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White paper

DOCUMENT :

LoRaWAN vs 15757-4/N2 :
An technical comparative analysis

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SUMMARY:

This white paper analyses the relative performance of two long range wireless standards in terms of coverage, energy efficiency and cost : LoRaWAN (in 868MHz band) vs EN13757-4/N2 (in 169MHz band).

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28/12/16	1A	R.Lacoste / ALCIOM	Initial version
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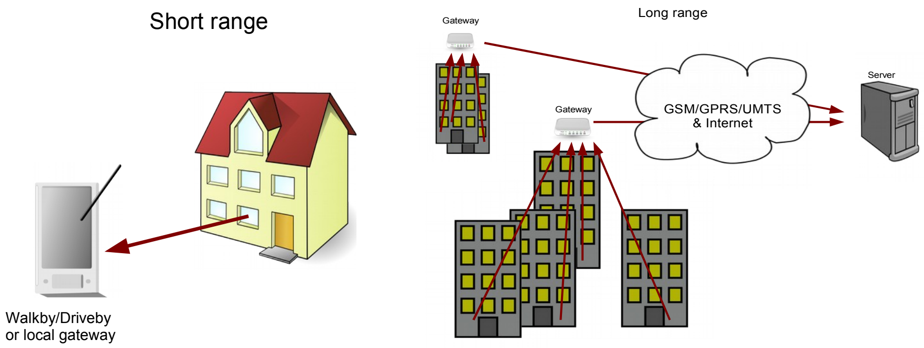
CONTENTS

1 Introduction

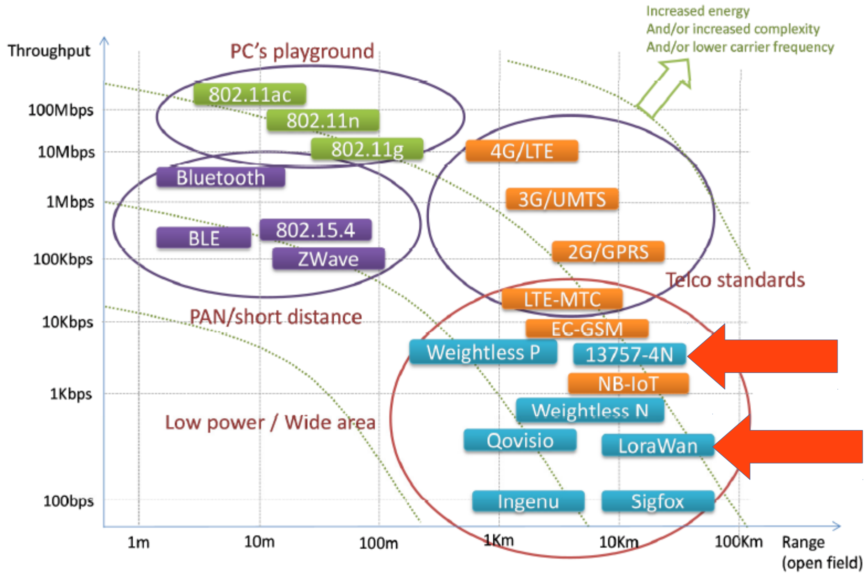
Metering systems could be split into two distinct application ranges :

- **Short range metering systems**, in which the useful data (reading of a water, gas or electricity counter, etc) must be transmitted to a closely located receiver. This is typically the case for domestic meter reading. In such systems the data receiver is either a low cost fixed gateway installed for example in corridors, or a moving receiver when using walk-by or drive-by techniques. In both cases the final data transfer to a central server is done through another channel than RF, like Internet.
- **Long range metering systems**, in which the data must be transmitted to a central server through a fixed transmission network. Such long range systems are usually built using relaying techniques, combining low cost RF links to fixed gateways. These gateways are usually installed on roofs, needs external power and are significantly more expensive than short range devices, so their number must be minimized in order to reduce deployment costs.



This white paper focuses on long range systems and more specifically on two of the most efficient low power / wide area networks (LPWAN) in terms of energy efficiency :

- **LoRaWAN in 868MHz band**
- **EN13757-4/N2 in 169MHz band**



Other configurations are of course possible but the intent of this white paper is to focus on these two technologies, which have proved to be both reasonably efficient solutions in terms of coverage for deep indoor smart metering applications.

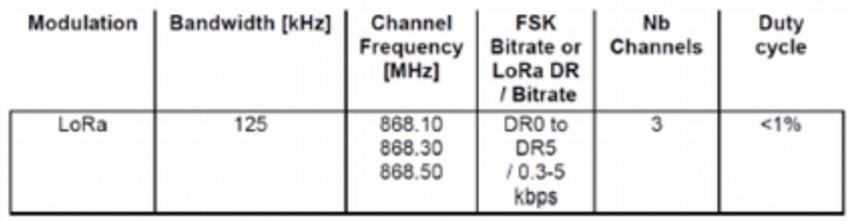
2 Quick presentation of both solutions

2.1 LoRaWAN

Overall : LoRa (“Long Range”) is a modulation technology developed by the French company Cycleo (Grenoble) and announced in September 2009. LoRa was then only a digital intellectual property module implementing the modulator and demodulator as well as early demonstrator platforms. Cycleo was then acquired by Semtech in March 2012. As a chip designer, Semtech integrated the LoRa IP into their RF transceivers, providing a one-chip solution.

In January 2015, the LoRa-Alliance (LoRaAlliance.org) is formed to support and develop a higher level protocol stack, LoRaWan, as an open standard. In June 2015 the specification of LoRaWan V1.0 achieved public release status.

Carrier frequency : In LoRaWAN, communication between end-devices and gateways is distributed via different frequency channels and data rates. LoRa uses mainly 3 channels in the unlicensed 868 MHz band for Europe

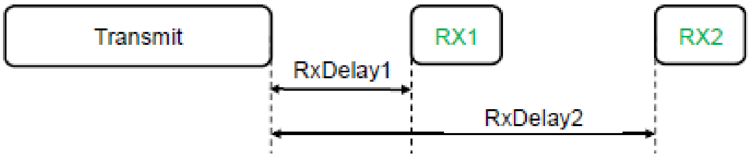


Modulation	Bandwidth [kHz]	Channel Frequency [MHz]	FSK Bitrate or LoRa DR / Bitrate	Nb Channels	Duty cycle
LoRa	125	868.10 868.30 868.50	DR0 to DR5 / 0.3-5 kbps	3	<1%

Data rate : Physically, the modulation is based on spread-spectrum coding with a variation of chirp spread spectrum (CSS) with integrated forward error correction (FEC). This modulation is managed digitally. For Europe, LoRaWAN data rates range between 292bps to 11kbps with LoRa modulation through different so-called spreading factors (from 12 to 7 respectively), plus one GFSK data rate at 50kbps.

The selection of channel and data rate is therefore a trade-off between communication range and message payload. To maximize both the battery life of the end-devices and network capacity, the LoRaWAN network server can manage the data rate for each connected sensor via an Adaptive Data Rate algorithm (ADR). Anyway the majority of devices are currently using a predefined data rate based on the application.

Bidirectionnality : LoRaWAN compatible-Smart meters are so called Class A devices. This mode allows for bi-directional communications whereby each end-device’s uplink transmission is followed by two short downlink receive windows (by default 1s and 2s after uplink frame, with listening time of 160ms each for 300bps transmission). The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol). This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server are queued automatically until the next scheduled uplink.



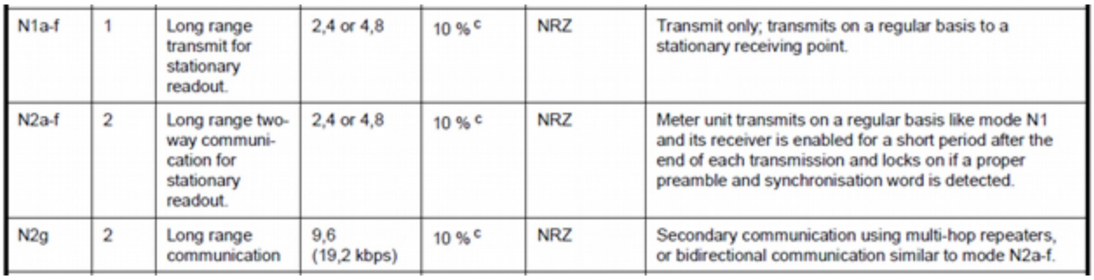
Performances : In upstream, the sensitivity of a LoRAWAN gateway at 293bps is about -141dBm conducted. Meters are limited by regulation to a +14dBm transmit power (radiated).

2.2 EN13757-4/N2

Overall : The EN137457-4 european standard is part of a “metering” standard suite managed by the CEN TC294 technical comitee. The CEN TC294 standardises communication for gas, water and heat meters as well as for heat cost allocators. The EN13757-4 defines the wireless low level interface of this standard, including physical and MAC layers. This standard includes a long list of variants.

In 2012, a new variant of the EN13757-4 variant, called variant N, was proposed by ONDEO SYSTEMS and GrDF. This variant, using a 169MHz frequency band, allows to implement an actual LPWA network, contrarily to the other options which have a significantly shorter range and/or rely on short range relays, thanks to the low frequency band and high authorized transmit power (500mW or +27dBm).

Carrier frequency : The EN13757-4 N modes uses standard modulations in the 169MHz frequency band. The band is 75KHz wide, split into 6channels of 12,5KHz each



N1a-f	1	Long range transmit for stationary readout.	2,4 or 4,8	10 % c	NRZ	Transmit only; transmits on a regular basis to a stationary receiving point.
N2a-f	2	Long range two-way communication for stationary readout.	2,4 or 4,8	10 % c	NRZ	Meter unit transmits on a regular basis like mode N1 and its receiver is enabled for a short period after the end of each transmission and locks on if a proper preamble and synchronisation word is detected.
N2g	2	Long range communication	9,6 (19,2 kbps)	10 % c	NRZ	Secondary communication using multi-hop repeaters, or bidirectional communication similar to mode N2a-f.

Data rate : Two data rates are specified by the standard (2400bps and 4800bps, plus a 9600bps mode for specific applications). Subsequent improvements where proposed by GrDF through the AFNOR group E17Z in order to add a standardized highly secure ciphering and authentication feature set as well as faster 6400bps modulation scheme and broadcast mode for firmware download over the air.

Bidirectionnality : Both bidirectional and unidirectional communications are supported, even if the typical applications use unidirectional links with rare downlink trafic. Each transmission is followed by a short reception window, typically 20ms long.

Performances : EN13757-4 mode N meters have usually +24 to+27dBm power amplifier (500mW), but have low gain antennas due to the mandatory small form factor (relatively to the wavelength), thus achieving about +15 to +17dBm radiated power. Modern SDR-based EN13757-4 receiver provides typical sensitivity of -128dBm at 2400bps.

2.3 Hypothesis

In this white paper, we assume that :

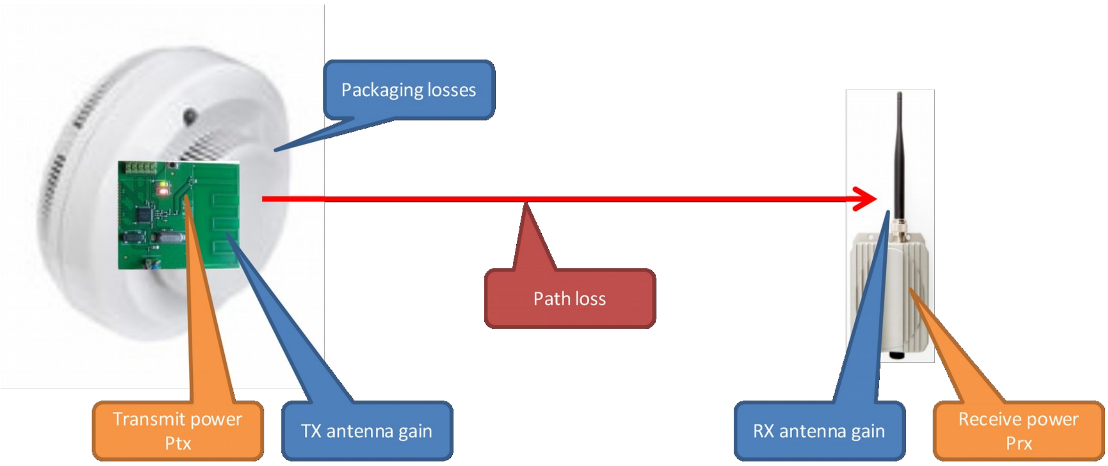
- LoRaWAN is used only in 292bps mode (SF12/DR0) and in 868MHz band, with a +13dBm conducted uplink transmit power
- EN13757-4/N2 protocol is used only in 2400bps mode and in 169MHz band, with a +24dBm conducted uplink transmit power
- Communications are bidirectionnal but downstream load can be neglected (typical of metering systems)
- Meters are typically installed in deep indoor configuration.

3 Deep indoor RF coverage comparison

3.1 Link budget

For any radiofrequency transmission, the goal is to receive a signal strong enough in order to decode it with a reasonable error rate. Therefore the estimation of the received signal strength is key. This estimation includes the transmit power and RF channel condition and is called a link budget. The overall link budget of a radio link can be simplified as follows :

$$P_{RX}(dBm) = P_{TX}(dBm) - PathLoss - PackagingLosses + AntennaGains$$



In this formula :

- P_{RX} is the received power in dBm (meaning in dB relatively to 1mW), which must be above the sensitivity threshold of the receiver for a successful transmission (cf 2.3.3) ;
- P_{TX} is the transmitted power
- PathLoss is the signal attenuation through the air (see below)
- PackagingLosses are all signal losses due to the product enclosure, surrounding objets, etc
- AntennaGains is the sum of the gains or RX and TX antennas.

One of these terms is usually several orders of magnitude higher than the others : The **path loss**. The Friis formula provides an evaluation of this loss. One version is the following :

$$PathLoss(dB) = 20\log_{10}(d_{km}) + 20\log_{10}(f_{MHz}) + 32,4 + PenetrationLoss + FadingLoss + PolarisationLoss$$

Here :

d is the distance between transmitter and receiver in kilometers
f is the carrier frequency in MHz
PenetrationLoss is the sum of all signal losses due to obstacles, walls, etc
Fadingloss is the signal attenuation due to multipath fading (reflected signals summed with inverted phases)
PolarisationLoss is the signal attenuation due to non-parallel polarization planes between TX and RX antennas

Even if it is only approximated, this equation shows that the carrier frequency has a huge importance in terms of long range communication : For the same RF characteristics (TX power, RX sensitivity, antennas gains, losses, etc), the range of a RF link is doubled when the carrier frequency is divided by two.

As a consequence, with the same hypothesis, same antenna gains and same link distance, a 169MHz solution will provide a $20\log_{10}(868/169)$=14dB better link budget than a 868MHz solution

3.2 Bit rate, channel width, and sensitivity

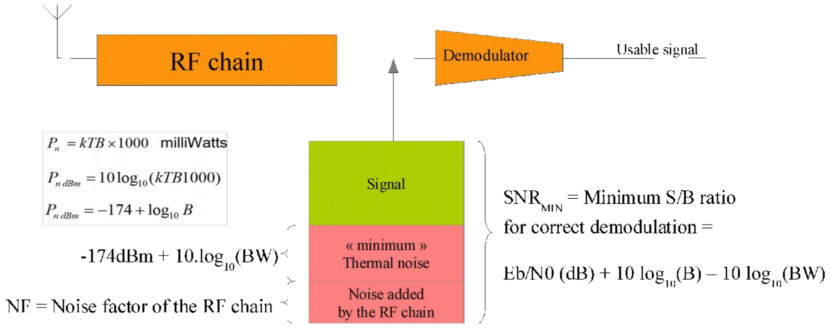
The generic formula for the sensitivity of a receiver is the following :

$$Sensibility(dBm) = -174 + 10\log_{10}(bitrate) + NF + Eb/N0$$

In this formula :

- Sensitivity is the minimum signal level in dBm that, when injected on the receiver antenna, allows the receiver to demodulate and decode the message with a given error rate ;
- Bitrate is the effective number of information bits transmitted per second (and NOT the channel bandwidth or the raw modulation bit rate) ;
- NF is the noise figure of the receiver, meaning a measure of the quality of the front-end electronics ;
- Eb/N0 is a figure of quality of the demodulator, meaning the amount of energy above noise that is required to demodulate an effective bit with the required error rate.

The following illustration explains where this formula come from :



$$\text{Sensi (dB)} = -174\text{dBm} + 10.\log_{10}(\text{BW}) + \text{NF} + \text{SNR}_{\text{MIN}} = -174\text{dBm} + \text{NF} + 10.\log_{10}(\text{B}) + \text{Eb/N0 (dB)}$$

Therefore the key factors to improve the range of a wireless communication are the following :

- **Reduce carrier frequency** (in order to limit the path loss at a given distance, at the expense of a larger antenna)
- **Increase transmit power** (up to the regulation limit, but with an impact on the power consumption)
- **Reduce the effective bitrate** (with an impact on the power consumption and system latency)
- **Increase the quality of the electronic of the receiver** (for a lower NF)
- **Increase the quality of the demodulator or use a more effective modulation** (to reduce Eb/N0)

If we put aside the carrier frequency (which is a system design decision), the next two options (increased TX power and reduced bit rate) have the same impact which **is increasing the transmit energy per bit** and so the power usage. All the LPWA solutions which uses a low bit rate to improve the range are basically increasing the energy used to transfer each bit of information as the first range enhancement mechanism. This is exactly the same than increasing the transmit power with a faster bit rate (legal constraints aside).

The last two options are more valuable but more complex. The **noise figure** improvement is costly as requiring high performance hardware, therefore the most studied aspect is the **Eb/N0 improvement**, through intense research since the 60's on energy efficient modulation schemes like PSK, synchronous demodulation, error correcting codes etc.

Therefore, a 300bps solution like LoRaWAN will provide a $10\log_{10}(2400/300)=9$dB better receiver sensitivity than a 2400bps link like EN13757-4N. This simply means that a lower bit rate gives a higher energy per bit as bits are longer.

3.3 Antennas efficiency

There are two issues linked to antennas : impedance matching and stability to varying environmental conditions. It can be showed that the lowest obtainable quality factor of an antenna can be approximated by the following formula :

$$Q=\frac{1}{(k\,a)^3}+\frac{1}{k\,a} \quad \text{(extended Chu-Wheeler criterion)}$$

If this formula a is the radius of a sphere enclosing the antenna, and k is calculated as :

$$k=\frac{2\pi}{\lambda} \quad \text{(equation 5)}$$

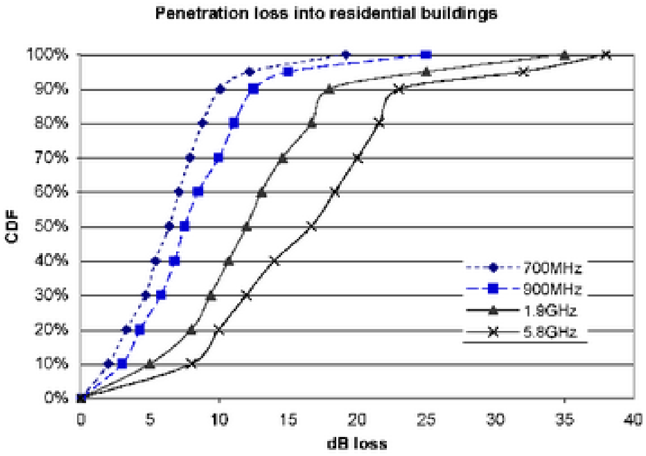
The wavelength at 169MHz is 5 times larger than at 868MHz. Assuming that the space available to fit the antenna is given (meaning that the 169MHz antenna must have roughly the same size than a 868MHz antenna) then the two formulas shows that Q will be significantly higher at 169MHz. For a narrow band antenna Q is simply the frequency divided by the bandwidth of the antenna. **Therefore, for the same physical size, an optimized 169MHz antenna will have a significantly smaller bandwidth than an optimized 868MHz antenna.**

That doesn't mean that it would be impossible to design a small 169MHz antenna as good as a small 868MHz antenna, however that means that the design will be far more difficult to tune in order to get the same performance. It also means that external changes (wiring, proximity of walls, etc) that could detune the antenna will have a stronger effect on a 169MHz antenna. Moreover a small 169MHz antenna will be farer to 50ohm than a 868Mhz antenna of the same size. Therefore the matching network will be more difficult to design and more sensitive to detuning.

In summary a 169MHz antenna is naturally 5 times larger than a 868MHz antenna. If space is constrained, as it is always in metering applications at least on the transmitter side, then the 169MHz antenna will have a smaller bandwidth and will be significantly more sensitive to detuning. **Experimentally a classical short (5-8cm) 868MHz can provide a gain of about 0dBi, whereas it is very challenging to design a 169MHz with the same size with a gain higher than -10 to -5dBi. So, when space is constrained, there is a real life 8 to 12dB advantage for 868MHz on the meter side.** Antennas on the gateway side have typically the same gain whatever is the carrier frequency.

3.4 Deep indoor penetration

LPWA networks, and especially for metering, are often used for indoor communications. In such a configuration, other parameters than free space path loss should be studied, in particular penetration loss. Penetration loss is the attenuation of the signal when it must go through an obstacle (walls, windows, etc). Usually the higher the rf carrier frequency, the highest the losses :



(source : http://morse.colorado.edu/~tlen5510/text/classwebch3.html)

So typical penetration losses into indoor environments are far higher when the carrier frequency increase. For example with a typical probability of 90% this figures shows that the penetration into light indoor environments is about 12dB at 868MHz but up to 20dB at 2,4GHz. It would be lower (8dB ?) at 169MHz. The phenomenon is even more significant for deep indoor coverage, an usual requirement for smart metering applications. Recent analysis showed that the typical penetration loss from street to a typical underground meter is about 25dB at 169MHz and 35db at 868MHz :

Penetration loss (order of magnitude)	169MHz	868MHz
Light indoor	8dB	12dB
Deep indoor (meters)	25dB	35dB

For the same distance, a 169MHz solution do provide a significantly lower deep indoor penetration loss than 868MHz-based solution. Here we will assume a 10dB difference, which is confirmed by experience.

3.5 Path loss comparison

With these hypothesis, the following table provide a theoritical comparison of the path losses tolerated by both solutions :

		LoRaWAN / 868MHz	EN13757-4/N2 / 169MHz
Meter side (TX)	Transmit power (conducted)	+13dBm	+24dBm
	Meter antenna gain (typical)	1dBi	-10dBi
Gateway side (RX)	Gateway antenna gain (typical)	6dBi	3dBi
	Sensitivity (typical)	-141dBm	-128dBm
Link budget	Deep indoor penetration loss (typical)	-35dB	-25dB
	Fading loss (average)	-7dB	-7dB
	Polarisation loss (average)	-3dB	-3dB
	Overall link budget	116dB	110dB
	Carrier frequency correction factor	0dB	+14dB
	868MHz equivalent link budget	116dB	124dB
	Equivalent free space coverage (théoritical)	17km	40km

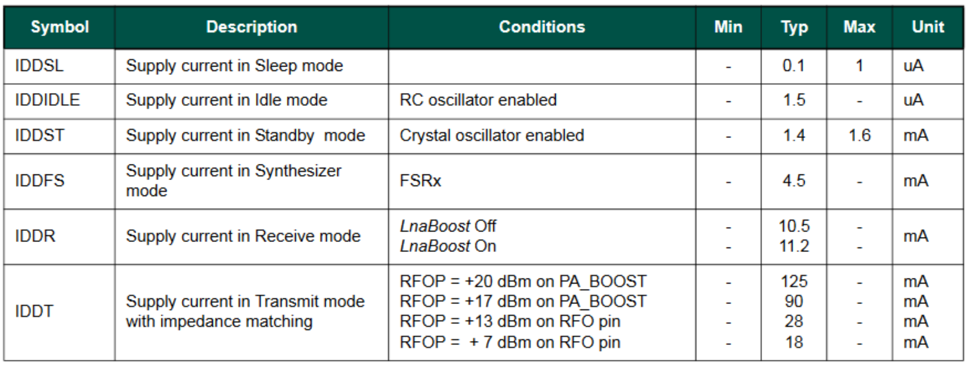
Quickly speaking and with the selected hypothesis, this analysis states that both solutions are more or less equivalent in terms of radiated power (13dBm+1dBi vs 24dBm-10dBi), and that the 13dB sensitivity advantage of LoRa is balanced by the 14dB advantage of the 169MHz carrier frequency for EN13757-4/N2. **This gives as a result a 8dB advantage for EN13757-4, linked to the better deep indoor propagation of the 169MHz carrier frequency.**

These figures are of course theoretical, but ate qualitatively consistent with field tests done on deep indoor meter networks, which showed a slightly better coverage using EN13757-4/N2 at 2400bps & 24dBm conducted power against LoRa at 292bps & 13dBm transmit power.

4 Energy comparative analysis

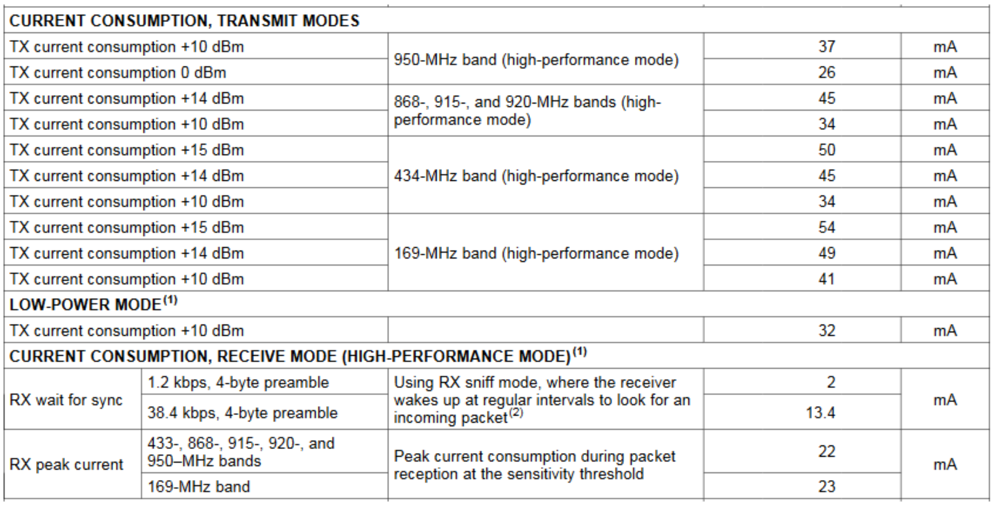
In order to compare the energy requirement of both solutions, we propose the following assumptions :

- For LoRaWAN, currents based on SX1272 transceiver figures @ 13dBm : 28mA in TX, 11mA in RX



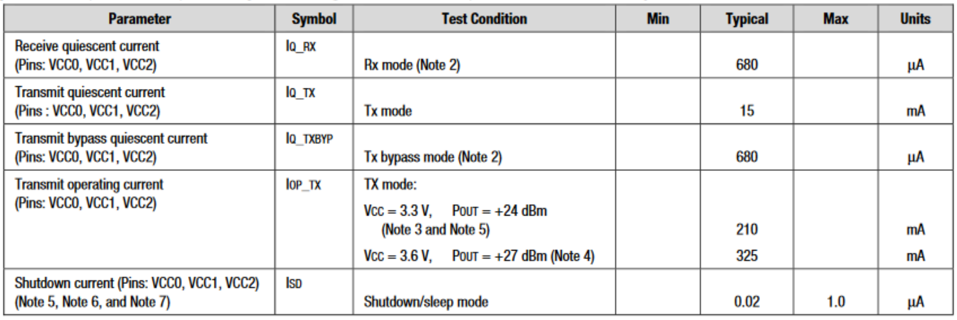
Symbol	Description	Conditions	Min	Typ	Max	Unit
IDDSL	Supply current in Sleep mode		-	0.1	1	uA
IDDIDLE	Supply current in Idle mode	RC oscillator enabled	-	1.5	-	uA
IDDST	Supply current in Standby mode	Crystal oscillator enabled	-	1.4	1.6	mA
IDDFS	Supply current in Synthesizer mode	FSRx	-	4.5	-	mA
IDDR	Supply current in Receive mode	*LnaBoost* Off *LnaBoost* On	- -	10.5 11.2	- -	mA
IDDT	Supply current in Transmit mode with impedance matching	RFOP = +20 dBm on PA_BOOST RFOP = +17 dBm on PA_BOOST RFOP = +13 dBm on RFO pin RFOP = + 7 dBm on RFO pin	- - - -	125 90 28 18	- - - -	mA mA mA mA

- For EN13757-4, currents based on CC1120 + SKY66100 amplifier @ 24dBm : 41+210=251mA in TX, 23mA in RX



CURRENT CONSUMPTION, TRANSMIT MODES				
TX current consumption +10 dBm		950-MHz band (high-performance mode)	37	mA
TX current consumption 0 dBm			26	mA
TX current consumption +14 dBm		868-, 915-, and 920-MHz bands (high-performance mode)	45	mA
TX current consumption +10 dBm			34	mA
TX current consumption +15 dBm		434-MHz band (high-performance mode)	50	mA
TX current consumption +14 dBm			45	mA
TX current consumption +10 dBm			34	mA
TX current consumption +15 dBm		169-MHz band (high-performance mode)	54	mA
TX current consumption +14 dBm			49	mA
TX current consumption +10 dBm			41	mA
LOW-POWER MODE(1)				
TX current consumption +10 dBm			32	mA
CURRENT CONSUMPTION, RECEIVE MODE (HIGH-PERFORMANCE MODE)(1)				
RX wait for sync	1.2 kbps, 4-byte preamble	Using RX sniff mode, where the receiver wakes up at regular intervals to look for an incoming packet(2)	2	mA
	38.4 kbps, 4-byte preamble		13.4	
RX peak current	433-, 868-, 915-, 920-, and 950–MHz bands	Peak current consumption during packet reception at the sensitivity threshold	22	mA
	169-MHz band		23	

Table 4. SKY66100-11 DC Electrical Specifications (Note 1)
(Vcc = +3.3 V, Tc = +25 °C, with Output Matching Network as Noted, Unless Otherwise Noted)



Parameter	Symbol	Test Condition	Min	Typical	Max	Units
Receive quiescent current (Pins: VCC0, VCC1, VCC2)	IQ_RX	Rx mode (Note 2)		680		µA
Transmit quiescent current (Pins : VCC0, VCC1, VCC2)	IQ_TX	Tx mode		15		mA
Transmit bypass quiescent current (Pins: VCC0, VCC1, VCC2)	IQ_TXBYP	Tx bypass mode (Note 2)		680		µA
Transmit operating current (Pins: VCC0, VCC1, VCC2)	IOP_TX	TX mode: VCC = 3.3 V, POUT = +24 dBm (Note 3 and Note 5) VCC = 3.6 V, POUT = +27 dBm (Note 4)		 210 325		 mA mA
Shutdown current (Pins: VCC0, VCC1, VCC2) (Note 5, Note 6, and Note 7)	ISD	Shutdown/sleep mode		0.02	1.0	µA

- Hypothesis of an additionnal 5mA constant current in RX and TX mode for CPU

- 32-byte overal frame length, or 256 raw bits. This translates to an hypothetical application-layer frame of 22 to 25 bytes depending on the protocols, but both LoRaWAN and EN13757-4/N2 have a quite similar overead. Both includes in particular a 4-byte MIC etc.

With these assumptions, the energy required for a single 32-byte uplink frame transmission are the following :

LoRaWAN solution :

Phase	Current (mA, typical)	Duration (ms, typical)	Energy (mA.s, typical)
Uplink TX	28+5=33mA	256 bits / 292bps = 877ms	28,9mA.s
Downlink RX window	11+5=16mA	2 x 160ms = 320ms	5,1mA.s
Total			34,06mA.s

EN13757-4/N2 solution :

Phase	Current (mA, typical)	Duration (ms, typical)	Energy (mA.s, typical)
Uplink TX	251+5=256mA	256 bits / 2400bps = 107ms	27,4mA.s
Downlink RX window	23+5=28mA	1 x 20ms = 20ms	0,56mA.s
Total			28,0mA.s

In summary, and given the hypothesis selected for this white paper, the EN13757-4/N2 solution using the 169MHz RF spectrum provides both an increased link budget (about 8dB difference) and a slightly lower energy consumption (28mA.s per uplink communication against 34mA.s, or 17% lower).

This difference would directly translate in a 17% longer battery life if the batteries were identical and used in the same conditions (assuming in particular the use of the currrent leveling capacitor to avoid the higher current peaks in the 169MHz version).

5 Cost comparative analysis

When considering only the bill of material of a typical meter, and using only public budgetary cost per 1000 units for the electronic parts, our cost comparison between both solutions is the following :

Part	LoRaWAN @ 13dBm	EN13757-4/N2 @ 24dBm
Microcontroller	Same	
Metering circuits	Same	
RF transceiver	SX1272 = 3,80Eur/3k	Ex : CC1120 = 2,55€/3k
RF reference frequency	20ppm crystal = 0,3€/1k	TCXO = 0,6€/3k
RF power amplifier	None	Ex : SKY66100 = 1,37€/1k
Antenna	PCB antenna = 0,1€	Wire antenna = 1€
Battery	Same	
Power supply	Same	
Buffer capacitor	None	Hypothesis : +0,7€
Overall (excluding common parts)	Common + 4,20€	Common + 6,22€

Therefore our comparison shows that a typical EN13757-4/N2 169MHz/24dBm based product will cost roughly 2€ more than a LoRaWAN 868MHz/13dBm variant.

6 Synthesis

In a nutshell, and for deep indoor long range transmission systems, this comparative analyse shows that the pros and cons of both solutions are the following :

	Pros	Cons
EN13757-4/N2 (169MHz, +24dBm transmit power, 2400bps mode)	Better deep indoor link budget (+8dB) Lower energy consumption (-17%)	Higher cost (+2Eur) Bigger size (antenna) More complex design
LoRaWAN (868MHz, +13dBm transmit power, 300bps mode)	Lower cost (-2Eur) Smaller size (antenna) Simpler design	Lower deep indoor link budget (-8dB) Higher energy consumption (+17%)