Toward the Internet of Things : Wireless Sensors Network

Report about NB-IoT

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1) Introduction

The Internet of Things is a never-ending growing field due to the merging of technologies like embedded systems, wireless sensor networks or automation. Because of that evolution, communication standards for IoT are being created and developed. The protocol NarrowBand Internet of Things (NB-IoT) is one of them. Through this paper, we will discuss and explain the basic features and characteristics of this standard.

2) General features

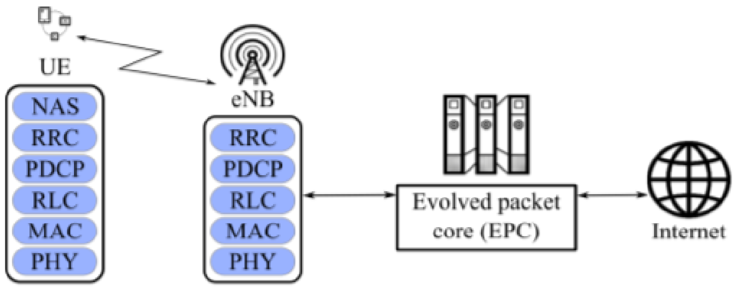
NB-IoT, also referred to as LTE Cat NB1, is a low-power wide-area network (LPWAN) radio technology standard compatible with 4G and 5G ready. It was developed by the 3rd generation partnership project (3GPP) in 2016.

NB-IoT is a wireless protocol specialized in connecting M2M or IoT devices on already established mobile networks, and handling small amounts of 2-way data [1].

Its main advantage is a very low power consumption: a battery supplying a NB-IoT system can last up to 10 years depending on the configuration. Because of that aspect, the component cost is very low. It also has a high extended range in buildings and underground [1]: in the most dense areas, the NB-IoT range is a few kilometers and in rural areas it can reach tens of kilometers. NB-IoT has an easy deployment into existing cellular network architecture. The standard guarantees network security and reliability.

However, the latency can go from 1 second to 10 seconds depending on the quality of the communication chip, of the network, of the reception signal and of the distance from the closest antenna [2]. NB-IoT has a relatively low data rate, going from 20 to 250 Kbit/s. That means NB-IoT can only connect devices that need small amounts of data, unlike voice or video transmission.

NB-IoT is not meant to be a real-time system but is supposed to send data infrequently [3]. The use cases are made for configurations that do not require such constraints. However, it can be used in real-time depending on the application.



Overview of a NB-IOT Network [4]

The general overview of a NB-IoT network includes the User Equipment (UE) such as sensors, the Evolved Node B which is the base station of mobile networks. It is the gateway between UE and radio antennas and the EPC (Evolved Packet Core). The EPC is a framework composed of the Serving gateway, the Packet Gateway, Mobile Management Entity and Policy and Charging Rules Function [4]. From The EPC, the data can be uploaded to the internet.

3) Physical layer

The physical layer is the interface between the MAC layer and the Radio Frequency transceiver. It consists of physical signals and physical channels.In the Nb-IoT standard, this layer carries upper layer information, through wireless medium. Nb-IoT works in half-duplex. It supports Half Duplex Frequency Division Duplexing (HDFD) to ensure that the transmitter and receiver operate using different carrier frequencies. It also supports Time-division duplexing, which means that all the signals operate at different times with the same frequency.

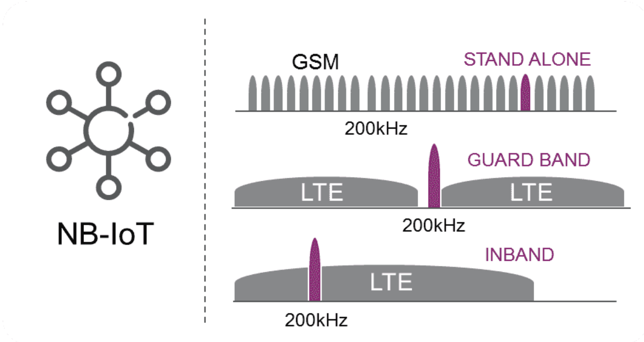
Its main functions are as follows [5]:

- It adapts the MAC layer format to make it suitable for the medium used.
- It enables exchange of data and control information between eNB and UE
- It enables error correction at the receiver with FEC (forward error correction) functionality
- It performs modulation and demodulation at the transmitter and receiver end.

The Nb-iot can work in three different modes [6]:

- “Stand Alone”, on an independant carrier signal of 200 kHz in the GSM Network
- “Guard Band”, with the LTE network which reserves resources for NB-IoT
- “Inband”, within an independent network

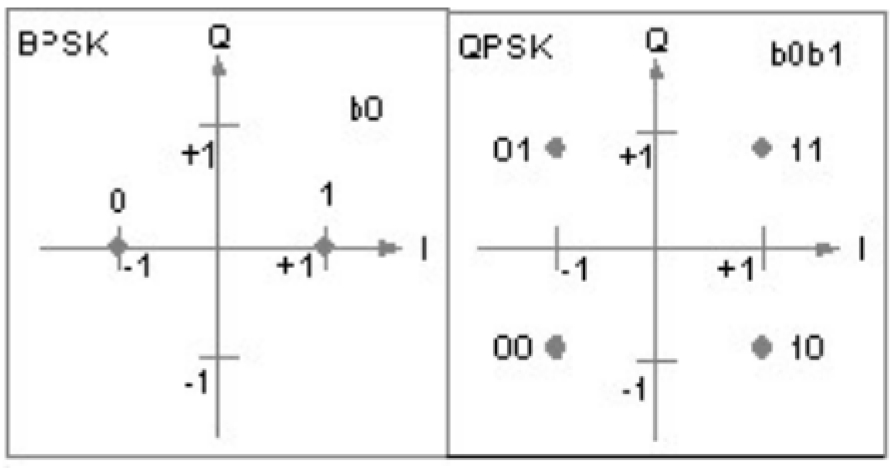
For its 3 ways of use, the channel bandwidth used will always be the same, to be precise 200khz. In reality, it occupies 180 kHz.



Different ways of using NB-IOT [19]

Regarding the modulation, the physical layer of NB-IOT protocol supports modulation schemes like BPSK (binary phase shift keying) and QPSK (quadrature phase shift keying).

BPSK is the simplest phase shift keying (PSK) scheme. It takes a single bit at a time and maps it to one of two constellation points that are 180◦ apart. QPSK uses a constellation diagram with four points, equidistant around a circle. With four phases, QPSK can code two bits per symbol. This allows the bit rate to be doubled compared to a QPSK system while maintaining the signal bandwidth.The figure below shows the bit mapping for these two modulation schemes. [20]



Constellation diagram of QPSK and BPSK [20]

4) MAC layer

The MAC or Medium Access Control layer controls the hardware in charge of the interaction between the wireless transmission medium. This layer is responsible for the establishment of a reliable and efficient communication link between Wireless Sensor Nodes (WSN) and is responsible for energy waste. This layer divides the radio channel between nodes and tells each one of them when it can transmit and when it is expected to receive data.

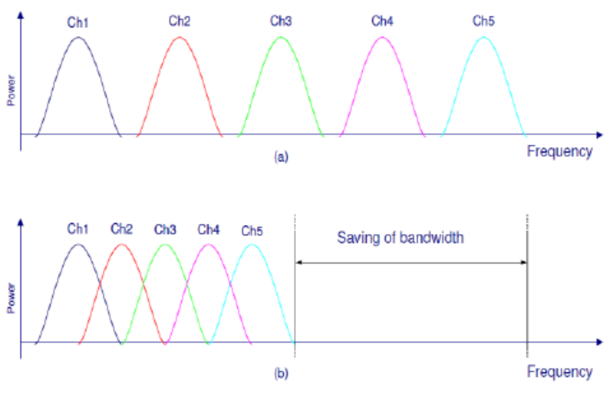
The MAC layer is responsible for the messages between User Equipment (UE) and the network [5].

It is possible to determine the main functions of the MAC layer :

- Mapping of logical channels on to transport channels
- Multiplexing of MAC SDUs from one or different logical channels onto transport blocks to be delivered to physical layer on UE side
  (The data from the MAC layer to the physical layer in LTE system is basically referred as transport block)
- Error protection (generally using frame check sequences)
- Priority handling between UEs by means of dynamic scheduling
- Arbitration and prioritization of access to one channel shared by all nodes

As it coexists in the LTE spectrum, NB-IoT follows older LTE technologies by using orthogonal frequency division multiplexing (OFDM) and single carrier frequency division multiple access (SC-FDMA) in the downlink and uplink transmission schemes, respectively [5].

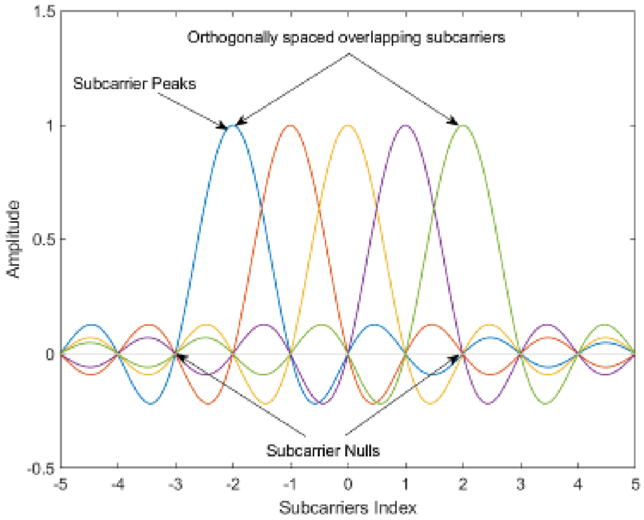
The OFDM is a variant of the FDM transmission. As we can see in the image below, FDM allows multiple users to use the same source by dividing available bandwidth into different non-overlapping subchannels in order to create a narrow band between each channel. With this method the signals are sent separately and avoid interference.



Comparison between FDM (upside) and OFDM (downside) [18]

In OFDM, on the other hand, there is no narrow band between each channel. They still have the same available bandwidth but they are overlapped which saves bandwidth. But how does OFDM prevent interference if the channels overlap each other ?

It is the principle of orthogonality, each signal in OFDM operates independently. When the carrier signal reaches a peak, the other signals are at null.



Principle of the OFDM [21]

This principle allows the OFDM to have more data transmission than FDM, which makes it very useful in network infrastructure.

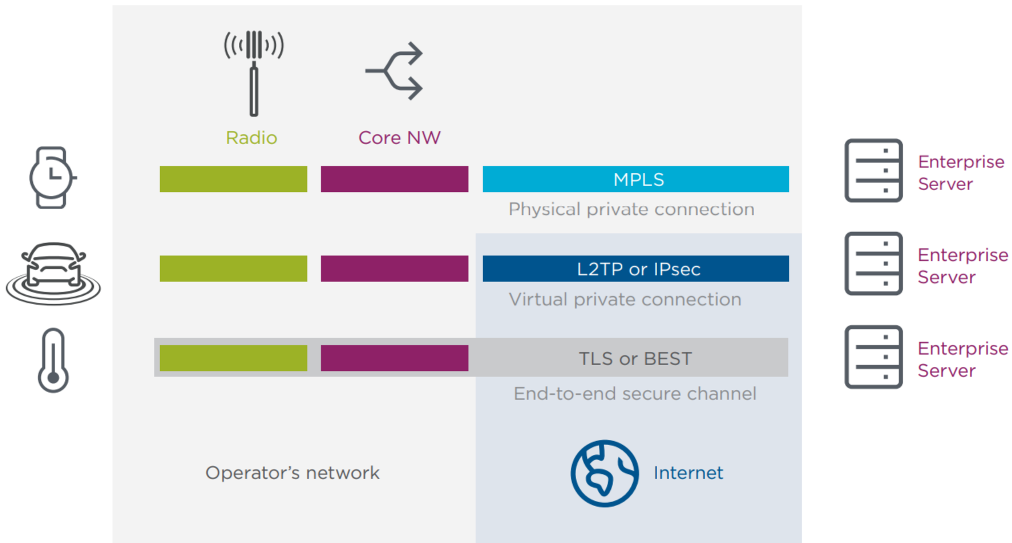
5) Security

The advantage of NB-IoT is that it is a cellular network that inherits the security mechanisms of mobile infrastructures, the security features being deployed by mobile operators, highlighting that NB-IOT are “secure by design”. IoT networks use some dedicated spectrum bands under the terms of the licences issued by the operators, interference from other radio waves is kept to a minimum. Moreover, mobile operators use SIM cards (Subscriber Identity Modules), which are highly controlled and contain a secure integrated circuit, to authenticate the devices accessing their network and services. Mobile operators ensure these capabilities with four major security features.

- Secure communication channels [7]

Mobile operators ensure that user data is encrypted between the moment the data enters its own infrastructure and the moment the data leaves the network. It is done to avoid any misuse of these data over a less secure environment (e.g internet).

Operators manage to secure the connection to the enterprise network using VPN Layer two Tunnelling Protocol (L2TP) or Internet Protocol security (IPsec), or by using an End-to-End security between the devices and the application using Datagram Transport Layer Security (DTLS) or Battery Efficiency Secure Transport (BEST) .Mobile operators can provide also Multiprotocol Label Switching (MPLS) to create a private network that doesn't travers public network such internet



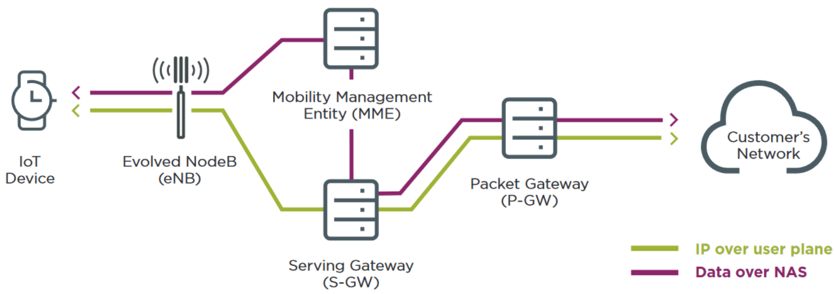
Mobile operator's public infrastructure between IoT devices and Enterprise Server [7]

- Manage communications [7]

IoT devices or applications need to be connected and communicate only with a set of servers. It is a good security practice to restrict these communication from the device to these specific servers. Thus, these devices will be unable to communicate with any other destination, limiting any potential threats.

- DATA OVER NAS (DoNAS) [7]

DATA OVER NAS (DoNAS) is a feature that transport users data within signaling messages via MME (Mobility Management Entity) by encapsulation them in NAS (No Access stratum), this feature can also encrypt the data using the same machine for network signalling to secure the same levels of protection. DoNAS can also transport IP and No-IP traffic.



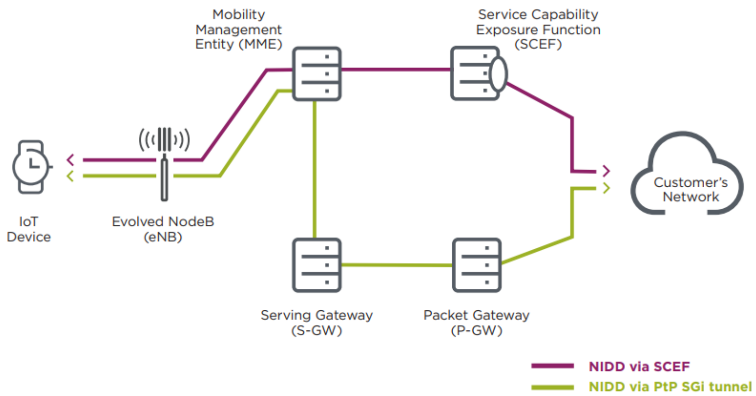
Data path for DoNAS and traditional IP over user plane [7]

- Non-IP Data Delivery (NIDD) [7]

IoT devices usually send small amounts of data because sending data as an IP packet is not optimised due to the size of IP headers. NIDD was introduced for this reason, in conjunction with DoNAS, allowing the network to transport no-IP data which means without an IP stack, without an IP address, and without IP header.

NIDD can be transported by two ways:

- Transport data using a Point-to-Point Serving gateway interface (PtP SGi), the communication is pre-defined and more secure
- Service Capability Exposure Function (SCEF), it can provide a way to securely expose service and network capabilities through network APIs, the IoT devices are restricted to the authorised and authenticated servers application.



No-IP Data Delivery (NIDD) by the Point-to-Point Serving Gateway interface (PtP SGi) and Service Capability Exposure Function (SCEF) [7]

6) Energy consumption

Nb-IoT has two optimization features: Power Saving Mode (PSM) and Extended Discontinuous Reception (eDRX).
When in PSM, the devices send or receive data intermittently. Between periods of data transmission and reception, they can sleep to minimize power consumption and maximize battery charge. When triggered by a timer for example, the UE wakes up to perform tasks like TAU (Tracking Area Update), RAU (Routing Area Update) and data transfer.
In Extended Discontinuous mode, a device will stay in a low-power sleep state during a period specified beforehand, and then wake up to see if any data is pending. The device can listen for pending data without having to establish a full network connection. This uses less power than a full network connection, and the time required to check for pending data is much shorter than the time it takes to establish a full network connection.

According to a scientific article published in 2018 [8], when the transmitted power TX is equal to 23 dBm, the power consumption varies according to the mode the device is in. This data is shown in the figure below.

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

† 23 dBm, ‡ I-eDRX for devices A & B, § PSM for devices A & B

Power consumption on device A & B VS 3GPP estimate[8]

Device A is commercially available while device B is a pre-commercial prototype.

If we consider in each mode the worst case scenario, namely a data rate of 20 Kb/s, we obtain the following energy consumption:

For the device B:

Transmission: $\frac{840}{20000} = 42\ \upsilon J/bit$

Reception: $\frac{240}{20000} = 12\ \upsilon J/bit$

eDRX: $\frac{23}{20000} = 1,15\ \upsilon J/bit$

PSM: $\frac{0.035}{20000} = 1,75.10^{-3}\ \upsilon J/bit$

For the device A:

Transmission: $\frac{716}{20000} = 35,8\ \upsilon J/bit$

Reception: $\frac{213}{20000} = 10,65\ \upsilon J/bit$

eDRX: $\frac{21}{20000} = 1,05\ \upsilon J/bit$

PSM: $\frac{0.013}{20000} = 0,65.10^{-3}\ \upsilon J/bit$

7) References

[1] Narrowband IoT (NB-IoT), ublox, accessed 9 October 2021 <https://www.u-blox.com/en/narrowband-iot-nb-iot>

[2] Narrowband Internet of Things Measurements, Rohde&Schwarz, 2021, accessed 9 October 2021 <https://scdn.rohde-schwarz.com/ur/pws/dl_downloads/dl_application/application_notes/1ma296/1MA296_2e_NB-IoT_Measurements.pdf>

[3] QU'EST-CE QUE NB-IOT ?, Integral System, 27 November 2018, accessed 9 October 2021 <https://blog.integral-system.fr/quest-ce-que-nb-iot/>

[4] Evolved Packet Core (EPC), TechTarget Contributor, accessed 9 October 2021 <https://www.techtarget.com/searchnetworking/definition/Evolved-Packet-Core-EPC>

[5] NB-IoT Protocol Stack | LTE-NB Protocol Stack, RF Wireless World, accessed 9 October 2021 <https://www.rfwireless-world.com/Terminology/LTE-NB-IoT-Protocol-Stack.html>

[6] Pourquoi le Nb-IoT peut être une alternative sérieuse?, Corentin Corde, accessed 9 October 2021 <https://blog.rtone.fr/nb-iot>

[7] Security Features of LTE-M and NB-IoT Networks, GSMA, accessed 9 October 2021

<https://www.gsma.com/iot/wp-content/uploads/2019/09/Security-Features-of-LTE-M-and-NB-IoT-Networks.pdf>

[8] M. Lauridsen, R. Krigslund, M. Rohr and G. Madueno, "An Empirical NB-IoT Power Consumption Model for Battery Lifetime Estimation," *2018* https://ieeexplore.ieee.org/document/8417653

[9] A Tutorial on NB-IoT Physical Layer Design, Matthieu Kanj, Vincent Savaux, Mathieu Le Guen, 2020, accessed 9 October 2021 <https://hal.archives-ouvertes.fr/hal-02952155/document>

[10] NB-IOT VS LTE-M : CHOISIR LA MEILLEURE TECHNOLOGIE POUR VOS BESOINS IOT, Integral System, 7 January 2020, accessed 9 October 2021 <https://blog.integral-system.fr/nb-iot-vs-lte-m-choisir-la-meilleure-technologie-pour-vos-besoins-iot/>

[11] Introduction aux réseaux LPWAN : Sigfox, Lora, Nb-IoT et LTE-M, Georges, 27 October 2020, accessed 9 October 2021 <https://www.matooma.com/fr/s-informer/actualites-iot-m2m/reseaux-lpwa-sommes>

[12] NB-IoT Frequency Bands, Editorial team - everything RF, 12 March 2018, accessed 9 October 2021 <https://www.everythingrf.com/community/nb-iot-frequency-bands>

[13] CableFree IoT – The Internet of Things, CableFree Wireless Technology, accessed 9 October 2021 <https://www.cablefree.net/wirelesstechnology/internet-of-things-iot/>

[14] How do NB-IoT network registration and coverage affect an IoT device's power consumption?, Otii Arc, 26 August 2021, accessed 9 October 2021 <https://www.qoitech.com/blog/how-do-nb-iot-network-registration-and-coverage-affect-an-iot-devices-power-consumption/>

[15] 3GPP TR 45.820 – Cellular system support for ultra-low complexity and low throughput Internet of Things (CIoT), iTecTec, accessed 9 October 2021 <https://itectec.com/archive/3gpp-specification-tr-45-820/#google_vignette>

[16] The MAC level, Jean Tourrilhes, accessed 9 October 2021 <https://hewlettpackard.github.io/wireless-tools/Linux.Wireless.mac.html>

[18] Differences between FDM and OFDM, Khaled Elleithy, March 2014, accessed 9 October 2021
<https://www.researchgate.net/figure/Shows-what-the-differences-between-the-FDM-and-OFDM-spectral-efficiencies-are-16_fig2_259649471>

[19] Narrowband IoT in the cloud, Anna Larmo, September, 2016, accessed 9 October 2021
<https://www.ericsson.com/en/blog/2016/9/narrowband-iot-in-the-cloud>

[20] Low-power Physical-layer Design for LTE Based Very NarrowBand IoT (VNB - IoT) Communication, Prashant Sharma, November 2017, accessed 9 october 2021
<https://core.ac.uk/download/pdf/154281786.pdf>

[21] Modulate frequency-domain signal using orthogonal frequency division multiplexing (OFDM), accessed 9 october 2021
<https://fr.mathworks.com/help/comm/ref/ofdmmod.html>