Report “Narrowband IoT”

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5th year ISS

January 2020

SUMMARY

1- Introduction

Narrowband IoT (NB-IoT) is a **low power wide area network (LPWAN)** radio technology specifically developed for the Internet of Things (IoT), for devices that require small amounts of data over long periods and indoor coverage. The main aim of NB-IoT is to support **massive machine-type communication (mMTC)** and enable **low-power**, **low-cost**, and **low-data-rate** communication.

NB-IoT is a recent cellular radio access technology based on Long-Term Evolution (LTE) **introduced by Third-Generation Partnership Project (3GPP)**. Its specifications were completed in **June 2016** in with the Release 13.

NB-IoT is considered 5G ready, that basically means that it's compatible with this new norm of transmission. A 5G solution for cellular IoT is expected to be part of the new 5G framework by 2020 with a slight improvement for narrowband solutions such as NB-IoT and EC-GSM-IoT.

This is an international standard that is nowadays well-deployed in North America, Western Europe and Eastern Asia, with a focus on the European market. In France, the implementation of NB-IoT faces lots of competition from technologies such as Sigfox and LoRa, which are more traditional to the market, made in France and backed up by huge telecommunication companies (SFR for Sigfox and Orange, Bouygues for LoRa).

2- Modes of operation

Due to its reduced bandwidth requirement (narrowband), NB-IoT has a **flexible deployment** that allows it to operate in three different modes (see Figure 1):

- Standalone: an operator can replace one GSM carrier of 200 kHz with NB-IoT, leaving a guard interval of 10 kHz on both sides of the spectrum.

- In-band: this is easiest for operators since no changes to hardware are needed. LTE spectrum is used. Many operators in Europe have adopted this.

- Guard-band: operators deploy NB-IoT in guard bands within existing LTE spectrum resources.

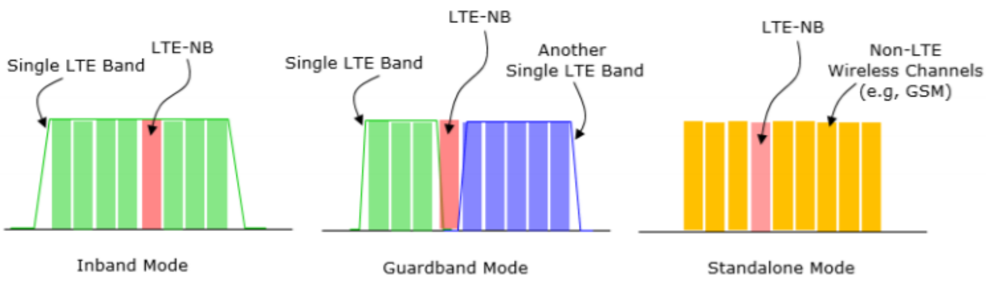

Figure 1: Modes of employment of NB-IoT.

3- Physical layer

NB-IoT adopts the same protocol stack as the Legacy LTE. However, some design changes in both physical and MAC layers were introduced to support the massive long-range connections with up to **additional 20dB MCL**.
The MCL (Maximum Coupling Loss), this parameter gives us a notion about the the coverage of the service. Without coverage enhancement, Legacy LTE systems (before Release 13) can operate up to approximately 142 dB MCL and in most cases for outdoor urban or sub-urban environments. However for underground and indoor the loss can be higher up to 50dB MCL. That explains why NB-IoT is an improvement for indoor applications.

3.1 - Frequencies and data rate

E-UTRA Operating 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}	Duplex Mode
1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	HD-FDD
2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	HD-FDD
3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	HD-FDD
5	824 MHz – 849 MHz	869 MHz – 894MHz	HD-FDD
8	880 MHz – 915 MHz	925 MHz – 960 MHz	HD-FDD
11	1427.9 MHz – 1447.9 MHz	1475.9 MHz – 1495.9 MHz	HD-FDD
12	699 MHz – 716 MHz	729 MHz – 746 MHz	HD-FDD
13	777 MHz – 787 MHz	746 MHz – 756 MHz	HD-FDD
17	704 MHz – 716 MHz	734 MHz – 746 MHz	HD-FDD
18	815 MHz – 830 MHz	860 MHz – 875 MHz	HD-FDD
19	830 MHz – 845 MHz	875 MHz – 890 MHz	HD-FDD
20	832 MHz – 862 MHz	791 MHz – 821 MHz	HD-FDD
25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	HD-FDD
26	814 MHz – 849 MHz	859 MHz – 894 MHz	HD-FDD
28	703 MHz – 748 MHz	758 MHz – 803 MHz	HD-FDD
31	452.5 MHz – 457.5 MHz	462.5 MHz – 467.5 MHz	HD-FDD
66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	HD-FDD
70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	HD-FDD

Figure 2: Frequency bands for NB-IoT.

Differently from the Sigfox and LoRa technologies that use Unlicensed ISM (Industrial Scientific and Medical) bands, NB-IoT only uses Licensed LTE frequency bands. In Figure 2, we show how 3GPP Rel13 defines NB-IoT profile for 14 different frequency bands, 10 of which are in sub-GHz range. These lower frequency bands offer **better indoor propagation as well as less power consumption**.

This list shown in Figure 2 is changing as more frequency bands are being added. For example, bands 11, 25, 31 and 70 had been added in Rel14 specifications.

3.2 - Bandwidth and data rate

NB-IoT operates using a channel **bandwidth limited to 180 kHz**. And it has a Data rate for transmission is limited at 250 Kbits/s, which corresponds to one resource block in LTE transmission. While LTE can operate with more wider bandwidths going from 1.4MHz to 20MHz.

The NB-IoT communication protocol is based on the LTE protocol. In fact, NB-IoT reduces LTE protocol functionalities to the minimum and enhances them as required for IoT applications.

These differences can justify how NB-IoT proposes a **low cost based solution**. Chips that support NB-IoT are cheaper because they're simpler to create. A 200 kHz NB-IoT is much simpler than a 1.4 MHz LTE resource block.

3.3 - Modulation

In the physical (PHY) layer, NB-IoT employs the quadrature phase-shift keying (QPSK) modulation.

Since NB-IoT operates with a bandwidth of maximum 180 KHz, it can coexist either in the Global System for Mobile Communications (GSM) spectrum or by occupying one of the legacy LTE Physical Resource Blocks (PRBs) as in-band or as guard-band. The physical NB-IoT layers have been designed with the requirements of in-LTE-guard-band coexistence, so the NB-IoT follows the legacy LTE numerologies: for downlink it uses **Orthogonal Frequency Division Multiplexing Access (OFDMA)** and for uplink the **Single-Carrier Frequency Division Multiple Access (SC-FDMA)**.

OFDM and SC-FDMA modulates the signal in time and frequency. We can see on the Figure 3 that how these two methods work. With OFDM, we attribute dynamically each sub carrier to one user, and the time represents a symbol. However, in the uplink, with SC-FDMA, instead of sending 4 symbols in the same time, we send one after the other. This method has a lower peak-to-average-power-ratio, which improves the battery autonomy.

Because of this set of configurations, the NB-IoT is presents a **low latency**. It allows to have speeds from 20 to 250 Kbit/s in download or upload with a latency of less than 10 seconds approximately. However, the latency will depend on the quality of the communication chip, the network, the reception quality and the distance to the nearest antenna.

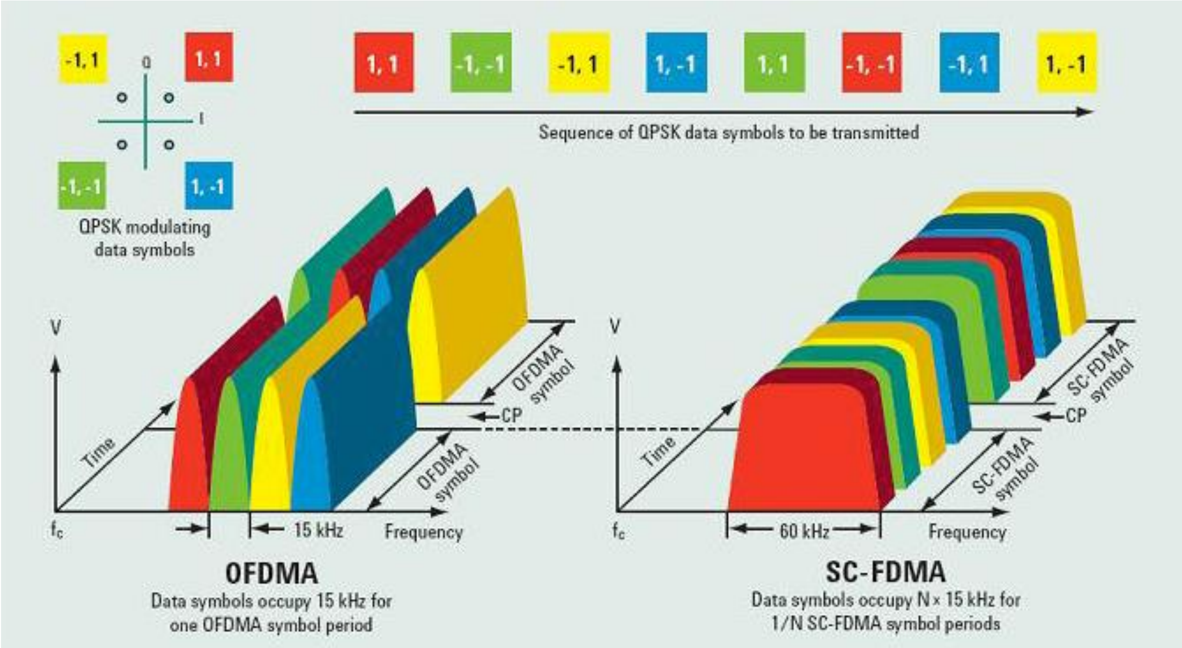

Figure 3: Comparison between the OFDMA and SC-FDMA methods.

3.4 - Channels

NB-IoT generally takes advantage of the existing LTE physical channels, readapting it to fit into the narrower bandwidth. In the downlink we have 3 channels:

- Narrowband Physical Downlink Control Channel (NPDCCH): carries scheduling assignments, as well as Hybrid Automatic Repeat reQuest (HARQ) acknowledgments and DCI (Downlink Control Indicators).
- Narrowband Physical Downlink Shared Channel (NPDSCH): carries data from the higher layers as well as system information messages, and the Random Access Response (RAR) message.
- Narrowband Physical Broadcast Channel (NPBCH): is transmitted in the first subframe and carries the Master Information Block - NarrowBand (MIB-NB) over eight consecutive radio frames.

For the uplink we have 2 channels:

- Narrowband Physical Uplink Shared Channel (NPUSCH): has two formats. Format 1 is used for carrying uplink data and uses the same LTE error correction code. Format 2 is used for signaling HARQ acknowledgment for NPDSCH and uses a repetition code for error correction.
- Narrowband Physical Random Access Channel (NPRACH) enables the random access procedure

4 - MAC Layer

Channel Layer

Handling retransmissions (HARQ), multiplexing, random access, timing advance, choice of transport block formats, priority management, and scheduling are the tasks executed by the MAC layer. The discussion on this part focuses on features such as radio resource management, link adaptation, coverage, and capacity improvement, power, and energy consumption reduction.

- Mapping of logical channels onto transport channels
- Multiplexing of MAC SDU's from one or different logical channels onto transport blocks to be delivered to physical layer on UE side
- Error correction through Hybrid Automatic Repeat reQuest (HARQ) retransmission
- Priority handling between UE's by means of dynamic scheduling
- Logical channel prioritization and Transport Block size selection

5 - Power Consumption

In IoT sector, the power management is crucial in order to ensure the autonomous aspect and the good functioning of the system. That's why NB-IoT uses **Low Power Wide Area Network** (LPWAN).

To perform power consumption measurements and estimate the battery life cycle of the NB-IoT node, we are going to use the U-Blox Sara N211 NB-IoT chip which is connected to a Base Station (BS) the voltage level is set constant and the current consumption is measured. The BS could be the 3 following networks: Commercial network A, B or a private network.

Results

The Figures 4 and 5 present the result of NB-IoT without Power Saving Mode (PSM).

These figures demonstrate the energy consumption over 3 different networks. Packet transmission cycle repeats every 30 seconds and it consists of transmission and idle phases. In the transmission phase, the device turns on the radio unit, the Radio Resource connection is established and the packet transmission is completed.

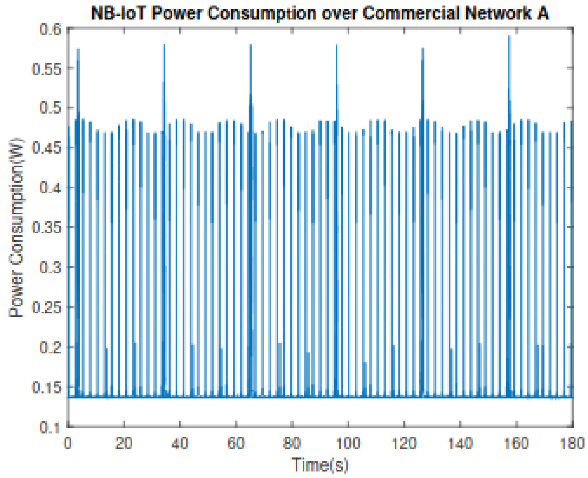

Figure 4: NB-IoT Power consumption Commercial Network A.

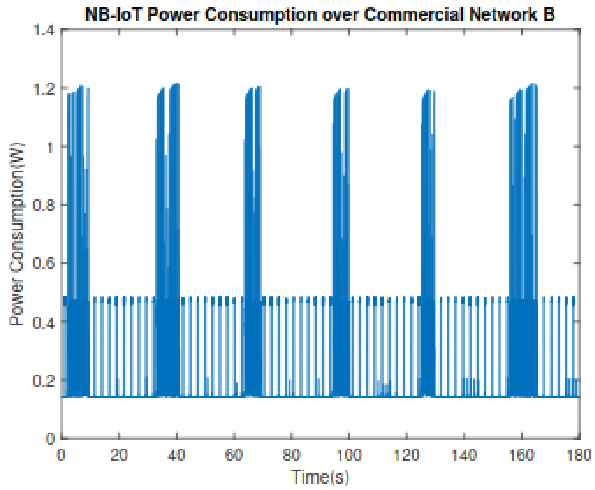

Figure 5: NB-IoT Power consumption Commercial Network B.

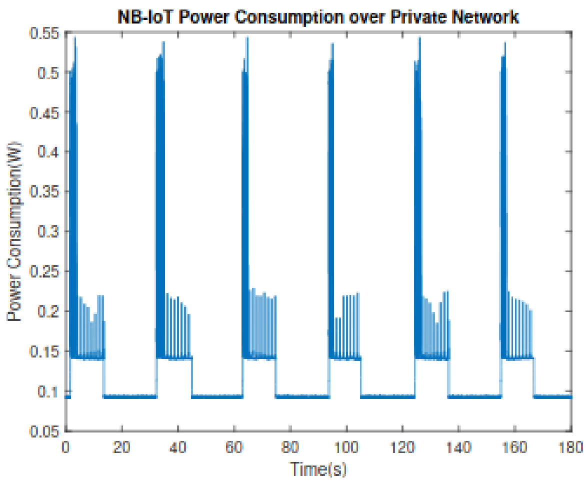

Figure 6: NB-IoT Power consumption Private Network.

In Figure 6, the main difference compared to the previous graphs is the presence of PSM in which the NB-IoT device enters into hibernation. However, the minimum power consumption is still around 0.09 W due to the Arduino peripheral.Therefore, the private network scenario has the lowest overall energy consumption.

Final conclusion on power consumption

The following tables present the battery lifetime calculations based on a 5000 mAh battery size.

With disable PSM:

OVERALL RESULTS FROM THE NB-IOT EXPERIMENTAL STUDY

	Packet Interval	Avg. Current Consum.	Expec. Batt. Life
Comm. Netw. A	30 s	27.7 mA	8.16 days
Comm. Netw. B	30 s	57.7 mA	5.00 days
Priv. Netw.	30 s	20.4 mA	9.97 days

With available PSM:

ACHIEVABLE NB-IOT BATTERY LIFETIME IN OPTIMIZED NETWORK CONFIGURATIONS

	Packet Interval	PSM Active	Optimized Peripheral
Comm. Netw. A	30 s	10.69 days	21.9 days
	5 m	12.81 days	222.65 days
	1 h	13.08 days	4.62 years
	1 d	13.10 days	10.89 years
Comm. Netw. B	30 s	6.00 days	7.3 days
	5 m	11.72 days	76.65 days
	1 h	12.97 days	2.12 years
	1 d	13.10 days	9.77 years
Priv. Netw.	30 s	9.97 days	18.25 days
	5 m	12.70 days	175.2 days
	1 h	13.07 days	4.01 years
	1 d	13.10 days	10.73 years

In PSM active state, power consumption of the NB-IoT chip is taken as 3μA and the consumption on the peripheral stays the same. In optimized peripheral case, it is assumed that the peripheral goes into deep sleep mode during the PSM of NB-IoT chip and both of them is assumed to require 50μA in total. From this table, we can observe how each feature improves the estimated battery life.

Moreover, in order to evaluate more precisely the power consumption we can make an estimation of LPWAN energy consumption in mWs/bit as shown in Figure 7 below:

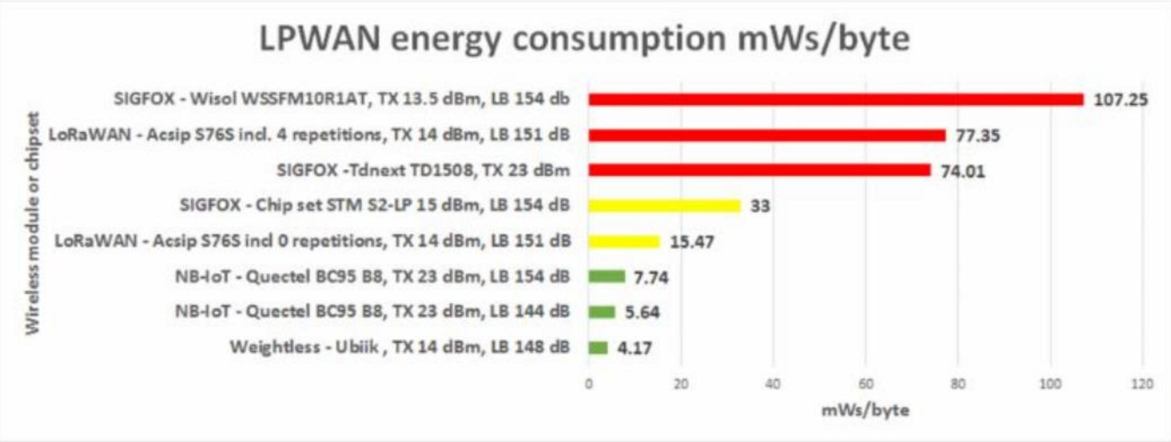

Figure 7: LPWAN energy consumption comparison.

6 - Security

NB-IoT uses a subset of the long-term evolution (LTE) standard but limits the bandwidth to a single narrow band of 200 kHz. In March 2019, the Global mobile Suppliers Association (GSA) announced that over 100 operators have deployed/launched either NB-IoT or long-term evolution for machines (LTE-M) networks.

Before delving into the NB-IoT network, it is necessary to take into account three basic pillars of IoT security that will allow us to have a panoramic view of the topic :

- The first, the **authentication**. With it, we guarantee that the device that sends data to the cloud is authorized and no one has replaced it with another. Likewise, we guarantee to the device that the cloud with which it is exchanging information is also true and nobody is substituting it or appropriating of the data illicitly.

- With **encryption**, we guarantee that a communications observer cannot understand the messages and only the cloud with the decryption keys can retrieve the messages.

- And with **non-manipulation**, we guarantee that no one has altered the message that the IoT device sends to the cloud.

APN or operator platform: Some operators offer for NB-IoT the 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 typically connected via a secure VPN connection to the operator's platform, and this makes the entire path from the device to the customer's cloud server secure.

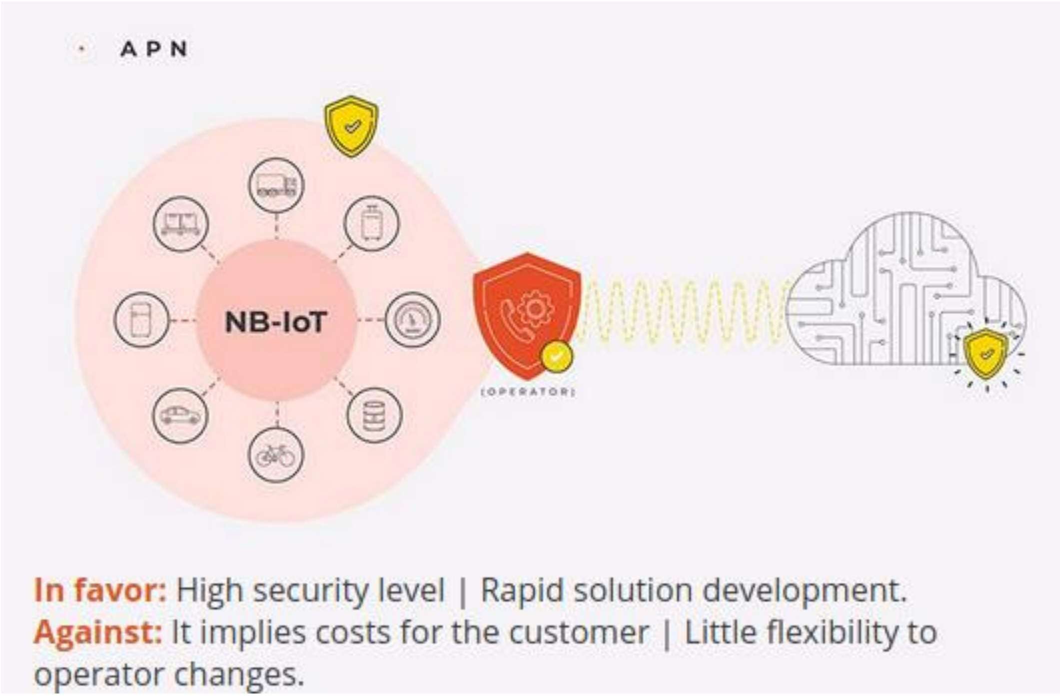

Figure 8: APN Protocols.

UDP protocol securing: In this case, data travels end-to-end encrypted by the same technology, and the cloud server is responsible for authenticating and decoding the data.

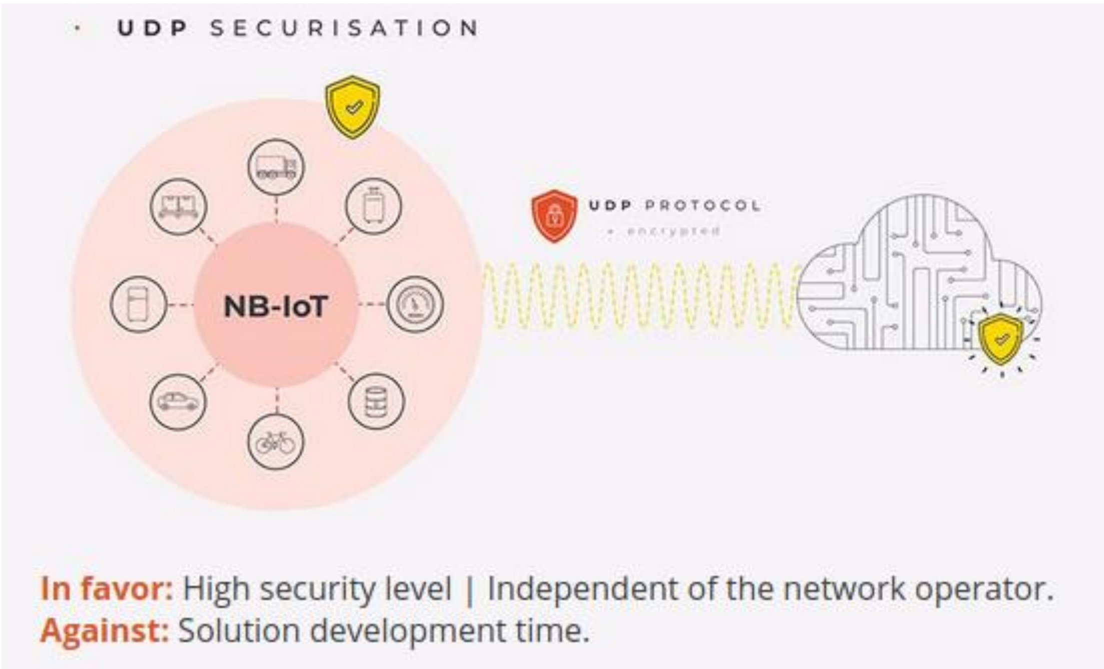

Figure 9: UDP securisation.

7 - Overview

Here we present comparisons (see Table 1) with some key factors that should be taken into consideration when choosing the best adapted LWAN for an IoT applications.

	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

Table 1: Comparison between Sigfox, LoRa and NB-IoT.

In terms of *Quality of Service (QoS)*, Sigfox and LoRa employ unlicensed spectra and asynchronous communication protocols while NB-IoT employs a licensed spectra and an LTE-based synchronous protocol. Thus, **NB-Iot is preferable when applications require a QoS**.

Concerning *energy consumption and latency*, **NB-IoT presents a higher consumption** of energy due to its synchronous protocol, its QoS and also because of the OFDM/FDMA to downlink and uplink that require higher peaks of current. So LoRa and Sigfox are better solutions regarding energy consumption. Whatsoever, NB-IoT presents a lower latency than both other options, so **for applications that require lower latency NB-IoT is a better solution**.

Regarding *scalability and payload*, **NB-IoT allows connectivity of up to 100K devices per cell** compared to 50K per cell for Sigfox and LoRa. Also, NB-IoT presents the highest payload being able to transmit up to **NB-IoT allows the transmission of up to 1600 bytes of data**. LoRa allows a maximum of 243 bytes of data to be sent while Sigfox allows the transmission of only 12 bytes of data (which limits a lot its use in applications that require a bigger sizes of data).

In range, Sigfox can reach a range of 10 km (in urban area), 40 km (in rural). LoRa is able to reach 5 km (urban) and 20 km (rural). And **NB-Iot presents the lowest range: 1 km (urban), 10 km (rural)**. It focuses more in reaching devices that are located indoors, undergrounds and not in area coverage.

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