Autonomie énergétique des capteurs pour réseaux LPWAN

– Expérimentations LoRa et LTE CAT-M –

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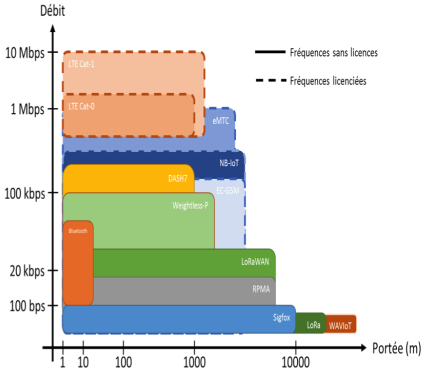
Journée Low-Power Wide Area Networks (LPWAN), GDR RSD
11 juillet 2019

LPWAN technologies

A large number of LPWAN technologies



LTE CAT-M vs LoRa ?

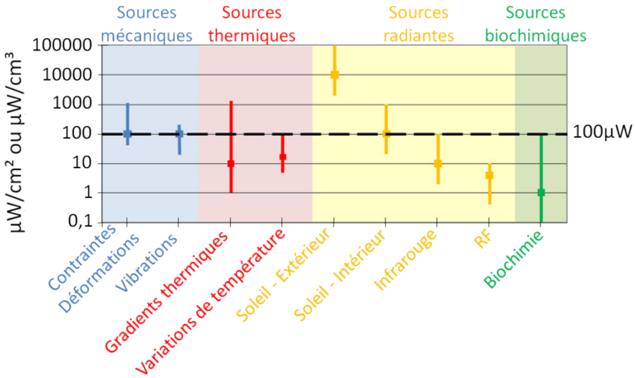
	sigfox	LoRa	NB-IOT	LTE-M
Standard	Proprietary	Proprietary	3GPP	3GPP
Modulation	UNB DBPSK(UL) GFSK(DL)	CSS or GFSK	OFDMA	OFDMA
Link Budget	160/149dB	161/157dB	164dB	156dB
Range (Urban)	++	+	++	++
Band	ISM (EU, US) 868/915 MHz	ISM (EU, US) 868/915 MHz	LTE In/Out/Guard	LTE in-band
Channel BW	100/600Hz	125kHz	200KHz	1.4MHz
PWR (UL)	14/20dBm	14/20dBm	20/24dBm	20/24dBm
Module Cost	<10$	>10$	~12$	~15$ AT&T 5-10$ Vz: 8-10$
BS Cost	-	+	++	++
Bitrate	100/600bps (UL)	0.3-50kbps(FSK)	<67kbps	<1Mbps
Battery Life	++	++	++	+

$\Rightarrow$ How to power LPWAN devices ?

Power issues

- Communication is one of the most energy consuming tasks
- Typical battery-powered IoT devices are doomed to die . . .
- . . . and changing the battery is not always feasible !

What about ambient available energy to power LPWAN devices ?



Outline

LPWAN energy consumption
- LTE CAT-M experiments
- LoRa experiments

Powering LoRa with energy harvesting
- Hardware dimensioning
- Software energy management

Conclusion and perspectives

LTE CAT-M: experimental setup

First experiments on LTE CAT-M1 network provided by Nokia/Orange

LTE-CAT-M setup

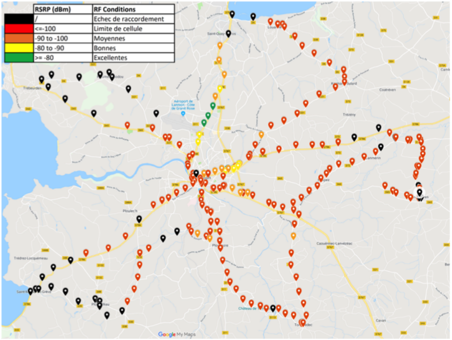
- Datarate: 375 kbps
- MQTT protocol: payload of 33 bytes

Experimental setup

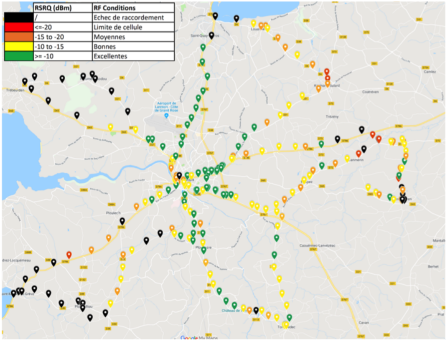
- Fipy board from Pycom
  - ESP32 microcontroller
  - Sequans Monarch modem
  - WiFi, Bluetooth, LoRa, Sigfox, **LTE CAT-M1** and NB1
- PyTrack extension (GPS)
- LiPo battery (500 mA.h)

LTE CAT-M: experimental results

RSRP (Reference signal Receive Power)



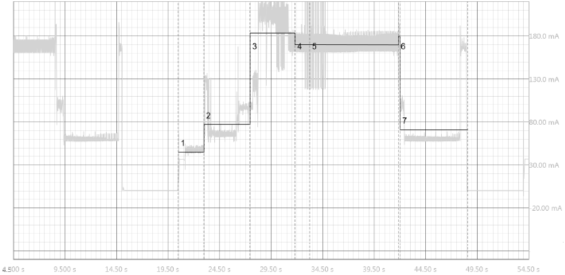
RSRQ (Reference Signal Receive Quality)



– Maximal range: 10.8 km
– Impact of the antenna orientation and shadowing

LTE CAT-M: energy consumption

Current consumption of a LTE CAT-M packet transmission



Num.	Label	Durée (s)	Conso. Moy. (mA)
1	Wake-up carte	2,477	44,9
2	Init. Carte	4,481	77,08
3	Attach	4,362	183,6
4	Connect	1,437	170
5	Envoi MQTT	8,615	169,8
6	DeInit LTE	0,141	179,8
7	Prépa. Sleep	6,582	71,14

Average current consumption of 123 mA during 28.1 s

- Energy per packet: 17.3 J for 33 byte payload
- Huge overhead due to MQTT encapsulation

⇒ Difficult to power using energy harvesting

LoRa: experimental setup

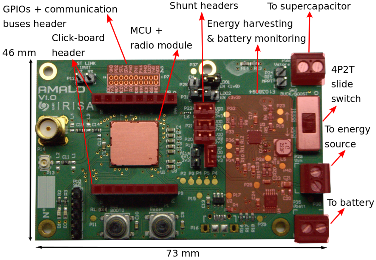
LoRa configuration

- 3 setups:
  - highest bit-rate (SH)
  - LoRa default (SD)
  - lowest bit-rate (SL)
- One device in Class A, one in Class C

	SH	SD	SL
CR	$\frac{4}{5}$	$\frac{4}{5}$	$\frac{4}{8}$
B (kHz)	500	125	125
SF	6	7	12
R_b (kbps)	37.5	5.47	0.183

Experimental setup

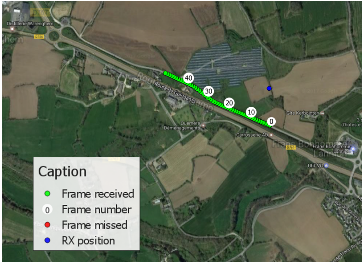
- Amalo board from IRISA laboratory
  - CMWX1ZZABZ-078 chip from Murata
  - STM32L082CZ micro-controller (Cortex M0+)
  - LoRa module (SX1276)
- GPS receiver
- LiPo battery (35mA.h)



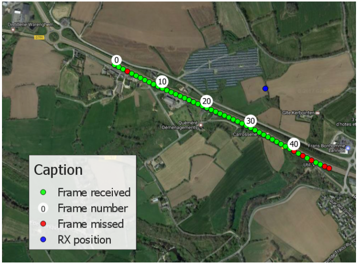
LoRa: experimental results

Speed has low impact . . .

LoRa setup: SD – Speed: 50 km/h

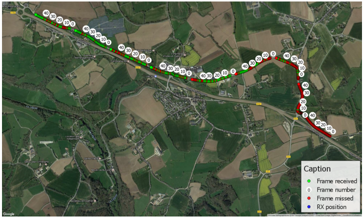


LoRa setup: SD – Speed: 100 km/h



. . . but the datarate and the shadowing

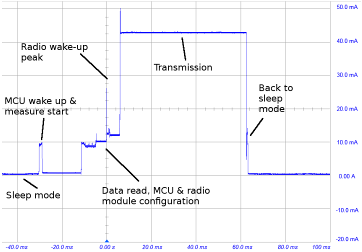
LoRa setup: SH – Speed: 30 km/h



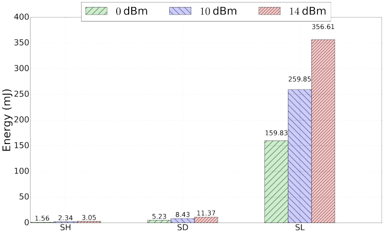
LoRa setup: SL – Speed: 30 km/h

LoRa: energy consumption

Current consumption of a LoRa packet transmission



Energy per packet (20 byte payload)



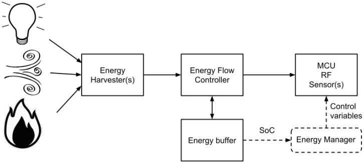
– Datarate has a huge impact on energy consumption
– LoRa consumes less than LTE CAT-M1

⇒ Let's harvest ambient energy

Powering LoRa with energy harvesting

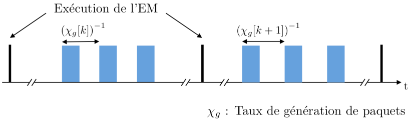
Hardware architecture

- Several energy sources (combined or not)
- Several radio transceiver
- Battery and/or supercapacitor



Software energy management

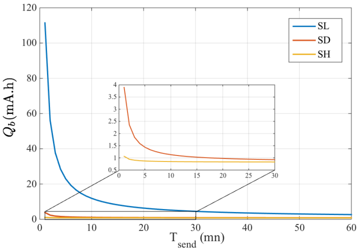
- Adapt energy consumption of the device
- Prediction algorithms . . . or not !

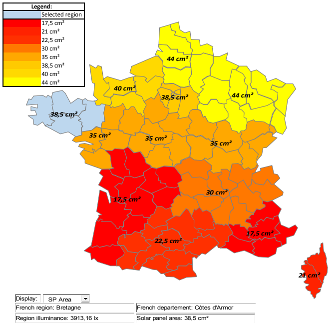


⇒ Goal: Maximise QoS while avoiding power failures

From single solar source . . . (1/2)

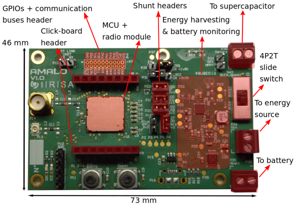
Fine dimensioning of both energy storage device and solar panel area





Experimental validation [mabon19wcmc]

- Amalo board from IRISA laboratory
  - Several harvesters: solar panel, Peltier, piezo . . .
  - Energy manager chip (SPV1050 chip)
  - Current monitoring (INA226 chip)



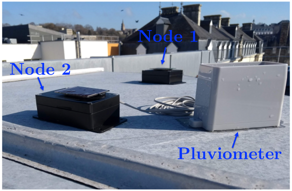
From single solar source ... (2/2)

Node 1:

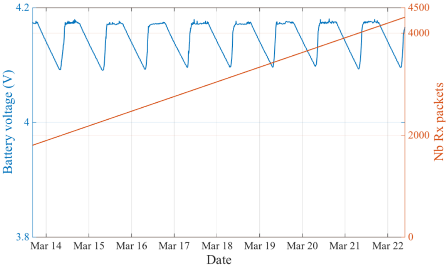
- Sending period: 5 min
- LoRa setup: SL
- Temperature only
- LiPo battery: 26 mA.h

Node 2:

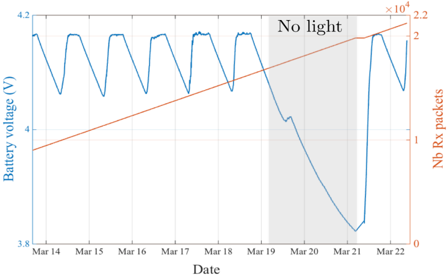
- Sending period: 1 min
- LoRa setup: SD
- Temperature and humidity
- LiPo battery: 4 mA.h



Node 1 (266.65 mJ per packet)



Node 2 (8.70 mJ per packet)

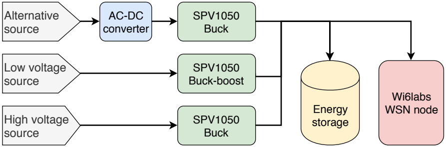


⇒ Running since March

. . . to multiple sources

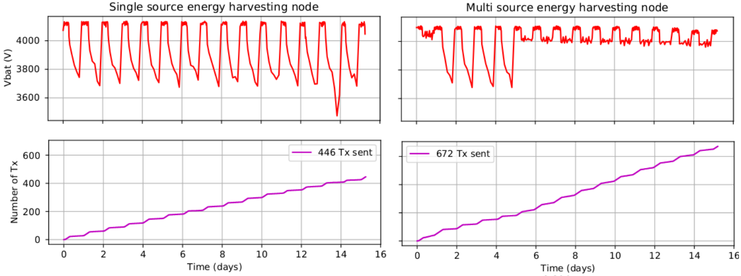
Multi-source energy harvesting to exploit complementary sources

Hardware architecture [gleonec16ogc]



Wi6labs node

Experimental validation [gleonec16phd] : two solar panels and a TEG



Energy Managers: QoS adaptation

Related works mainly adapt sending period as QoS for short-range networks

Using predictors

- KAN-PM [kansal07acmtes]: exponentially weighted moving average filter
- WVR-PM [le15ieeesensors]: Wake up Variation Reduction through quantization, more consistency
- GRAPMAN [aitaoudia15pimrc]: Highest QoS for finite horizon

Model-free

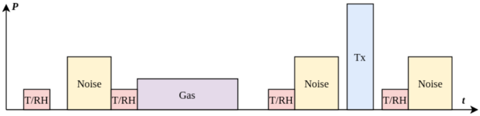
- LQ-Tracker [vigorito07secon]: Linear-Quadratic Tracking, technique from adaptive control theory
- P-FREEN [peng14ahn]: Duty-cycle maximization problem as a non-linear programming problem
- PID-based [le13arcs]: Difficult to tune
- Fuzzyman [aitaoudia16icc]: leveraging fuzzy control
- RLman [aitaoudia18ieeegcn]: leveraging reinforcement learning

$\Rightarrow$ Not efficient for LoRaWAN network [gleonec18ict]
(convergence time vs duty cycle constraint)

Multi-task energy allocation

Maximize the number of executions of K tasks over a time slot

- Data packet is transmitted only once, at the end of each time slot



A task i is defined by

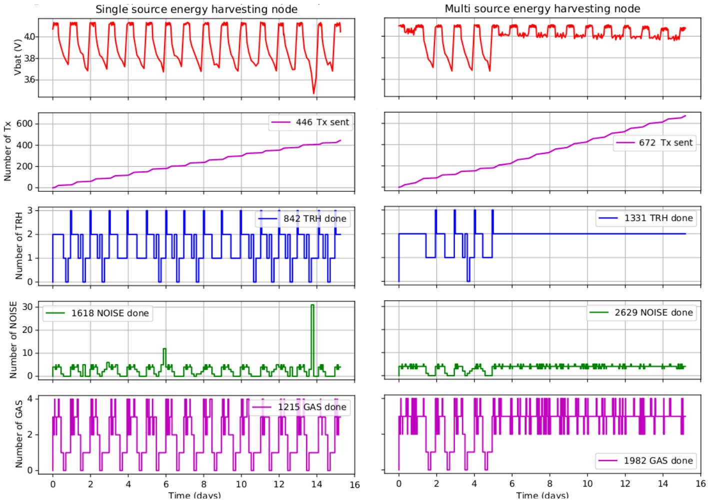
- its priority ρ_i
- its energy consumption E_C^i
- its number of executions ϕ_i between two transmissions

Allocation problem

$$\max_{\phi_i} \left(E_C^{Total} = \sum_{i=1}^{K} (\phi_i \times E_C^i) \right)$$
$$s.t. \quad E_C^{Total} \leqslant E_B - E_C^{TX}$$

Experimental results

Sensing task	Energy consumption (J)	Minimal number of executions	Maximal number of execution
Temp./ Humidity	0.098	1	2
Noise	0.209	0	4
Gas (CO_2)	0.172	1	3



Conclusion: towards energy autonomous LPWANs

LPWAN energy consumption

- LTE CAT-M: high data-rate but important protocol overhead
  → high energy consumption
- LoRa configuration improves range but increases energy
  → adaptive data-rate is necessary

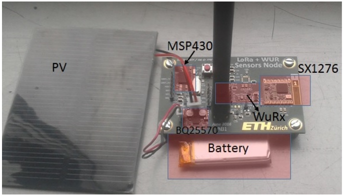
Energy harvesting

- Fine dimensioning is necessary to reduce costs
- Energy manager/allocator improves QoS
- LTE CAT-M is still an issue

Perspectives: Combining LoRa and Wake-up radio

ANR Wake-up: Short-long range heterogeneous networks

WULora platform wit ETHZ [magno17date]



- Low latency downlink communications
- Energy efficiency
- Local / distributed processing

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