Comparative Analysis of LTE-M and NB-IoT Node Battery Life in Different Coverage Environments

Nassim LABDAOUI[2] Fabienne NOUVEL[1] Stéphane DUTERTRE[2]

[1]Univ Rennes, INSA Rennes, CNRS, IETR-UMR 6164, F-35000 Rennes, France

[2]Watteco, 6 Rue Gutenberg ZI de Kerandré, 56700 Hennebont, France

Résumé – Cet article étudie la consommation d'énergie d'un nœud LTE-M/NB-IoT intégrant un module u-blox SARA-R422S. Les résultats montrent que, dans certaines conditions, ces technologies peuvent atteindre une durée de vie opérationnelle de 5 ans. La taille des données transmises n'a pas d'impact significatif sur la consommation d'énergie dans des conditions de couverture favorables, mais peut rapidement affecter la durée de vie de la batterie dans des conditions de couverture difficiles. Nous constatons que les performances de NB-IoT en terme d'autonomie sont inférieures à celles de LTE-M.

Abstract – This article investigates power consumption of LTE-M and NB-IoT devices with u-blox SARA-R422S modules. Our findings suggest up to 5 years lifespan, and data size doesn't impact power consumption under favorable coverage conditions but can affect battery life in harsh coverage. It provides insights and is useful for IoT technology users. We find that the performance of NB-IoT in terms of battery life is lower than that of LTE-M.

1 Introduction

This study compares the energy consumption of LTE-M [1] and NB-IoT [2] devices using the u-blox SARA-R422S [3] module under real-world network conditions. The impact of the payload size, network coverage, and data transfer periodicity on energy consumption is analysed.

Battery replacement and field servicing can often incur significant cost, underscoring the importance of understanding the operational battery life of deployed devices. Our analysis covers all phases of operation, including network attachment, Data exchange, eDRX Mode (Extended Discontinuous Reception) and PSM (Power Saving Mode). We provide a comparative analysis of LTE-M and NB-IoT, including their respective battery lifetime.

The rest of the article is organized as follows: In Section 2, we present a model for estimating energy consumption, followed by a description of the experimental setup for measuring power consumption in Section 3. Section 4 presents the results obtained from the experiments, and a comparison between the two technologies is provided in Section 5. Finally, we conclude the paper with a summary of our findings.

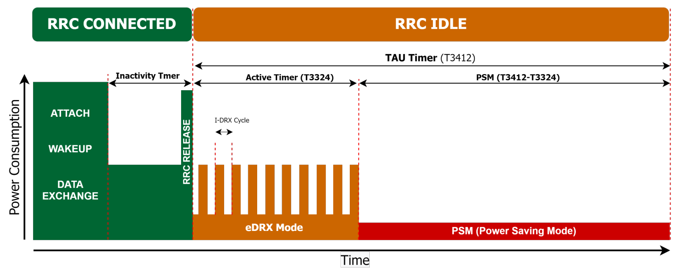


Figure 1 – Illustration of RRC Protocol States for an LTE-M/NB-IoT Terminal: Features available on Orange and SFR networks

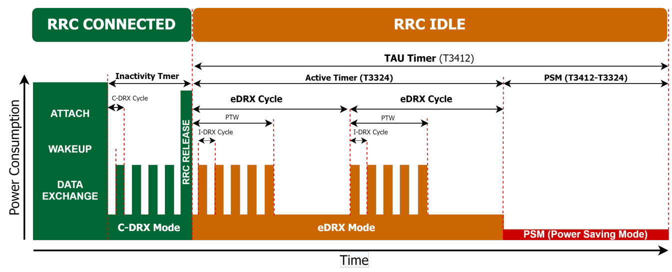


Figure 2 – Illustration of RRC Protocol States for an LTE-M/NB-IoT Terminal (eDRX, cDRX functionalities available)

2 Consumption Model

This section presents a model that characterizes the energy consumption of an LTE-M/NB-IoT cell module based on the RRC protocol specifications. The model, previously proposed in [4] for NB-IoT, is applied in our study to estimate the energy consumption of both LTE-M and NB-IoT technologies.

The cellular modem operates in two states: RRC CONNECTED STATE and RRC IDLE STATE. In RRC CONNECTED STATE, the modem exchanges data with the base station during network attachment, wake-up, and data transmission. In RRC IDLE STATE, the modem enters eDRX mode then PSM.

The modem's duration in RRC CONNECTED STATE, called the *Inactivity Timer*, depends on the network, while the duration in RRC IDLE STATE is controlled by the user-configurable T3412 timer. In RRC IDLE STATE, the modem listens to the downlink channel for a duration set by the user-configurable T3324 timer. The duration in PSM can be calculated as $T_{PSM} = T3412 - T3324$.

Certain functionalities, like eDRX and cDRX (Connected Discontinuous Reception) modes, are currently not supported, as observed in our experiments. Consequently, we had to modify the model to estimate the energy consumption of our LTE-M/NB-IoT device without these functionalities. Figure 1 illustrates the RRC functionalities available in the LTE-M

(Orange) and NB-IoT (SFR) networks, while Figure 2 shows the complete range of functionalities.

The total energy consumption of a terminal can be calculated using equation 1:

$$E_{TOTAL} = E_{RRC\_CONNECTED} + E_{RRC\_IDLE} \quad (1)$$

By replacing $E_{RCC\_CONNECTED}$ and E_{RCC_IDLE} in equation 1 we obtain:

$$E_{TOTAL} = E_{ATTACH} + E_{TX/RX} + E_{eDRX} + E_{PSM} \quad (2)$$

The total energy consumption when both the current and the VCC voltage are taken into account can be expressed as shown in equation 3:

$$E_{TOTAL} = VCC \times [\bar{I}_{ATTACH} \times T_{ATTACH} + \bar{I}_{TX/RX} \times T_{TX/RX} + \bar{I}_{eDRX} \times T_{eDRX} + \bar{I}_{PSM} \times T_{PSM}] \quad (3)$$

with: $T_{PSM} = T_{3412} - T_{3324}$ and $T_{eDRX} = T_{3324}$

To estimate battery life, the average current consumption of the module is measured over its operational duration. It has been observed that the modem's power consumption during wake-up phases is comparable to that during attachment phases in LTE-M/NB-IoT networks. The average current consumed by the modem throughout its lifespan is equivalent to the average current consumed during a periodically repeated operational cycle. This cycle encompasses the following stages: network attachment, connection to the MQTT server, data transmission, disconnection from the MQTT server, eDRX mode lasting T3324 seconds, and ultimately transitioning to PSM for $T_{PSM} = T3412 - T3324$. The average current consumed by the module $\bar{I}_{Module}$ is given in equation 4:

$$\bar{I}_{Module} = [\bar{I}_{ATTACH} \times T_{ATTACH} + \bar{I}_{TX/RX} \times T_{TX/RX} + \bar{I}_{eDRX} \times T_{eDRX} + \bar{I}_{PSM} \times T_{PSM}]/T_{TOTAL} \quad (4)$$

with:
$T_{TOTAL} = T_{ATTACH} + T_{TX/RX} + T_{eDRX} + T_{PSM}$

The calculation of battery life $T_{Battery\ Life}$ is based on Equation 5:

$$T_{Life\ Time} = \frac{C_{Bat} \times SD_{Bat}}{\bar{I}_{Module} + \bar{I}_{components}} \quad (5)$$

We assume that the electronic board is powered by a Lithium Thionyl Chloride (Li-SOCl2) battery with a capacity of $C_{Bat} = 3.6\ Ah$ and a self-discharge factor of $SD_{Bat} = 0.75$. Assuming that $\bar{I}_{components}$ is in the range of a few μA, we will neglect it in our calculation.

3 Experimentations

The current consumption of the u-blox SARA R422S radio module was measured using a KEITHLEY DMM6500 digital multimeter [5]. The multimeter was connected in series with the voltage regulator powering the radio module, with VCC set to 3.8 V. These measurements solely represent the current consumption of the radio module and do not consider other components on the prototype board. Figure 3 depicts the test bench setup for the current consumption measurement, which included the use of attenuators to simulate varying coverage conditions. Moreover, We use Mosquitto MQTT server [6] for data transmission.

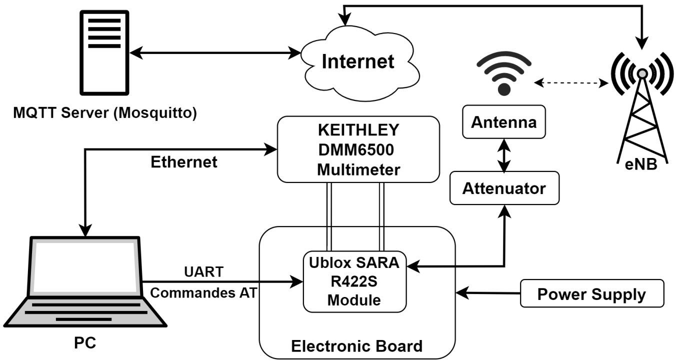
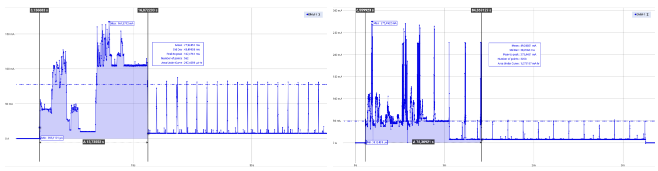


Figure 3 – Measuring and Evaluating Performance with an Experimental Test Bench

4 Results

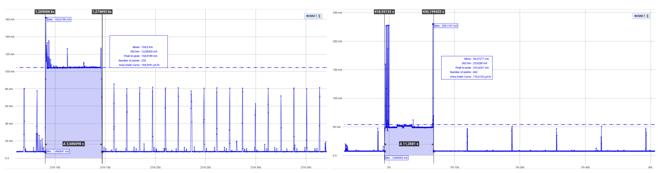
In this section, we present the measurements conducted in LTE-M and NB-IoT under different coverage conditions. Figures 4a to 8a show the current consumption of the radio module in LTE-M for various indoor operations, including attachment, eDRX mode and MQTT exchange. Similar measurements were conducted in NB-IoT for indoor coverage, and the results can be seen in Figures 4b to 8b.



(a) LTE-M **(I = 77.92 mA, T = 13.73 s, eDRX Cycle = 1.28 s)**

(b) NB-IoT **(I = 49.24 mA, T = 78.30 s, eDRX Cycle = 10.24 s)**

Figure 4 – Network Attach and eDRX Mode

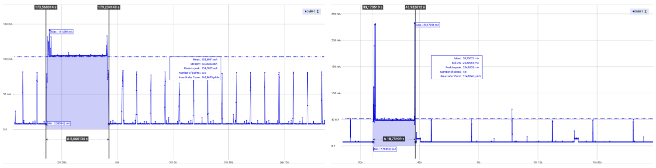


(a) LTE-M **(I = 104.5 mA, T = 5.68 s)**

(b) NB-IoT **(I = 54.37 mA, T = 11.26 s)**

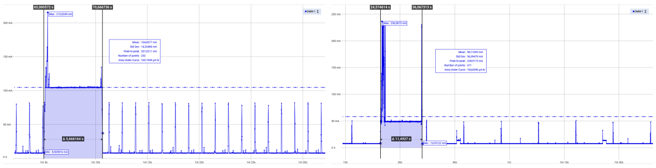
Figure 5 – MQTT Connection

In Table 1, the energy consumed by the modem in LTE-M and NB-IoT for the different phases are summarized according to the attenuation. As the attenuation value increases, indicating a weaker signal, there is a corresponding increase in power consumption. Overall, the measurements show that NB-IoT exhibits higher energy consumption than LTE-M due to the longer duration of consumption slots. NB-IoT is not



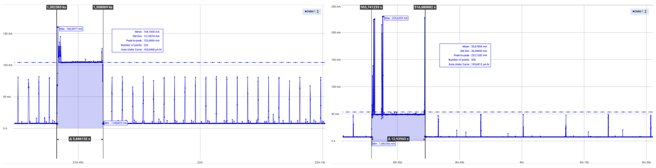
(a) LTE-M (**I = 103.49 mA, T = 5.66 s**) (b) NB-IoT (**I = 51.75 mA, T = 10.75 s**)

Figure 6 – Sending 1 Byte



(a) LTE-M (**I = 104.85 mA, T = 5.66 s**) (b) NB-IoT (**I = 58.11 mA, T = 11.49 s**)

Figure 7 – Sending 1024 Bytes



(a) LTE-M (**I = 104.14 mA, T = 5.68 s**) (b) NB-IoT (**I = 53.67 mA, T = 12.93 s**)

Figure 8 – MQTT Disconnection

less consumer than expected because of the *Inactivity Timer* duration. The relationship between Signal Power and the RSSI value (Received Signal Strength Indicator) is provided in [3].

5 LTE-M/NB-IoT Comparison and Battery Lifetime

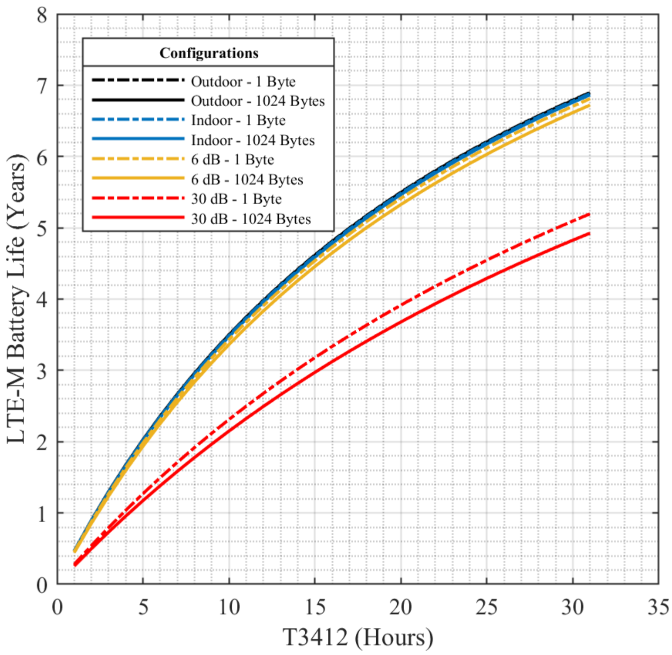


Figure 9 – Evaluating the Impact of LTE-M Coverage on Electronic Board Lifetime. (T3324 = 6 seconds)

To estimate the battery life, we take into account the measured average current during the different state of the RRC protocol and according to the current model. We assume that the UE remains in eDRX mode during T3324 = 6 seconds (The configurable minimum value). During this time the UE periodically monitors the downlink channel, with a monitoring period of 1.28 seconds in LTE-M and 10.24 seconds in NB-IoT, as shown by the duration between two consecutive peaks in eDRX Mode in Figures 4a and 4b.

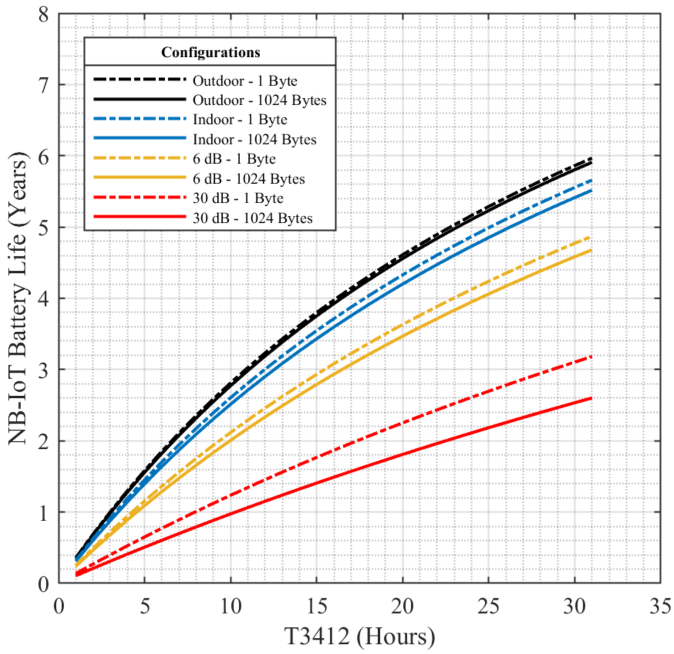
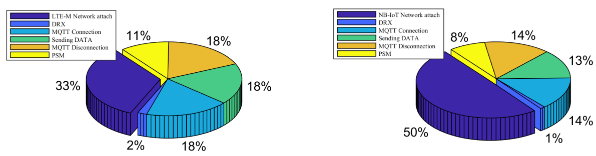


Figure 10 – Evaluating the Impact of NB-IoT Coverage on Electronic Board Lifetime. (T3324 = 6 seconds)

Figures 9 and 10 present respectively the estimated lifetime of an LTE-M and NB-IoT node, depending on the periodic waking up T3412. In LTE-M, the results indicate that under optimal coverage conditions, the node could potentially operate for up to 6 years when transmitting once per day. However, with 30 dB of attenuation, the estimated lifetime is reduced to around 4 years. In NB-IoT, the terminal can potentially operate for up to 5 years with a periodic wake-up and daily data transmission in outdoor coverage condition. In scenarios with 6 dB of attenuation, the estimated lifetime is reduced to approximately 4 years, and 2.1 years in case of 30 dB.

Based on the presented results, the device's lifespan is found to be longer in LTE-M compared to NB-IoT. This disparity is primarily attributed to the duration of consumption slots during RRC CONNECTED STATE, which lasts approximately 5 seconds in LTE-M and around 10 seconds in NB-IoT. The duration is determined by the *Inactivity Timer* specified in the LTE-M/NB-IoT standards, and its value is operator-dependent and may vary between different base stations.



(a) LTE-M (b) NB-IoT

Figure 11 – Distribution energy consumed according to the radio procedures. (Indoor environment, Data Size = 1024 Bytes, $T_{eDRX} = 6\,seconds, T_{3412} = 24\,hours$)

Table 1 – Energy Consumption [mJ] Comparison of LTE-M and NB-IoT for Different Coverage Conditions. (T3324 = 6 seconds and T3412 = 24 hours)

		Attenuations	Outdoor	Indoor	3dB	6dB	10dB	15dB	20dB	30dB
LTE-M		**Signal Power**	**31**	**25**	**22**	**19**	**17**	**14**	**12**	**10**
	RCC CONNECTED	$E_{NetworkAttach}$	4215	4078	4772	4232	4650	4147	3733	7375
		$E_{Wake-up}$	3972	3989	4026	4188	4205	4253	5490	6724
		$E_{MQTTConnect}$	2169	2255	2225	2213	2265	2315	2384	3709
		$E_{TX1Byte}$	2127	2220	2211	2244	2251	2293	2314	3631
		$E_{TX1024Bytes}$	2139	2270	2270	2314	2305	2547	2711	5014
		$E_{MQTTDisconnect}$	2134	2247	2249	2284	2278	2326	2325	3597
	RCC IDLE	E_{eDRX}				249				
		E_{PSM}				1313				
NB-IoT		**Signal Power**	**21**	**18**	**16**	**14**	**12**	**9**	**8**	**6**
	RCC CONNECTED	$E_{NetworkAttach}$	7261	8276	8343	9122	10579	10721	10770	20089
		$E_{Wake-up}$	7202	7509	8178	9264	10623	10753	10985	17859
		$E_{MQTTConnect}$	2179	2349	2394	2589	2971	3056	3386	6201
		$E_{TX1Byte}$	2105	2114	2256	2493	2558	2700	2992	4424
		$E_{TX1024Bytes}$	2320	2710	2703	3584	3588	3795	3814	13597
		$E_{MQTTDisconnect}$	2491	2401	29785	2693	3216	3010	3683	5627
	RRC IDLE	E_{eDRX}				179				
		E_{PSM}				1313				

The results show that under favourable cover conditions, the payload size has a negligible influence on the battery life, both in LTE-M and NB-IoT. However, in NB-IoT with 30dB of attenuation, the payload size has a significant impact on the lifetime, resulting in a loss of 7.2 months of battery, against only a loss of 2 months in LTE-M with the same conditions.

Figure 11 depict the breakdown of energy consumption across different phases and modes of operation in LTE-M and NB-IoT. The attachment procedure to the LTE-M or NB-IoT network is the most energy-intensive.

6 Conclusion

In this paper, we describe an experimental approach for characterizing the energy consumption of an LTE-M/NB-IoT terminal. Our approach allows us to estimate the battery life of an LTE-M/NB-IoT device based on T3412 and T3324 parameters, the number of periodic awakenings, and the payload size for transmitting data over MQTT.

The results show that the lifetime of the device is highly operator-dependent, and in particular on the *Inactivity Timer* parameter. Estimates show that a node can reach a lifetime of 6 years in LTE-M (Orange operator) if data is transmitted every 24 hours. On the other hand, a terminal operating on an NB-IoT network (SFR operator) will have a lifetime of approximately 5 years. Hence, when comparing the two operators, LTE-M demonstrates greater efficiency in terms of battery life compared to NB-IoT, primarily attributed to the variation in the *Inactivity Timer* parameter adopted by each operator.

The excessive consumption in challenging coverage conditions can be attributed to the coverage extension mechanisms specified in the LTE-M and NB-IoT standards. LTE-M encompasses two operating modes: CE (Coverage Enhancement) Mode A, supporting up to 32 repetitions, and CE Mode B, accommodating up to 2048 repetitions. On the other hand, NB-IoT defines three coverage extension levels, namely ECL (Coverage Enhancement Level) 0, ECL 1, and ECL 2. In NB-IoT, the maximum number of repetitions is, 2048 in the downlink and 128 in the uplink.

High current intensities are critical in extreme coverage conditions for LTE-M or NB-IoT devices. Consumption peaks can exceed 500 mA (with 30 dB attenuation) and reach 140 mA outdoors. Suitable battery selection is vital. Lithium-manganese dioxide (Li-MnO2) [7] batteries are recommended for their maximum continuous current of 1.5 A, while Lithium Thionyl Chloride (Li-SOCl2) [8]batteries support only up to 100 mA.

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