NB-IoT

Sylvain Dupouy Léo Picou Mohan Selvarak

January 2020

1 Physical specs

1.1 Spectrum

1.1.1 Bands used

Unlike other LPWAN technologies (Sigfox, LoRa, DASH7..) which use the ISM bands, NB-IoT use the licensed spectrum. 3GPP released a lot of bands [2] :

- Release 13 : 2, 3, 5, 8, 12, 13, 17, 18, 19, 20, 26, 28 and 66.
- Release 14 : 11, 25, 31 and 70.
- Release 15 : 4, 14 and 71.

But in practice, only few bands have been used among all regions [4] :

- North America : 2, 4, 5, 12, 66, 71, 26
- Europe : B3, B8, B20
- Asia Pacific : 1, 3, 5, 8, 18, 20, 26, 28

We notice that for example in France, B3 B8 and B20 bands are widely used in GSM and LTE communications. It has been designed on purpose, indeed the use of the widely implemented cellular network provide an optimal coverage among urban areas. Unfortunately this situation brings two inconvenient, a tremendous price per MHz, and a not so good coverage in rural areas.

1.1.2 Deployment

A NB-IoT transmission takes places inside a 180 kHz band, which represents a single resource block (RB) in LTE communication. The standard state that an specified NB-IoT resource block can be allocated at three different places :

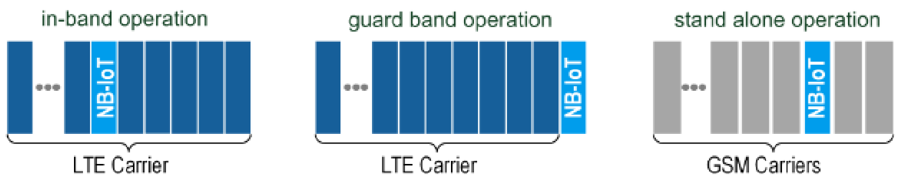

Figure 1: NB-IoT Deployment modes

It is stated that the In-band and Guard-Band's configuration can be deployed very easily and are already supported by the LTE's base station. In the other hand, the stand alone deployment needs the GSM base stations to be upgraded (only software) to process the NB-IoT transmissions. [4]

1.2 Modulation

Depending on the number of tones set for the transmission, NB-IoT uses either QPSK or $\frac{\pi}{2}$-BPSK as modulation. This modulated signal is then transported inside a subdivision of a resource block. Each RB (180 kHz) can be divided into 12 sub-bands of 15 kHz. Sub-bands are then allocated to each user (sometimes multiple sub-bands can be allocated to one user) to have a multiple access scheme :

- Downlink : OFDMA
- Uplink : SC-FDMA

In OFDMA, each subdivisions represents an orthogonal sub-carrier. The user's data are therefore multiplexed in both time and frequency domains. OFDMA has an higher spectrum efficency than SC-FDMA, but its drawback is its higher PAPR (Power to average-power-ratio). Since OFDMA is an addition of multiple sub-carriers, and SC-FDMA is a single carrier modulation scheme, we can understand why OFDMA is more prone to have an higher PAPR.

With an higher PAPR, the device's front-end linear amplifier needs to be improved. This results in a higher cost and a higher volume. That's why we keep OFDMA for downlink transmission only, since the power is provided by a static base station.

These parameters allow NB-IoT to achieve these data rate [1] :

- Downlink : 26 kbits/s
- Uplink : 16.9 kbits/s

[1] Depends heavily on release version (3GPP 13,14,15)

1.3 Sensitivity

The NB-IoT's sensitivity is impressive when compared to other LPWAN available technologies.

- NB-IoT : -141 dBm
- LTE-M : Up to $\approx$ -120 dBm

LTE-M is the other 3GPP's IoT technology, which is made to have an higher data rate, but with more bandwitdh. We can have an easy guess why LTE-M is really less sensible due to the Johnson–Nyquist noise :

$$N = k_B T B$$

Where N is the noise power, k_B the Boltzmann constant, T the temperature (in Kelvin) and B the bandwidth. With a very narrow bandwidth, the thermal noise decreases, hence the SNR is improved.

2 Protocols

2.1 Protocol stack

NB-IoT reuses already existing LTE functions but tries to strip them from their complexity. Indeed, this standard wants to have a low complexity in order to focus on the required part of the LTE protocols and optimize them as much as possible. Using the same protocol stack allows to minimize the deployment costs.

The NAS (Non Access Stratum) protocols are responsible for the IP connectivity of the end device. The RRC protocol allows, among other things, for the device to connect and retrieve information about the network status, and for the network to know the state of the device (IDLE or CONNECTED).

PDCP and RLC are respectively tranport and data link layer protocols.

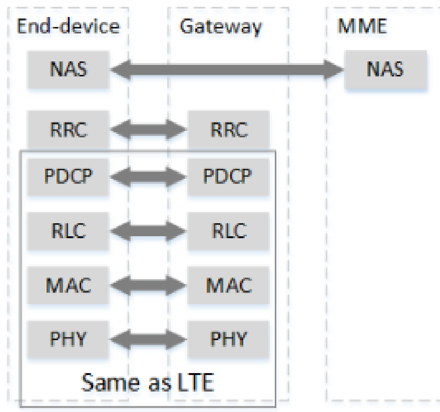

Figure 2: NB-IoT Protocol stack (taken from [3])

2.2 MAC Layer

The medium access control is implemented in NB-IoT through the RACH (Random Access Channel) protocol. Its goal is to provide 2 services :

- Uplink synchronization between the device (UE) and the cell (eNodeB)
- Allocate the resources for subsequent communication

Uplink synchronization allows the UE to know the timing parameters used by the eNodeB. The resources allocated are primarly a unique ID and a unique communication channel (either by FDD or by TDD).

A more detailed call diagram and procedure explaination is available at [1]. Basically, the UE sends a preamble and its identity to the eNodeB. If no response, the UE increases its power and retries. The eNodeB should respond with the local identity assigned to the UE, the timing advance so that the UE can synchronize and the channel (FDD or TDD) assigned to it. The UE can then connect to the network through the RRC protocol.

2.3 Mobility

LTE uses a functionality called handover. This allows seamless and uninterrupted data transfer between the network and the UE while it is moving from an eNodeB to another. Because of its complexity, this functionality was removed from the NB-IoT specifications. However, eNodeB can share RRC connection information to prevent the UE from going through a new RRC connection phase when switching eNodeB.

3 NB-IoT Network coverage

3.1 URBAN Coverage

NB-IoT as a Low Power network fills the gap between the 'short-range' wireless network and the 3G/4G/LTE cellular network. The network coverage of NB-IoT totally depends on the availability of the 4G/LTE infrastructure. In the Urban areas, due to wide spread of 4G/LTE network infrastructure, the usage of NB-IoT is more suitable. The coverage ranges between 2 – 4 kms based on the number of transmission repetitions.

3.2 Rural coverage

In case of the rural areas, the NB-IoT coverage can extend between 10 – 15 kms. But, since the 4G/LTE infrastructure is not wide spread across rural areas, for end-to-end connectivity, as a gap filler, other LPWAN technologies such as LoRA & Dash7 are combined with NB-IOT for rural use-cases.

4 NB-IoT Use-Cases

As mentioned, NB-IoT suits better for the urban use-cases due to its support for low power, low latency and high dense IoT network. Some of the suitable use-cases are,

4.1 Pallet Tracking

Pallets as connected objects will be using the 'short-range wireless' technologies within the company premise. Once, the pallets are out of the company range, NB-IoT suits as a better technology for tracking.

4.2 Health-Care

Health-care/Elder care institutions and hospitals use NB-IoT to track their patients who are in remote places. Because, NB-IoT is deterministic in nature, it is preferred over other LPWAN technologies.

4.3 Smart Vehicles

In smart vehicles use-cases, mobility and downlink communication are critical requirements as the applications range from surveillance, passenger assistance services such as road navigation, weather maps. NB-IoT suits best as it is designed for both uplink and downlink communications.

5 E-Bike Management real-world deployment

5.1 Problem Background

In this presentation, we investigated the NB-IoT real world deployments and identified a 'E-Bike management' deployment at China.

In Zhengzhou, the capital of east-central China's Henan province, electric bikes pose a challenge to the local government. According to statistics, 70% of reported theft, 30% of traffic accidents, and 9% of fires were caused by electric bikes in the local in 2017.

5.2 Solution

The Zhengzhou Public Security Bureau, in partnership with China Mobile, Huawei and Tendency have deployed about three million electric bikes and got them connected to theft and fire protection solutions using the NB-IoT network.

6 Battery Life Estimation

6.1 Background

To estimate the battery life of the E-bikes, we used

- assumptions on the deployment case
- NB-IoT test results on the mangOH Embedded IoT card
- A sample battery specification

Assumptions	
Length of a transmission	2s
Number of transmissions / day	200
Power consumption of a transmission	1.40W

mangOH - TRANSMISSION MODE	
Current	0.1 A
Voltage	3.7 V
Power	0.5 W
Duration of transmission/day	400 s
Energy consumption in a day	0.056Wh/d

BATTERY LIFE CALCULATION		
Total energy consumption / day	0.0675	Wh / day
Standard battery	28.86	Wh
BATTERY LIFE	427.5555556	days

References

[1] Random Access Procedure in LTE.

[2] 3GPP. *3GPP Release 13*.

[3] w. ayoub, A. E. Samhat, F. Nouvel, M. Mroue, and J.-C. Prévotet. Internet of Mobile Things: Overview of LoRaWAN, DASH7, and NB-IoT in LPWANs standards and Supported Mobility. In *2018 25th International Conference on Telecommunications (ICT)*, 2018 25th International Conference on Telecommunications (ICT), St. Malo, France, June 2018. IEEE.

[4] GSMA. *NB-IoT Deployment Guide*. https://www.gsma.com/iot/wp-content/uploads/2019/07/201906-GSMA-NB-IoT-Deployment-Guide-v3.pdf.