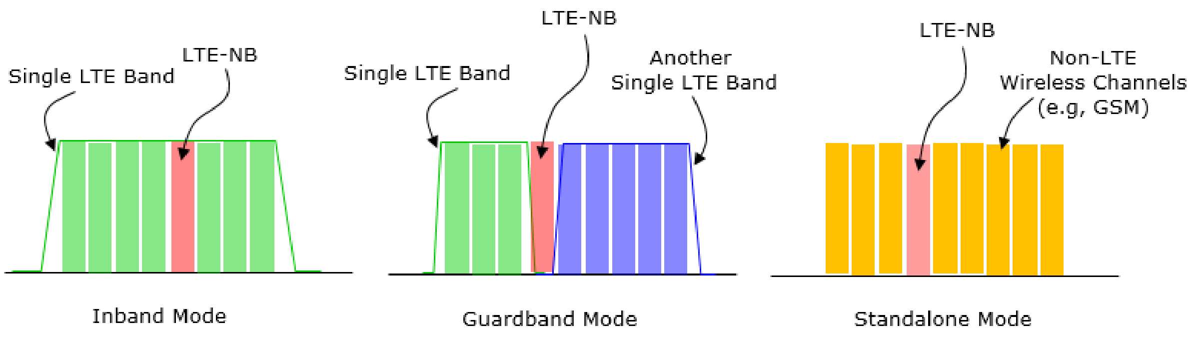


Figure 2: Schematic of the 3 operation modes

As an example, for ***in-band operation***, restriction exists. A LTE band with 1.4MHz bandwidth is not supported for NB-IoT. Indeed, conflicts may occur for resources allocation for NB-IoT such as specific Cell Reference Signals (CRS) or downlink control channel at the beginning of each subframe.

For ***guard band operation***, the user equipment synchronizes to signals for which the frequency bands are totally in the guard band.

To be able to work in various radio conditions, 3 Coverage Enhancement (CE) levels can be used by the network itself (0 to 2, being the worst). In the release 13, the duplex mode - ***FDD Half Duplex type B*** - tells us that Uplink and Downlink are separated in frequency, so that the user equipment transmits or receives, but not at the same time. It is the guard subframe, existing between every switch from Uplink to Downlink, which allows the user equipment to switch between its transmitter and receiver chain.

1.2. Modulation, Downlink, Uplink

NB-IoT is based on **Direct-sequence spread spectrum** (DSSS) modulation. This technique is utilized to reduce overall signal interference, by using the data signal and combine it with a high data rate bit sequence, which divides user data based on a spreading ratio.

Among the benefits of this modulation technique, DSSS allows jamming resistance (cf. time hopping), single channel sharing for multiple user or less background noise.

Furthermore, NB-IoT modulation schemes are mostly **QPSK** (4-Phase-Shift Keying) for Downlink and Uplink:

Downlink	------------------	QPSK
Uplink	Single Tone* Multi Tone**	π/QPSK, π/BPSK QPSK

**Single Tone: for resource units with one subcarrier*
***Multi Tone: for all other resource units*

*To be fully understandable, a **resource unit** (RU) is the smallest unit to map a transport block.*

- For **Downlink**, there are 3 physical channels…
  - **NPBCH**, the narrowband physical broadcast channel
  - **NPDCCH**, the narrowband physical downlink control channel
  - **NPDSCH**, the narrowband physical downlink shared channel

  …and 2 physical signals:

  - **NRS**, Narrowband Reference Signal
  - **NPSS** and **NSSS**, Primary and Secondary Synchronization Signals

- For **Uplink**, there are two physical channels…
  - **NPUSCH**, the narrowband physical uplink shared channel
  - **NPRACH**, the narrowband physical random-access channel

  and the...

  - **DMRS**, Demodulation Reference Signal

1.3. Data frame

This part is really complicated to understand, and we chose to stay at a large level to understand the **global** behaviour before having a real class on the subject.

NB-IoT frame structure is represented in a schematic way in the pictures below. At the highest level, it starts with hyper frame cycle in which one hyper frame cycle has 1024 hyper frames, each consisting of 1024 frames.

For Downlink and Uplink Subcarrier Spacing 15kHz: (*Figure 3*)

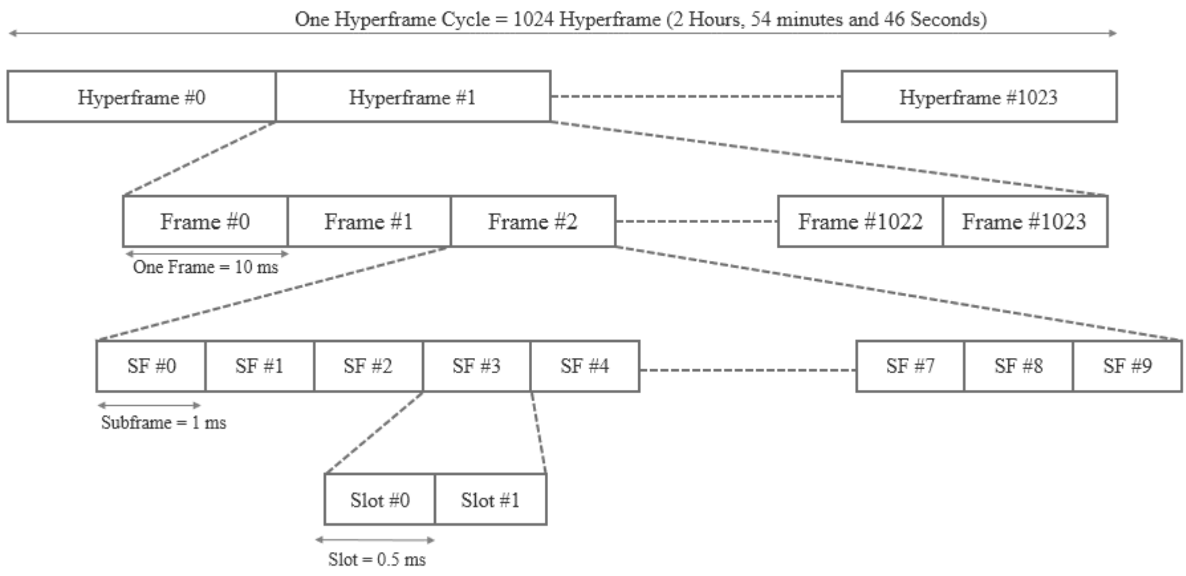


Figure 3: NB-IoT frame structure for 15kHz subcarrier spacing – Uplink & Downlink

For Uplink Subcarrier Spacing 3.75kHz: (*Figure 4*)

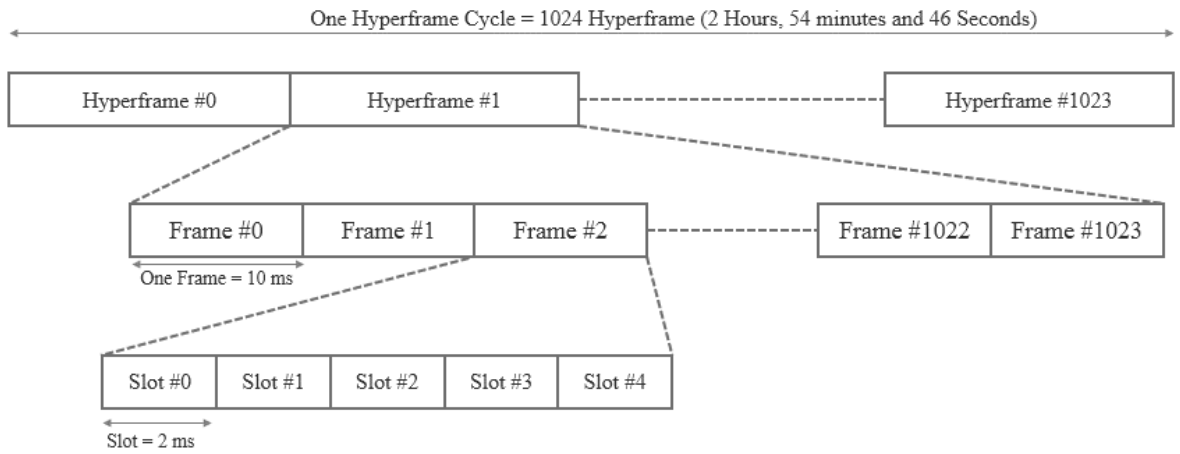


Figure 4: NB-IoT frame structure for 3.75kHz subcarrier spacing – Uplink only

One frame consists of 10 sub-frames and each subframe is divisible into two slots each of **0.5ms** which is similar to traditional LTE system. For Downlink and Uplink transmission, the NB-IoT design supports a sub-carrier spacing of **15kHz**, for which each frame contains 20 slots. For Uplink, the NB-IoT design supports an additional sub-carrier spacing of **3.75kHz**. In the case of this alternative sub-carrier spacing, each frame is directly divided into five slots, each of **2ms**. As a consequence, there is not subframe concept.

2. Power consumption

As LoRaWAN, NB-IoT is designed for **low power long range communication**. The goal, studying the power consumption, is to estimate the battery lifetime for a NB-IoT device.

NB-IoT (LTE Cat NB1)	**Downlink Peak Rate**	**Uplink Peak Rate**	**Latency**
Release 13 (3GPP)	$250kbps$	$250kbps$ (multi-tone) $20kbps$ (single-tone)	$1.6s - 10s$

In general, the power consumption levels are slightly higher than the 3GPP estimates:

- The **peak of power consumption** is reached with **uplink transmission** (**$716mW$ when transmitting at 23 dBm**, due to a power amplifier efficiency of 37%)
- When we are in **downlink, receiving** control and data channels requires $213mW$
- Idle-mode extended Discontinuous Reception requires $21mW$
- Power Save Mode sleep states consumes $13\mu W$

At the peak of power consumption, we have $\frac{716}{3600} = 0{,}19889\ mW/s = 198{,}89\ \mu W/s$

We also have $250kbps$ of data rate, then, $\frac{189{,}89}{250.10^3} = 0{,}75956.10^{-3}\ \mu W = 759.56\ pW$ for one bit transmitted.

TABLE II
Measured power consumption versus 3GPP estimate from [4].

	Device A	Device B	3GPP [4]
Transmit†	716 mW	840 mW	480 mW
Receive	213 mW	240 mW	75 mW
Sleep‡	21 mW	23 mW	3 mW
Standby§	0.013 mW	0.035 mW	0.015 mW

The real measured power consumption us higher than the estimation, but still very good for an IoT device. The Device A is a commercially available device, the Device B is a pre-commercial prototype.

3. MAC LAYER

The uplink of NB-IoT uses Single-Carrier Frequency-Division Multiple-Access (SC-FDMA), in SC-FDMA, multiple access among users is possible. The downlink uses orthogonal frequency-division multiple-access (O-FDMA).

NB-IoT reuses the **LTE design**.

<u>MAC layer functions:</u>

- **Dynamic scheduling** of radio resources, **priority handling**: determining the UEs that can be served during the Transmission Time Interval and on which bandwidth they have to transmit
- Generation of **Transport Blocks** by multiplexing Protocol Data Unit (PDU) coming from upper layers. Transport Blocks are delivered to physical layer on User Equipment (UE) side.
- **Error correction with HARQ** retransmission (Hybrid Automatic Repeat Request): implementation of a Stop&Wait (S&W) protocol. The PDU transmission starts only after the transmitter receives an **ACK**. To avoid deadlock situations: an N-channel variant leading to a max of N = 8 process operating in parallel.
- Mapping of logical channels onto transport channels
- Logical channel prioritization
- **Transport format** selection and **Transport Block** size selection

<u>Scheduling algorithms</u> can be implemented in LTE, for example:

- ***Round Robin (RR) Scheduler:*** allows the UE to access the resources in circular order, with an equal access opportunity for all. It gives a great fairness and a good bandwidth utilization but provides a max outflow. Used in scenarios with no high speed required.
- ***Proportional Fair (PF):*** works by scheduling the user when the instantaneous channel quality is better with respect to its condition over time. PF scheduling improves multi-user diversity by scheduling high channel quality during different time slots.
- ***Best CQI Scheduler:*** assigns priority on the process to the users that have higher channel quality. It offers better resources allocation to the users that are near the Base Station while those that are located far have less probability of getting access to the shared resources.

4. NB-IoT & Security

The NB-IoT uses **UDP protocol**. It is a very simple protocol and is ideal for NB-IoT because of its low consumption, because it does not need to establish a connection in order to send data. When a UDP packet travels over the Internet, all its data is visible to third parties.

Security is important in any IoT deployment, the basic pillars of IoT security are:

- Authentication
- Encryption
- Non-manipulation (no altered message)

Mobile network security

NB IoT is part of the mobile network, fully managed with standardized security to guarantee the credential and integrity of all data running through it

3GPP Security Protocols

NB IoT has passed security protocols as outlined by 3GPP, the organisation responsible for managing the mobile network. NB-IoT is a 3GPP standard, therefore it inherits LTE's strong security features, making it the safest choice.

Possibilities

- **APN or operator platform**: possibility of mounting an intermediate server that collects the data from the NB-IoT network without going through the Internet. The customer's final platform is connected via a secure VPN connection to the operator's platform: the entire path is secure.

  + High security level, Quick solution development

  - Expensive, Little flexibility to operator changes
- **UDP protocol securing**: data travels end-to-end encrypted by the same technology, and the cloud server is responsible for authenticating and decoding the data.

  + High security level, Independent of the network operator

  - Solution development time

Also, a secret key built into the NB-IoT SIM at point of manufacture is used to mutually authenticate the network and the device, and to generate frequently updated session keys for encrypting traffic between the device and the core network.

CONCLUSION

To conclude, NB-IoT is a very interesting and promising technology for the near future. It seems the best in its sector for IoT purpose and its next challenges with Smart Cities and 5G for example. Its low power consumption is very useful for wireless devices. Also, NB-IoT doesn't need a software update for the already installed 4G antennas.

We chose to represent below a comparing table given by Vodafone, one of the leader in NB-IoT, to sum up in what NB-IoT can overhang LoRa and Sigfox wireless networks.

	Sigfox	LoRa	NB-IoT
Coverage	160dB	157dB	164dB
Technology	Proprietary	Proprietary	Open LTE
Spectrum	Unlicensed	Unlicensed	Licensed (LTE/any)
Duty Cycle restrictions	Yes	Yes	No
Output power restrictions	Yes (14dBm = 25mW)	Yes (14dBm = 25mW)	No (23dBm = 200mW)
Downlink data rate	0.1kbps	0.3 – 50kbps	0.5 – 200kbps
Uplink data rate	0.1kbps	0.3 – 50kbps	0.3 – 180kbps
Battery life (200b/day)	10+ years	10+ years	15+ years
Module cost	<$10 (2016)	<$10 (2016)	$7 (2017) to <$2 (2020)
Security	Low	Low	Very high

Fig 1. Key technical specifications for NB-IoT (from R1-157741, Summary of NB-IoT evaluations results, 3GPP RAN1#83, Nov 2015), Sigfox, and LoRa (from LoRaWAN: a technical overview of LoRa and LoRaWAN, LoRa Alliance, Nov 2015).

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