Lower Cost, Longer Range Sensing Systems for Surveillance Infrastructures

MAPCI seminar

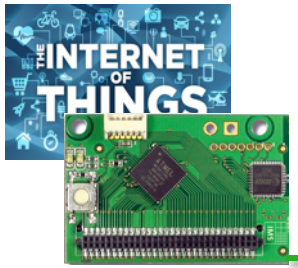
Lund University

March 17th, 2016

Prof. Congduc Pham

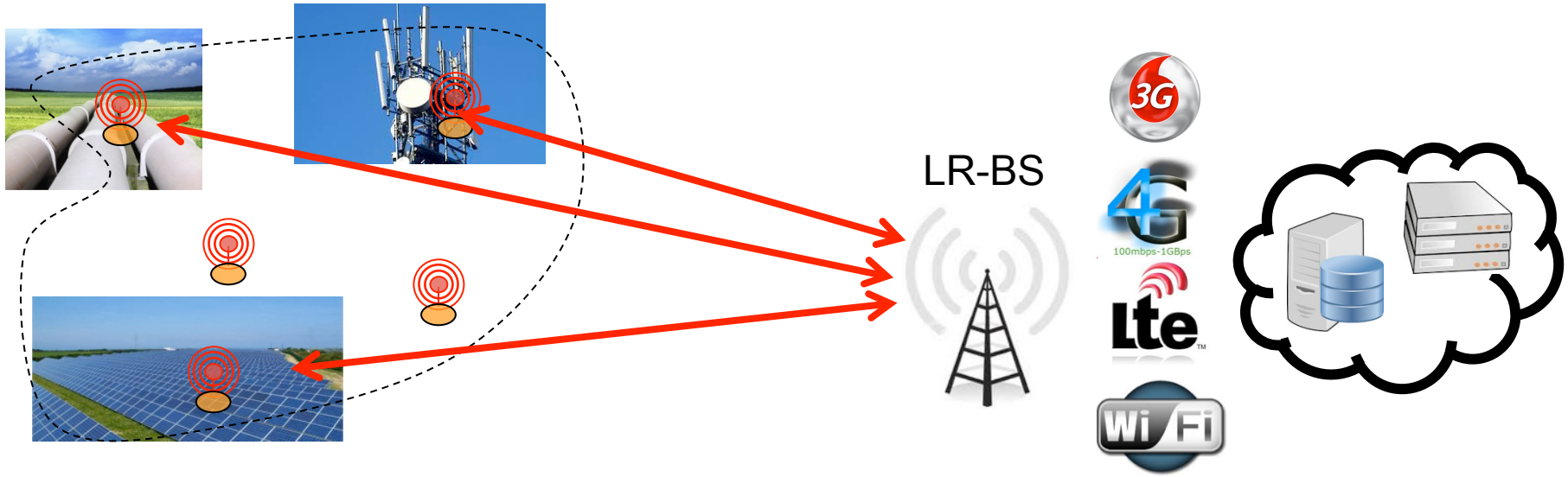
http://www.univ-pau.fr/~cpham

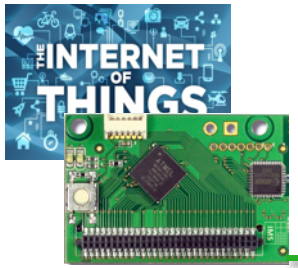
Université de Pau, France



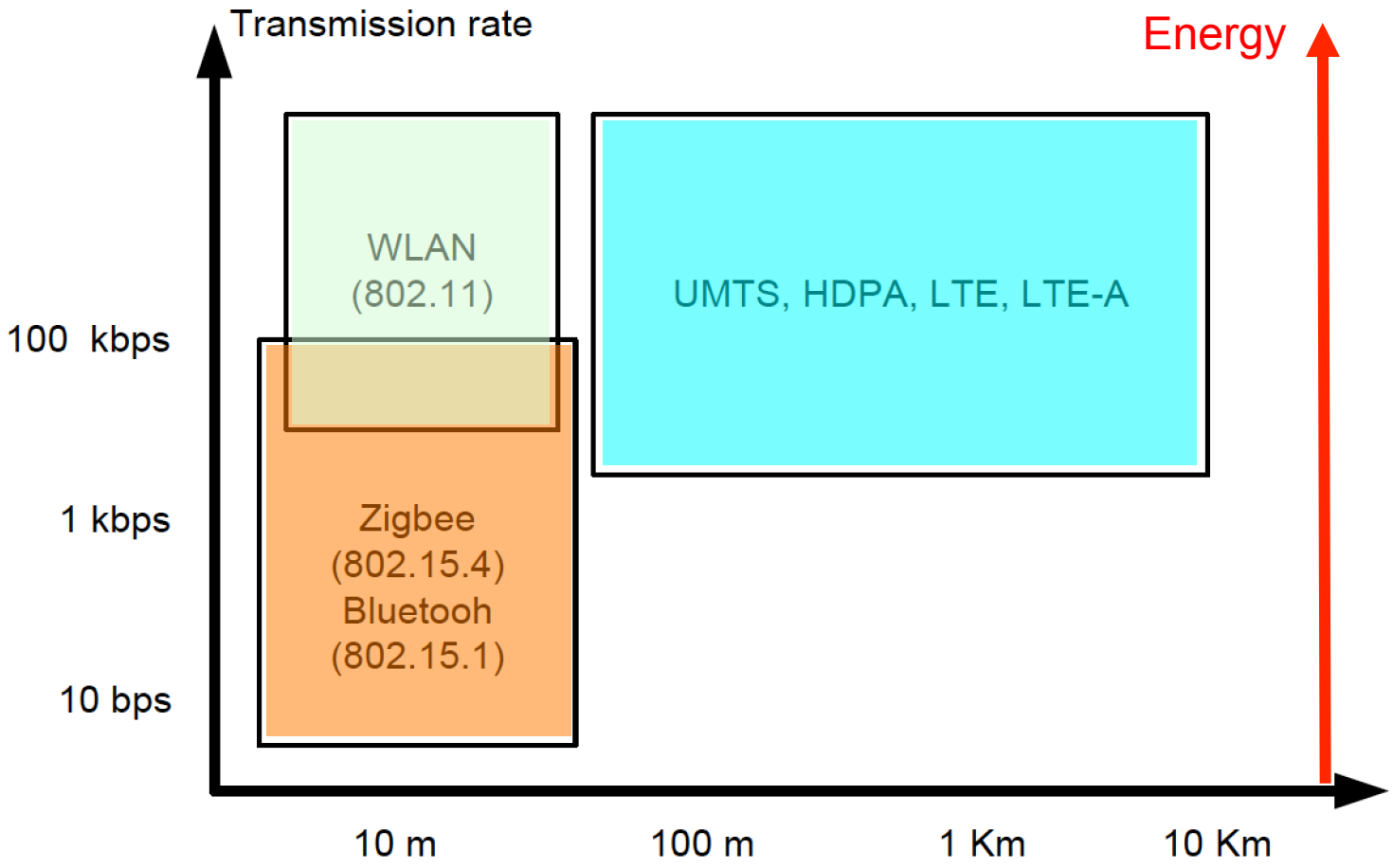
Sensing systems

IoT/WSN deployment made easier in single-hop model !!!

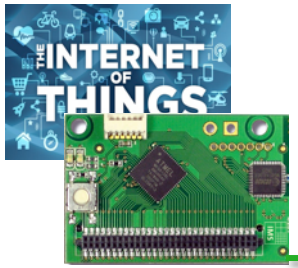




Energy-Range dilemma



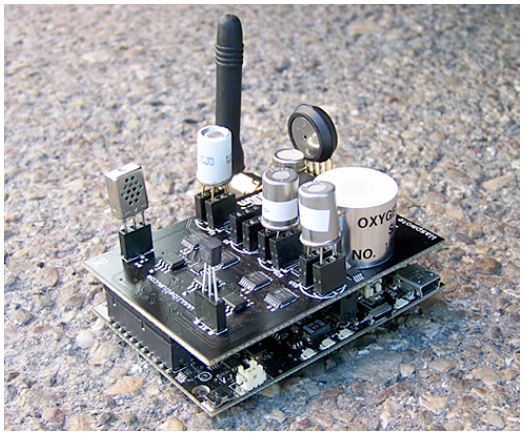
Enhanced from M. Dohler "M2M in SmartCities"



How costly is transmission?

Technology	2G	3G	LAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m
Tx current consumption	200-500mA	500-1000mA	100-300mA
Standby current	2.3mA	3.5mA	NC

Energy consideration



18720 Joules

TX power: 500mA

P = I x V = 500 x 3.3 = 1650mW

E = P x t -> t = E/P

11345s or 3h9mins

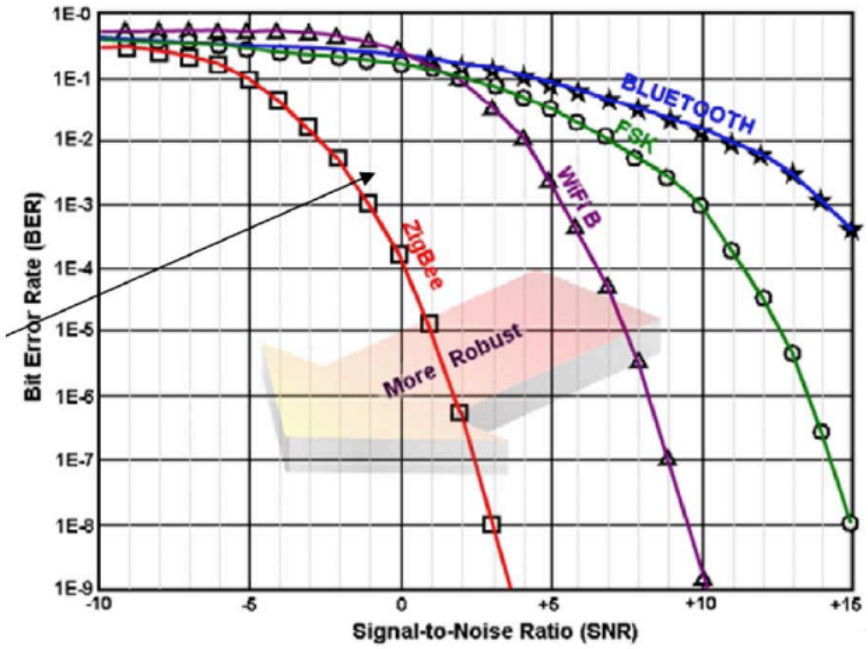
Technology	2G	3G	LAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m
Tx current consumption	200mA-500mA	500mA – 1000mA	50mA
Standby current	2.3mA	3.5mA	NC

Haven't considered:

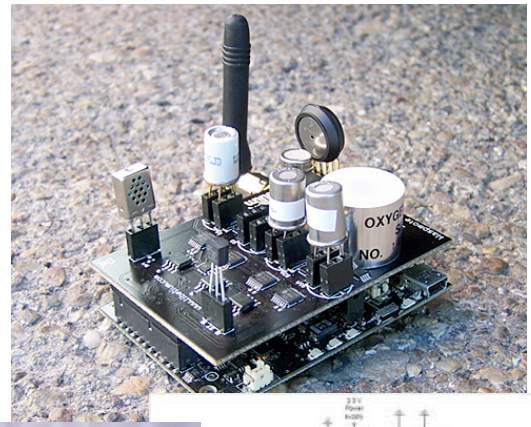
- Baseline power consumption of the sensor board
- RX consumption!
- Event capture consumption
- Event processing consumption

IEEE 802.15.4 in ISM 2.4GHz

- Low-power radio in the 2.4GHz band offering 250kbps throughput at physical layer
- Power transmission from 1mW to 100mW for range from 100m to about 1km is LOS
- CSMA/CA
- BPSK, used as physical layer in ZigBee



Energy consideration



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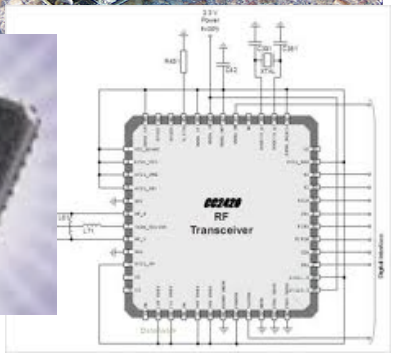


TX power 0dbm: 17.4mA

P = I x V = 17.4 x 3.3 = 57.42mW

E = P x t -> t = E/P

326018s or 90.5h

Haven't considered:

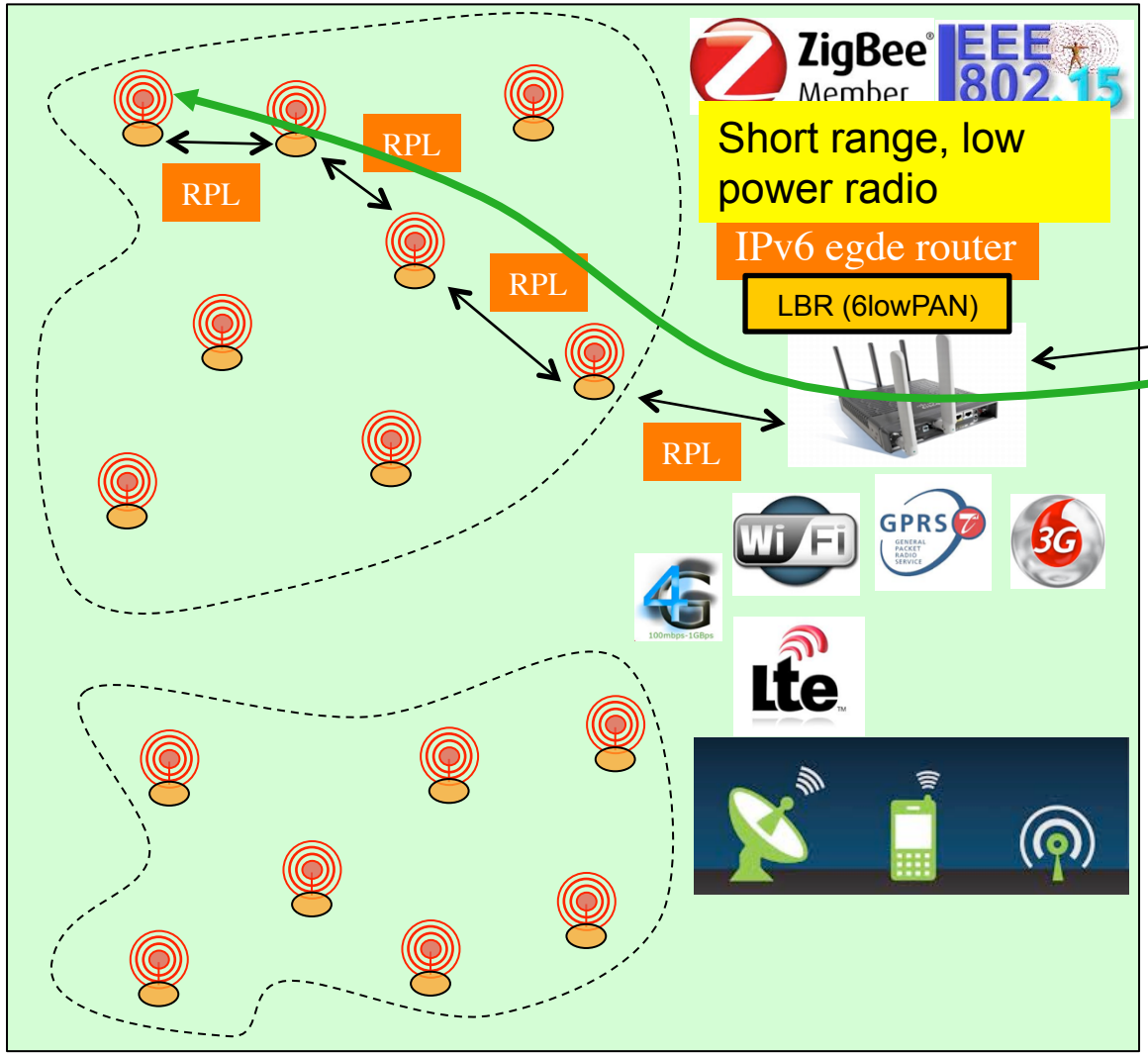
- Baseline power consumption of the sensor board
- RX consumption: 18.8mA!
- Event capture consumption
- Event processing consumption

Chipcon Products from Texas Instruments

CC2420

Parameter	Min.	Typ.	Max.	Unit	Condition / Note
Current Consumption, transmit mode:					
P = -25 dBm		8.5		mA	The output power is delivered differentially to a 50 Ω singled ended load through a balun, see also page 55.
P = -15 dBm		9.9		mA	
P = -10 dBm		11		mA	
P = –5 dBm		14		mA	
P = 0 dBm		17.4		mA	

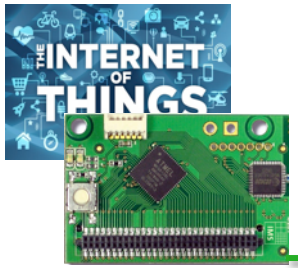
15 YEARS OF MULTI-HOP ROUTING?



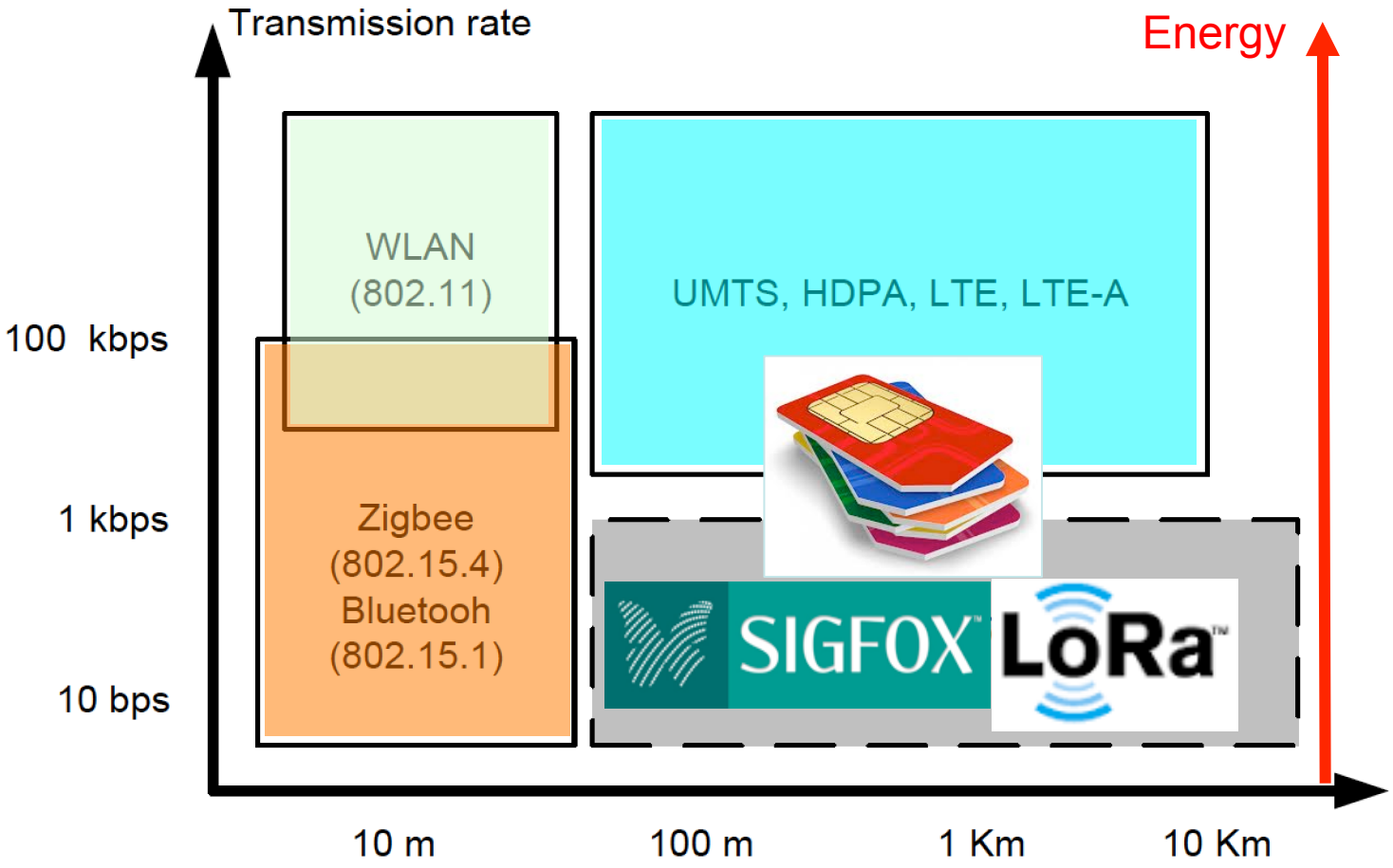
Routing over low Power&Lossy Networks (RPL)

RPL is the 4th protocol standardized by IETF (RIP, OSPF, BGP)

6LowPan provides end-to-end IPv6 connectivity



Low-power and long-range?



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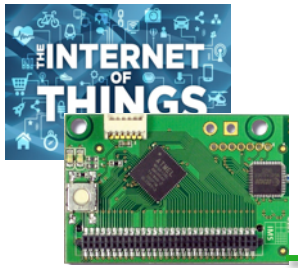
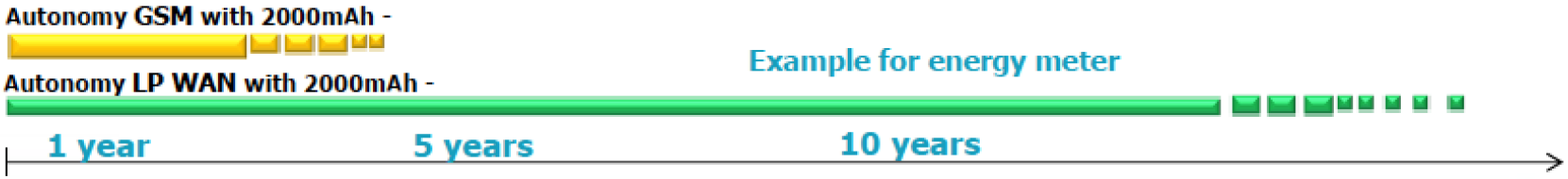
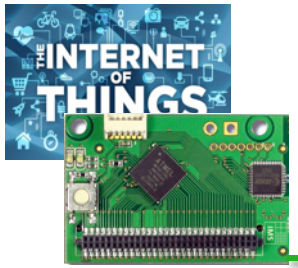


Low Power WAN ?

Tables from Semtech

Technology	2G	3G	LAN	ZigBee	Lo Power WAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m	O: 90m I: 30m	Same as 2G/3G
Tx current consumption	200-500mA	500-1000mA	100-300mA	18mA	18mA
Standby current	2.3mA	3.5mA	NC	0.003mA	0.001mA
Energy harvesting (solar, other)	No	No	No	Possible	Possible
Battery 2000mAh (LR6 battery)	4-8 hours(com) 36 days(idle)	2-4 hours(com) X hours(idle)	50 hours(com) X hours(idle)	60hours (com)	120 hours(com) 10 year(idle)
Module Revenue Annually	12 $	20 $	4 $	$3	3 $





TYPICAL SCENARIOS

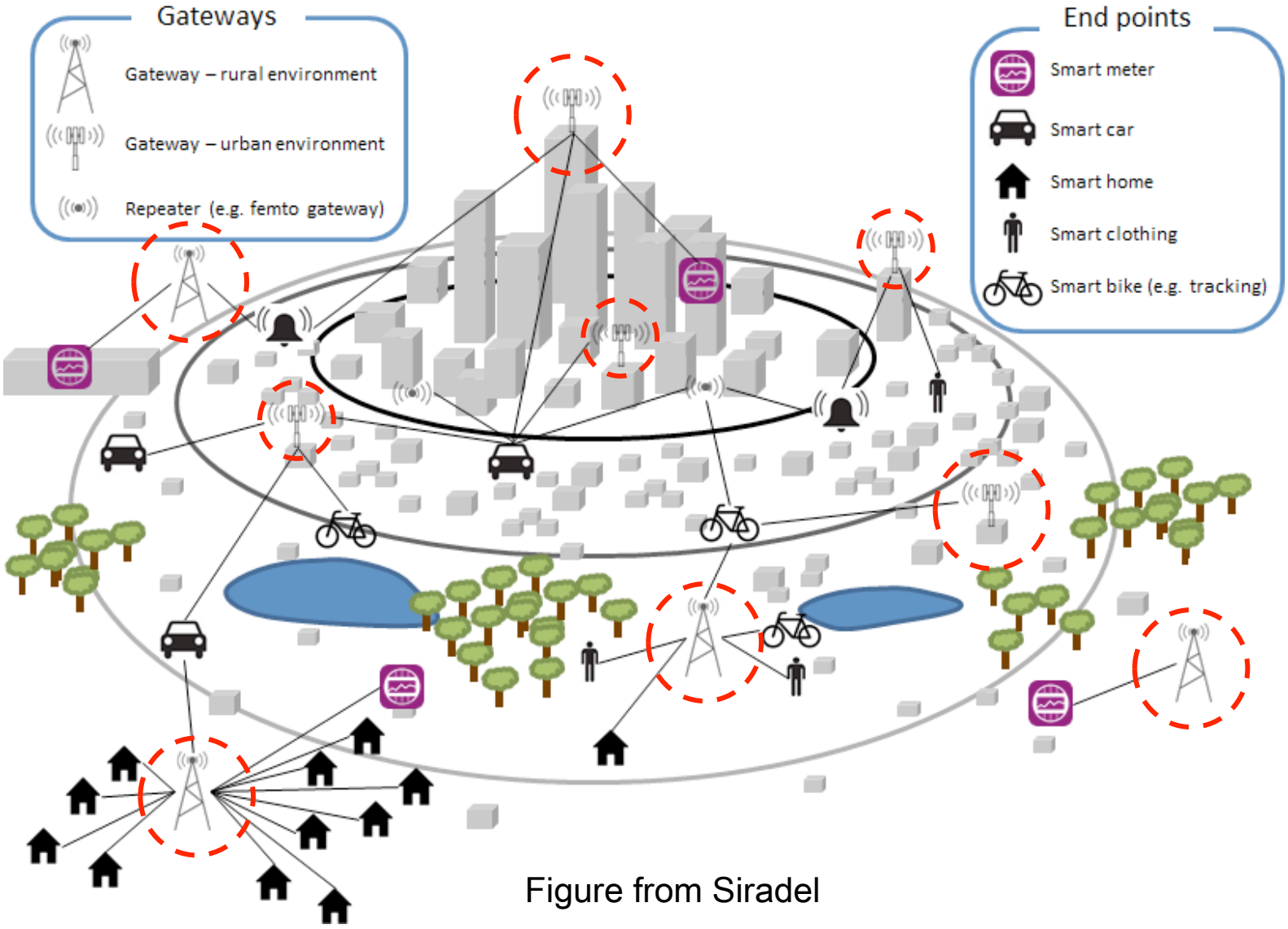
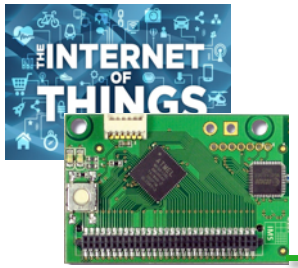
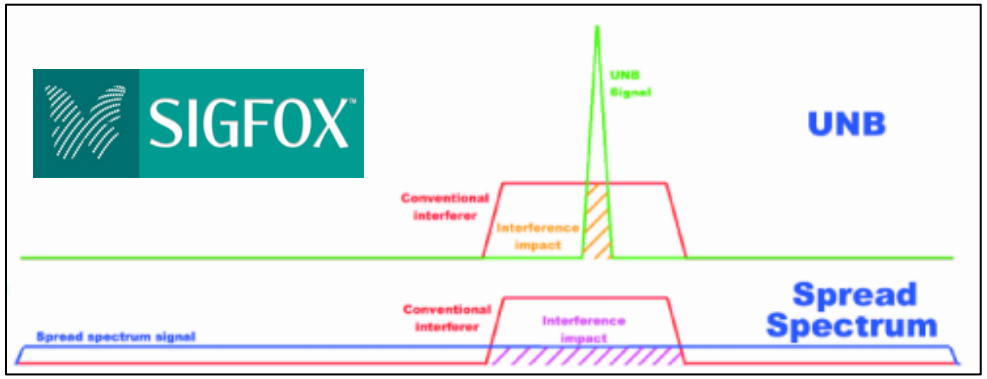


Figure from Siradel



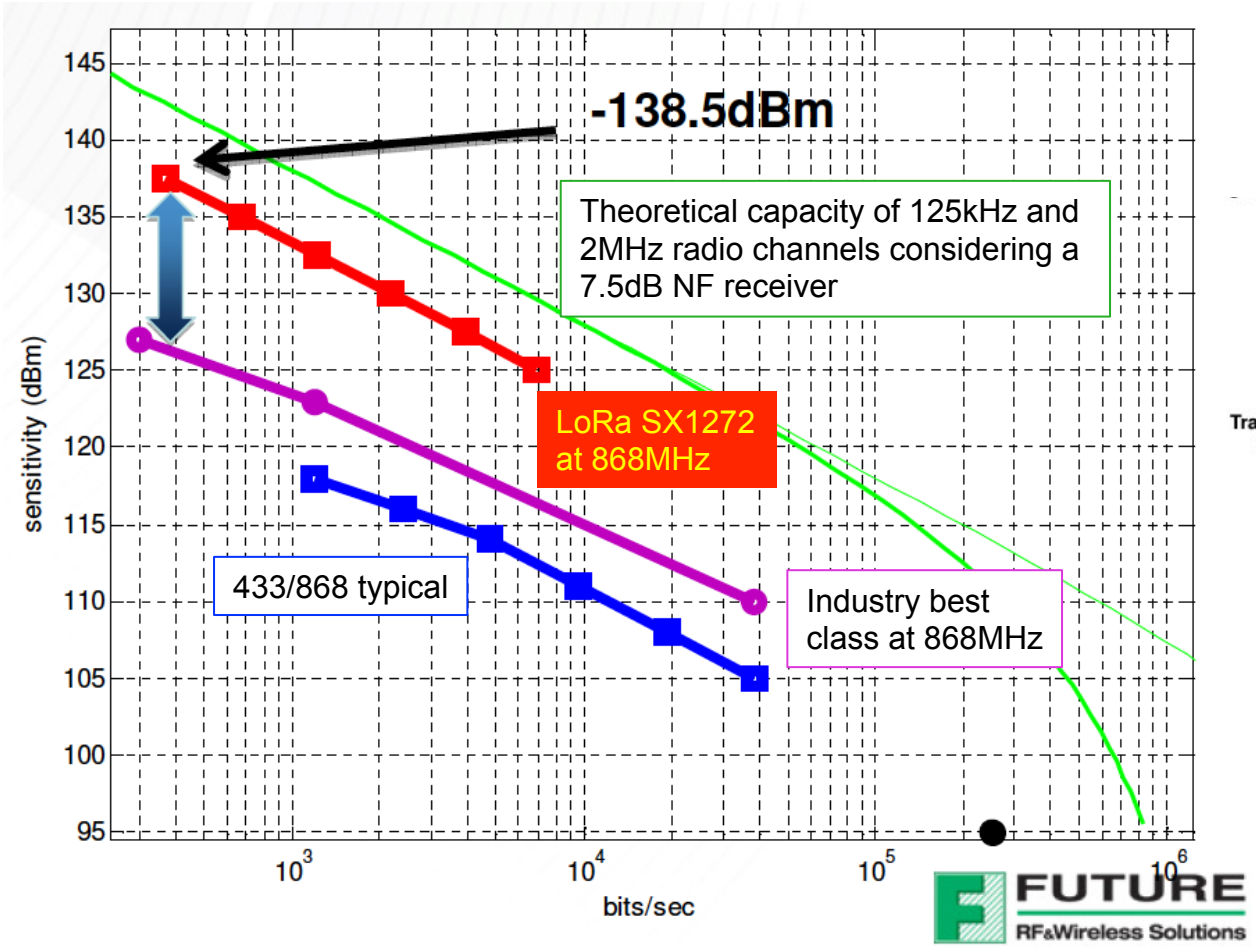
Increasing range?

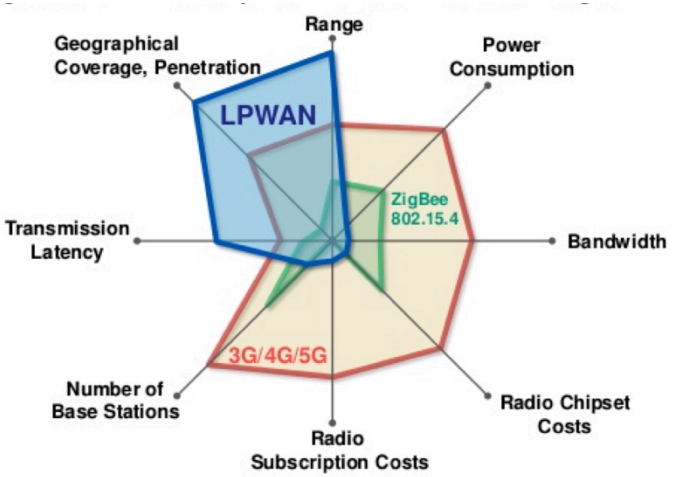
- Generally, robustness and sensitivity can be increased when transmitting (much) slower
- A[Sigfox message is sent relatively slowly in a very narrow band of spectrum (hence ultra-narrow-band) using Gaussian Frequency-Shift Keying modulation]
- LoRa also increases time-on-air when maximum range is needed. But LoRa uses spread spectrum instead of UNB



LoRa™

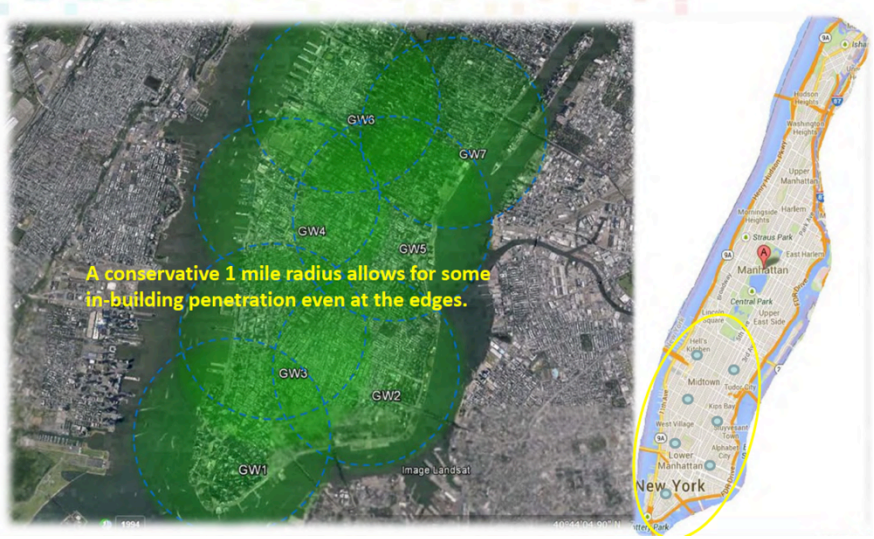
WHY THE LPWAN REVOLUTION?





From Peter R. Egli, INDIGOO.COM

Versatile LPWAN!



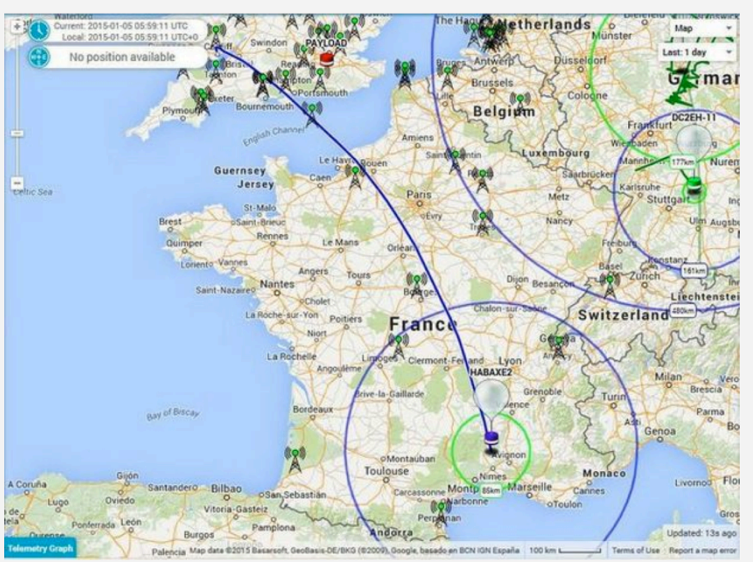
Dense urban areas

Rural areas

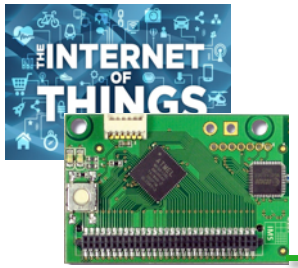
Indoor

Underground

Extreme long-range!



UK HAB (High Altitude Ballooning) trials gave 2 way LoRa™ coverage at up to 240 km. Lowering the data rate from 1000bps to 100bps should allow coverage all the way to the radio horizon, which is perhaps 600 km at the typical 6000-8000m soaring altitude of these balloons. Balloon tracking can be made



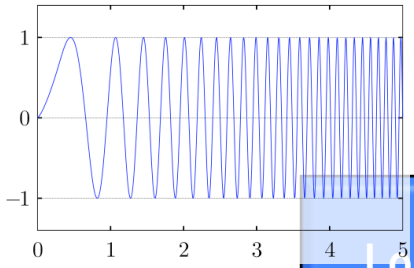
What about the throughput?

SIGFOX

Sigfox uses ultra-narrow band (UNB) of about 100Hz with GMSK (~BPSK)

Typical throughput is about 100bps

Devices can typically send up to 140 messages of 12-bytes per day (operator limits)

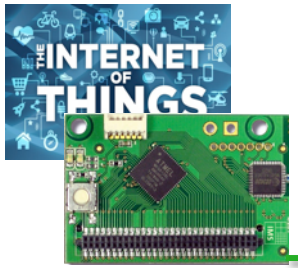


LoRa™

LoRa modulation is more versatile, using CSS variant

Sensitivity and throughput depend on 3 LoRa parameters: BW (bandwidth), CR (coding rate) and SF (spreading factor)

Throughput range is 240bps to 37500bps



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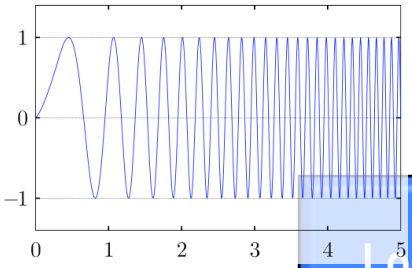

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…end

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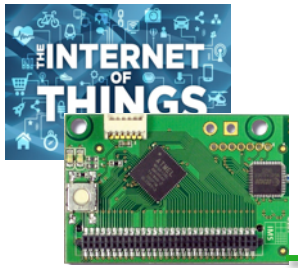
EAI Endorsed Transactions
on the Internet of Things

Research Article ICST.ORG

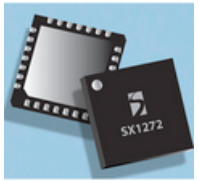
Dedicated networks for IoT : PHY / MAC state of the art and challenges

C. Goursaud[1,*], J.M. Gorce[1]

[1]Univ Lyon, INSA Lyon, Inria, CITI, F-69621 Villeurbanne, France



LoRa's parameters



$$R_b = SF * \frac{Rate\ Code}{\left[\frac{2^{SF}}{BW}\right]}\ bits/sec$$

- Parameters
  - Bandwidth: 62.5kHz, 125kHz, 250kHz, 500kHz
  - Rate code: 4/4+CR (CR=1, 2, 3, 4)
  - Spreading factor: 6 to 12

Sensitivity: lowest input power with acceptable link quality, typically 1% PER

SpreadingFactor (RegModemConfig2)	Spreading Factor (Chips / symbol)	LoRa Demodulator SNR
6	64	-5 dB
7	128	-7.5 dB
8	256	-10 dB
9	512	-12.5 dB
10	1024	-15 dB
11	2048	-17.5 dB
12	4096	-20 dB

Bandwidth (kHz)	Spreading Factor	Nominal Rb (bps)	Sensitivity (dBm)
125	6	9380	-122
125	12	293	-137
250	6	18750	-119
250	12	586	-134
500	6	37500	-116
500	12	1172	-131

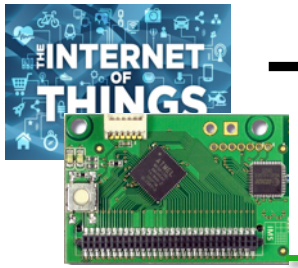
Rule of thumb

6dB increase = twice the range in LOS

12dB needed for urban areas

Bandwidth (kHz)	Spreading Factor	Coding rate	Nominal Rb (bps)	Sensitivity (dBm)
125	12	4/5	293	-136
250	12	4/5	586	-133
500	12	4/5	1172	-130

Tables from Semtech



Time on air for various LoRa settings

				time on air in second for payload size of					
LoRa mode	BW	CR	SF	5 bytes	55 bytes	105 bytes	155 Bytes	205 Bytes	255 Bytes
1	125	4/5	12	0.95846	2.59686	4.23526	5.87366	7.51206	9.15046
2	250	4/5	12	0.47923	1.21651	1.87187	2.52723	3.26451	3.91987
3	125	4/5	10	0.28058	0.69018	1.09978	1.50938	1.91898	2.32858
4	500	4/5	12	0.23962	0.60826	0.93594	1.26362	1.63226	1.95994
5	250	4/5	10	0.14029	0.34509	0.54989	0.75469	0.95949	1.16429
6	500	4/5	11	0.11981	0.30413	0.50893	0.69325	0.87757	1.06189
7	250	4/5	9	0.07014	0.18278	0.29542	0.40806	0.5207	0.63334
8	500	4/5	9	0.03507	0.09139	0.14771	0.20403	0.26035	0.31667
9	500	4/5	8	0.01754	0.05082	0.08154	0.11482	0.14554	0.17882
10	500	4/5	7	0.00877	0.02797	0.04589	0.06381	0.08301	0.10093

Range

Throughput

LoRa vs SigFox

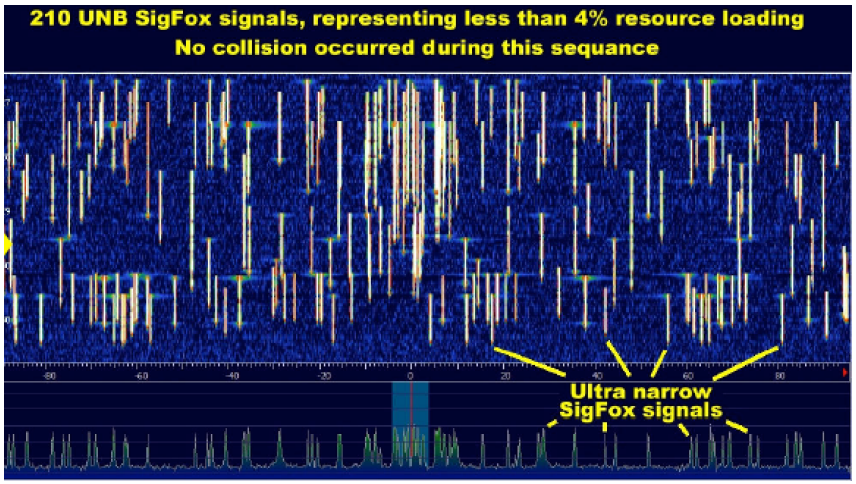


Figure from SigFox

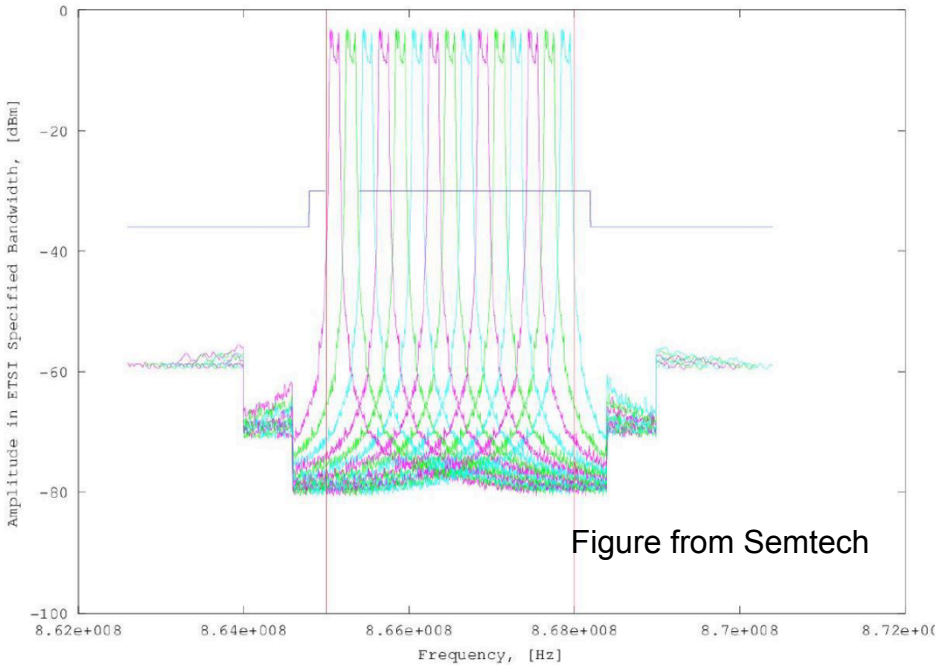


Figure from Semtech

Usual (ultra) narrow-band (UNB) vs spread spectrum (SS) arguments

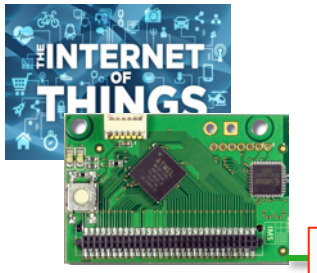
UNB has lower in-band receive noise and SigFox can have more channels than LoRa

But UNB needs tighter receiver synchronization and more complex signal processing at receiver (SigFox uses advanced SDR at receiver to analyse the total band)

SS can more rapidly be saturated so LoRa may have more interference issues in dense environments

From networking guys perspective, LoRa is more versatile with possibility to build ad-hoc mesh networks

From scoop.it
(N. Ayu



SIGFOX and Glen Canyon Corp. to 1 Million Smart Meters to of Things

LoRa™ technology to be integrated into FLASHNET's street lighting management solution

Tata Communication world's largest IoT n India

Semtech and STMicroelectronics aborate to Scale LoRa nology to Meet High-Volume Demands of rnet of Things Applications

OTIO to Connect 1 Million Devices to SIGFOX

From www.businesswire.com - February 22, 4:59 PM

OTIO, a subsidiary of Groupe HBF specializ electrical equipment, lighting and home automation, has chosen the SIGFOX netwo deploy its new international offer of connec devices.

Swisscom sets up a Swiss-wide network for the Internet of Things

From www.swisscom.ch - March 14, 7:49 PM

The Internet of Things has long connected millions of objects and devices to one another and to people. In the future, this number will reach into the billions worldwide. Swisscom is the first provider in Switzerland to set up an additional network dedicated to the Internet of Things: the Low Power Network, designed for the transmission of small amounts of data independently of the electrical network.

From www.sudo 16, 2015 2:24 PM

" Gestionnaire les Landes, e Dordogne, So ondes radio de Sigfox pour relever les compteurs et surveiller l'état des canalisations

Le compteur..."

From www.enevo.com - March 6, 4:12 PM

T-Mobile to cover Republic with the for the Internet of

From September 10, 4:41 PM

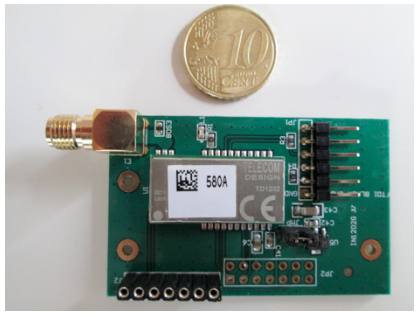
Following a pilot opera Czech Republic that ex expectations, T-Mobile SimpleCell Networks w SIGFOX's Internet of Th network throughout the country.

Rise from the Ashes?

" French Telecom LoRa radio domestic IoT and M2M network."

network, a narrow-band technology which guarantees connectivity at a reduced energy consumption rate and at a lower cost. Orange has chosen to rely on LoRa (Long Range) technology to deploy this network that will cover the whole of metropolitan France.

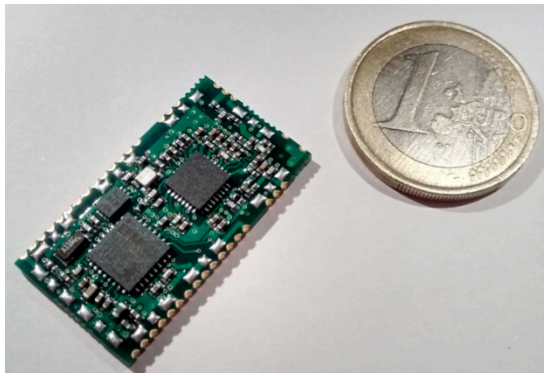
Some SigFox radio modules



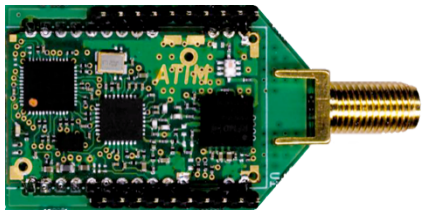
TD120x serie from Telecom Design

SigFox module from CookingHack (Libelium)

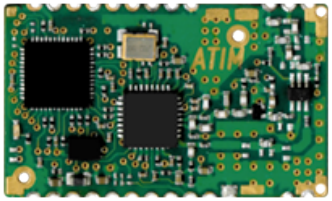
Adeunis SI868



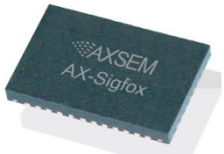
SIGT002 from CG-Wireless



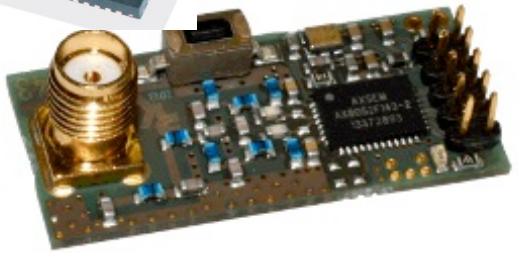
SigBee module from ATIM



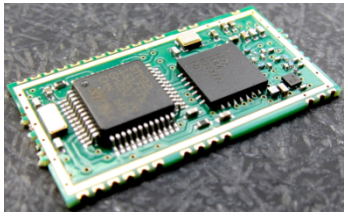
ARM-Nano N8 SigFox module from ATIM



AXSEM SigFox module

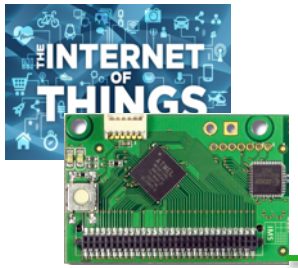


SigFox module from Snoc

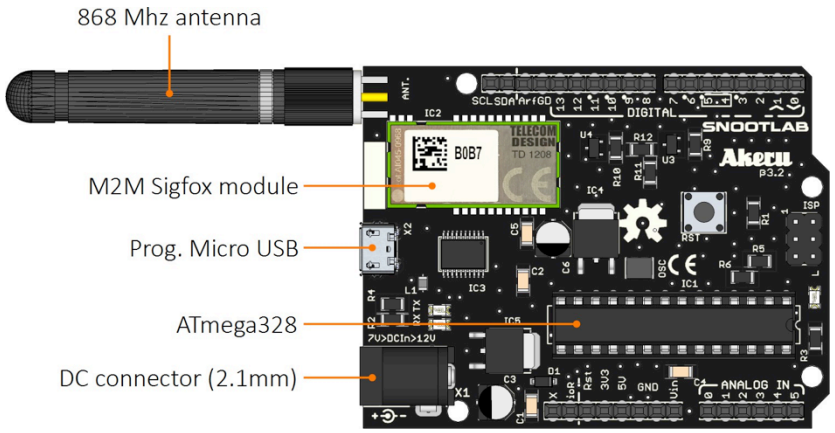


Nemeus MM002-LS-EU LoRa/SigFox

RC1682-SIG from RadioCraft



Some ready-to-use SigFox devices



Snootlab Akeru is Arduino-like

SigFox demonstrator by Adeunis

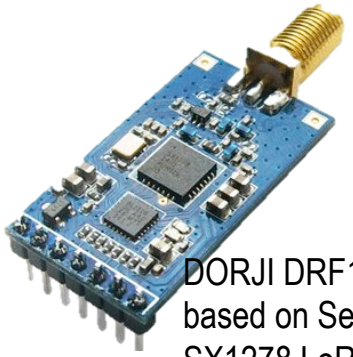
SigFox ready sensor by ATIM

Sens'it from Axible Technologies

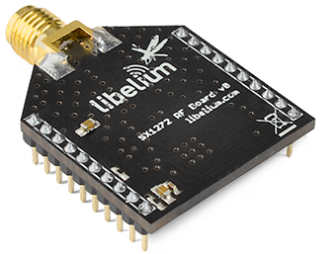
HidNSeek

Universal push button from Bttn Inc

LoRa modules from Semtech's SX127x chips



DORJI DRF1278DM is based on Semtech SX1278 LoRa 433MHz

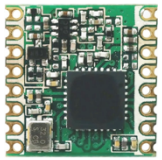


Libelium LoRa is based on Semtech SX1272 LoRa 863-870 MHz for Europe

inAir9/9B based on SX1276

Froggy Factory LoRa module (Arduino)

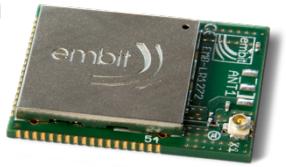
IMST IM880A-L is based on Semtech SX1272 LoRa 863-870 MHz for Europe



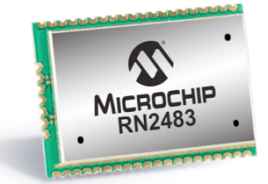
HopeRF RFM series

HopeRF HM-TRLR-D

LinkLabs Symphony module



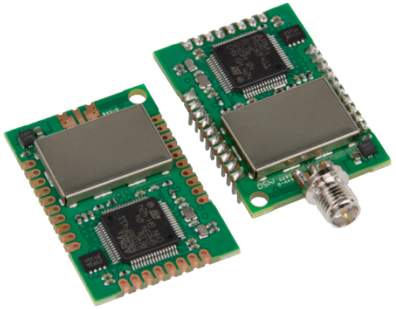
Embit LoRa



Microship RN2483

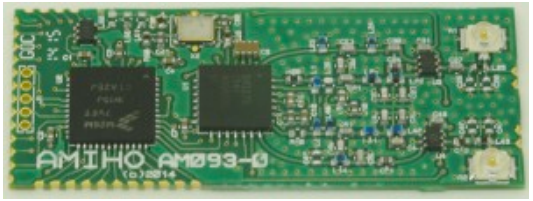
habSupplies

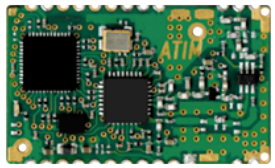
Adeunis ARF8030AA- Lo868



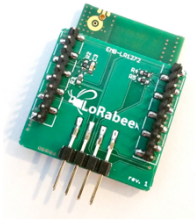
Multi-Tech MultiConnect mDot

AMIHO AM093





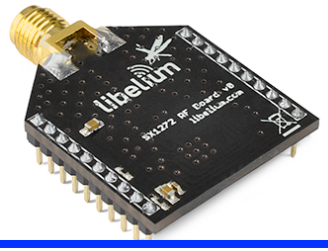
ARM-Nano N8 LoRa module from ATIM



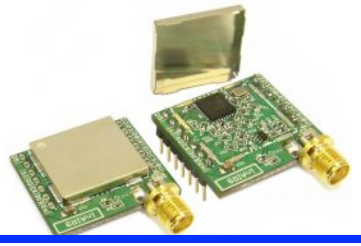
SODAQ LoRaBee Embit

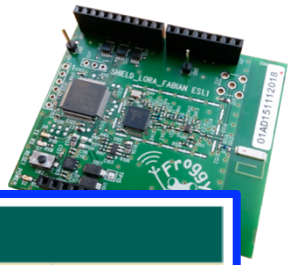
SODAQ LoRaBee RN2483

LoRa modules from Semtech's SX127x chips



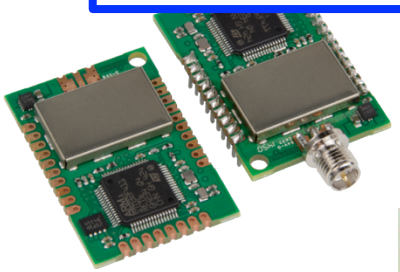
Libelium LoRa is based on Semtech SX1272 LoRa 863-870 MHz for Europe





LoRa® Transceivers

Part Number	Frequency Range (MHz)	Link Budget (dB)	Rx Current (mA)	FSK max DR (kbps)	LoRa DR (kbps)	Max Sensitivity (dBm)	Tx Power (dBm)
SX1272	860 – 1020	158	10	300	0.3 – 37.5	-137	+ 20
SX1273	860 – 1020	150	10	300	1.7 – 37.5	-130	+ 20
SX1276	137 – 1020	168	9.9	300	0.018 – 37.5	-148	+ 20
SX1277	137 – 1020	158	9.9	300	1.7 – 37.5	-139	+ 20
SX1278	137 – 525	168	9.9	300	0.018 – 37.5	-148	+ 20



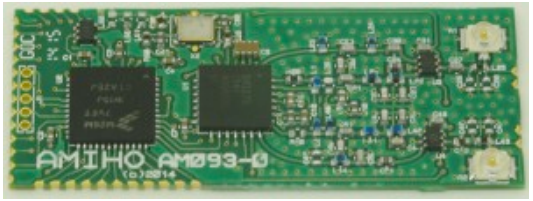
Multi-Tech MultiConnect mDot

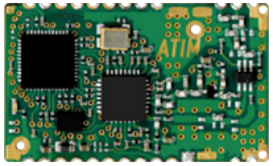
habSupplies

Adeunis ARF8030AA- Lo868

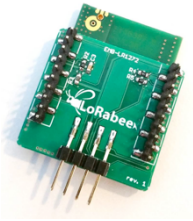
Microship RN2483

AMIHO AM093





ARM-Nano N8 LoRa module from ATIM

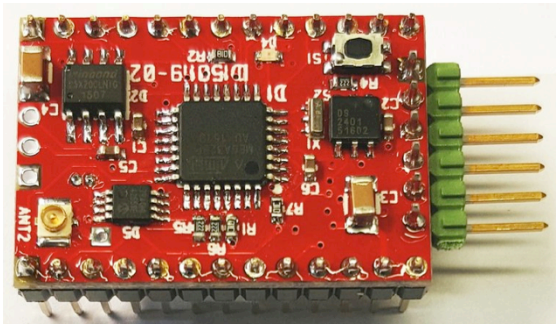


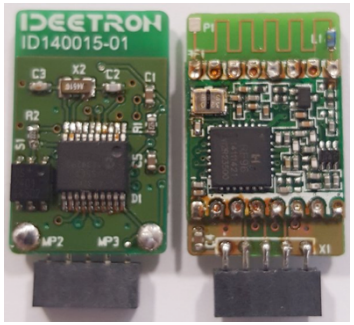
SODAQ LoRaBee Embit

SODAQ LoRaBee RN2483

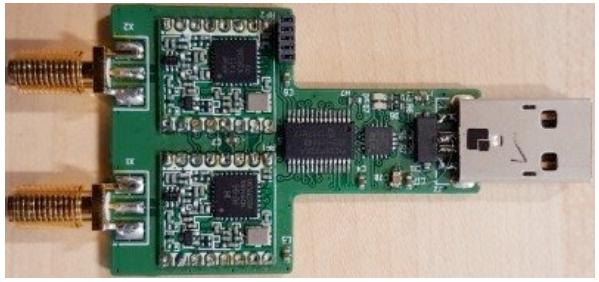
Some ready-to-use LoRa devices

LoRa Mote from Semtech

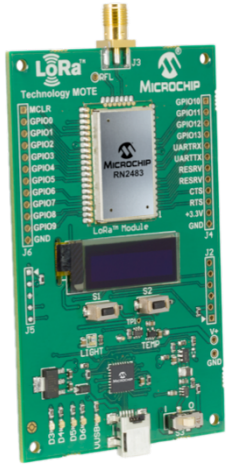




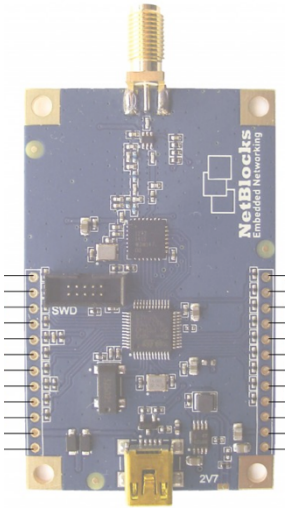
LoRa™ Alliance



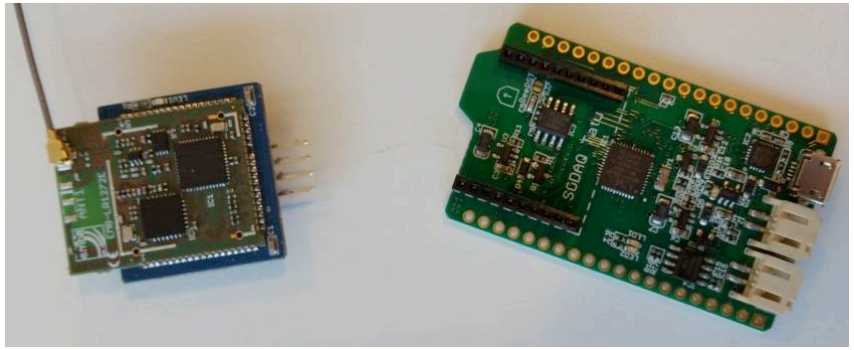
HopeRF/Ideetron motes



Microchip LoRa mote

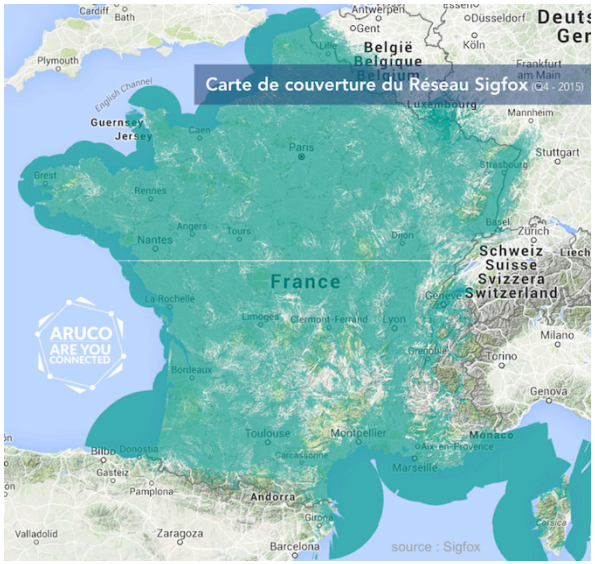


NetBlocks XRange

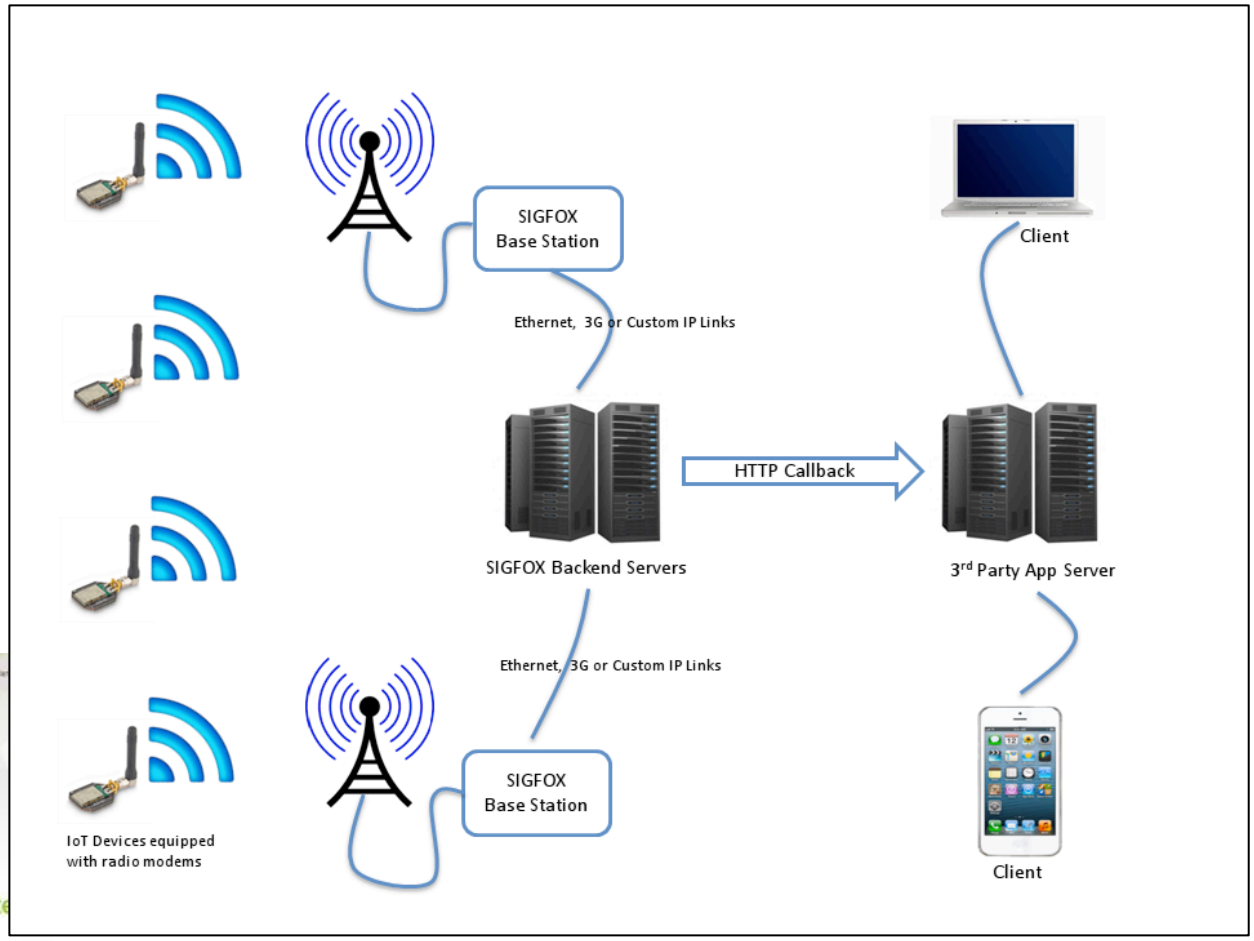


SODAQ Tatu with LoraBee (Embit)

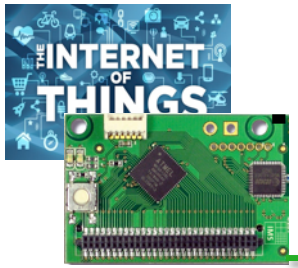
Sigfox's model for M2M: the « operator » (all-in-one) approach



Figures from SigFox



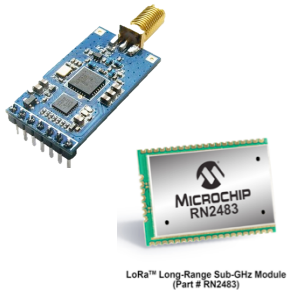
http://www.scoop.it/t/toulouse-networks/?tag=SigFox



...vs PRIVATE LONG RANGE NETWORKS WITH LoRA

Add LoRa radio module to your preferred dev platform

Install a LoRa gateway and start collecting data



LoRa™ Long-Range Sub-GHz Module (Part # RN2483)

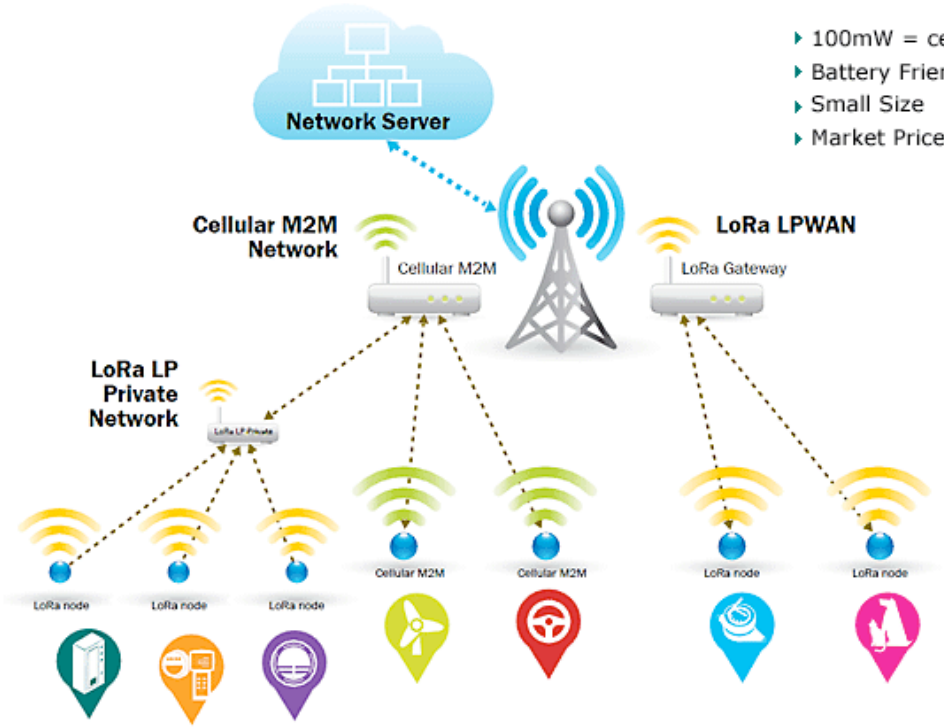


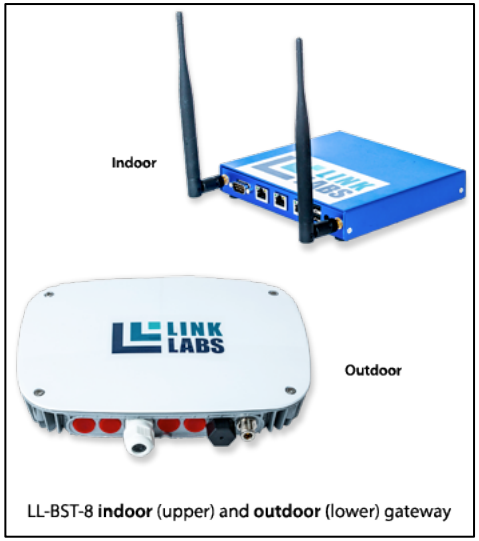
Figure from Semtech

LoRa Gateways
(non exhaustive list)

Multi-Tech Conduit

Embedded Planet
EP-M2M-LORA

Ideetron Lorank 8



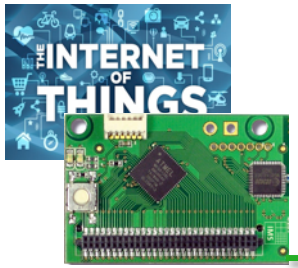
LinkLabs Symphony

Kerlink IoT Station

PicoWAN from
Archos

TheThingNetwork

Or build your own one:
Arduino, Rasperry PI, …



OTHER LONG-RANGE TECHNOLOGIES

Weightless
N, P

LTE
Cat-0
Cat-1
Cat-M1

RPMA
(Ingenu)

802.11ah

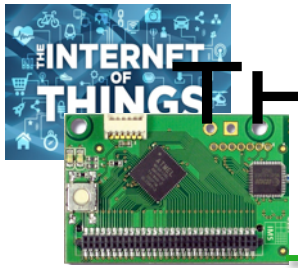
NWave

Telensa

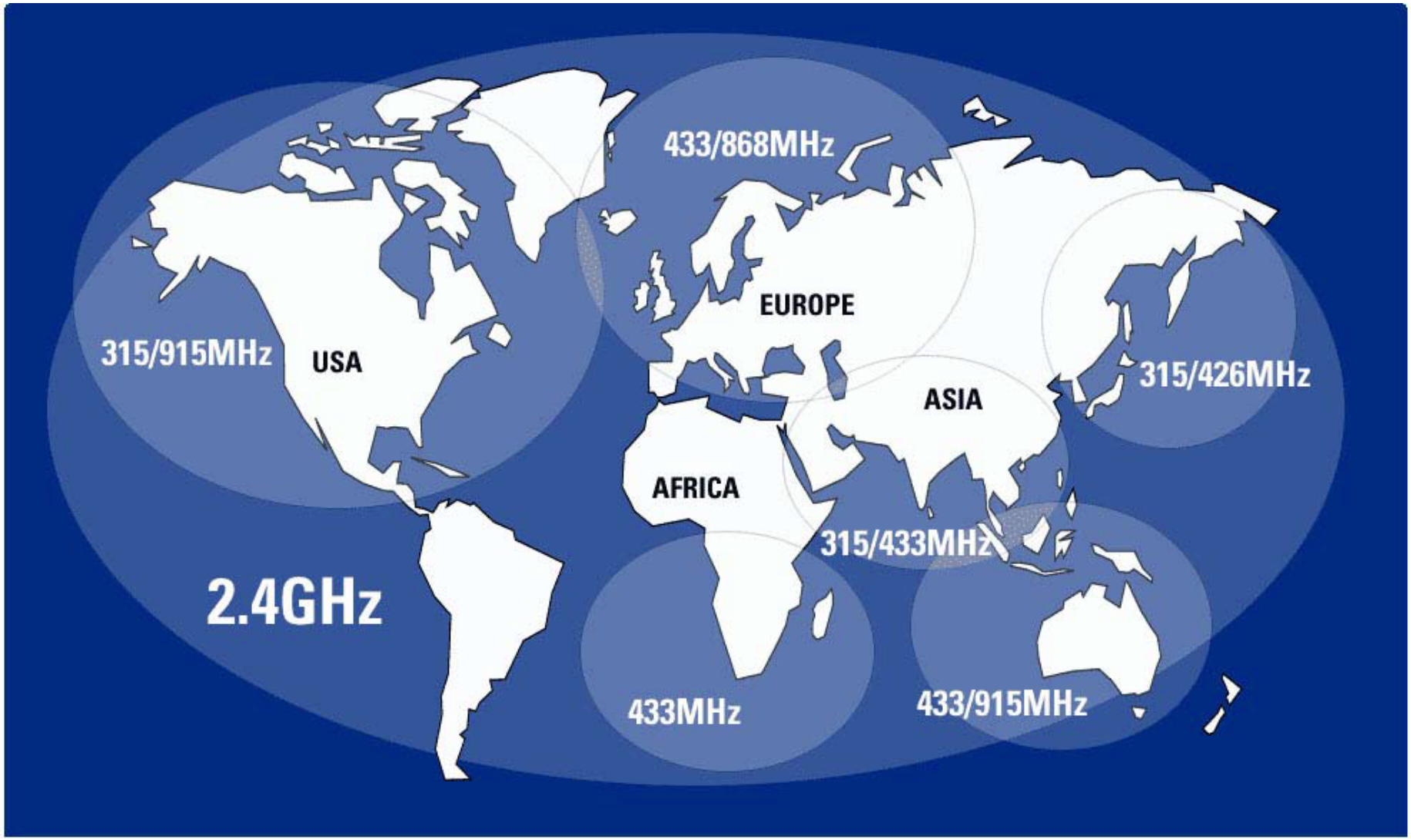
NB-IoT

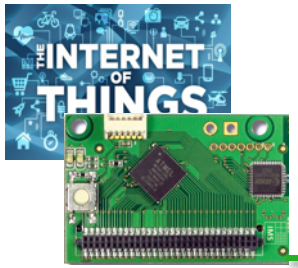
Amber
Wireless

waviot



The ISM/SRD License-Free Frequency Bands



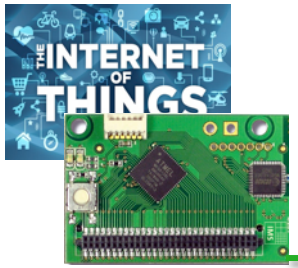


License-free Sub-GHz constraints

- Shared medium so long-range transmission in dense environments can create lots of interference!
- Activity time is constrained from 0.1%, 1% 10% duty-cycle depending on frequency: 3.6s, 36s/hour to 360s/hour

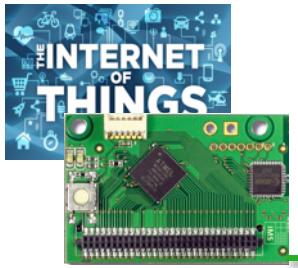
Band	Edge Frequencies		Field / Power	Spectrum Access	Band Width
	Fe-	Fe+			
g(Note 7)	865 MHz	868 MHz	+6.2 dBm /100 kHz	1 % or LBT AFA	3 MHz
g(Note 7)	865 MHz	870 MHz	-0.8 dBm / 100 kHz	0.1% or LBT AFA	5 MHz
g1	868 MHz	868.6	14 dBm	1 % or LBT AFA	600 kHz
g2	868.7 MHz	869.2 MHz	14 dBm	0.1% or LBT AFA	500 kHz
g3	869.4 MHz	869.65 MHz	27 dBm	10 % or LBT AFA	250 kHz
g4	869.7 MHz	870 MHz	7 dBm	No requirement	300 kHz
g4	869.7 MHz	870 MHz	14 dBm	1 % or LBT AFA	300 kHz

For SigFox, the operator typically limits the number of messages per day (140) with penalty for over usage. e.g. new messages/ day = 140 – (2 * « #msg_overuse») applied during «#msg_overuse» days



LBT+AFA

- Listen Before Talk and Adaptive Frequency Agility can relax the duty-cycle constraints…
- … but still
  - 100s / hour on every 200kHz BW
  - **no more than 1s for a single transmission ☹☹**
- … so may not be that interesting!



LoRa™ Alliance

Wide Area Networks for IoT

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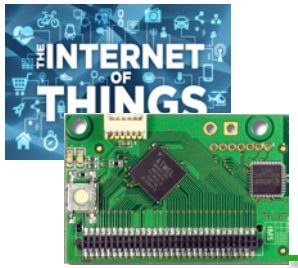
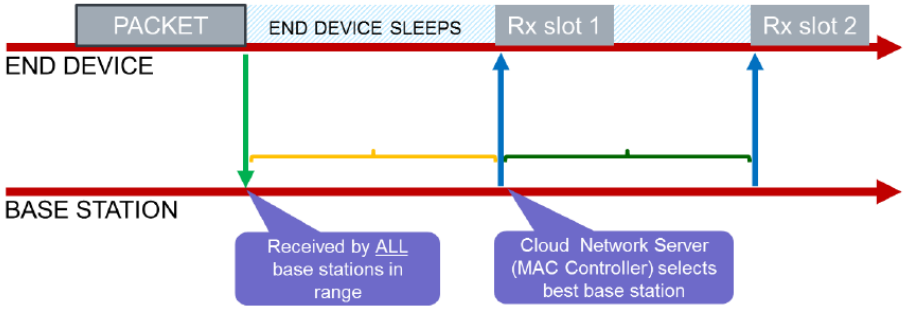


What is LoRaWAN?

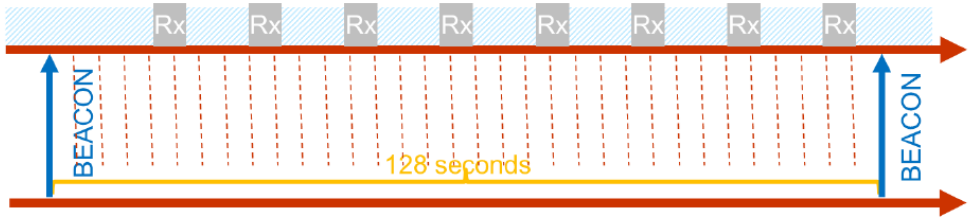
Class A: Receiver Initiated Transmission strategy (RIT)



Class B: Coordinated Sampled Listening (CSL)

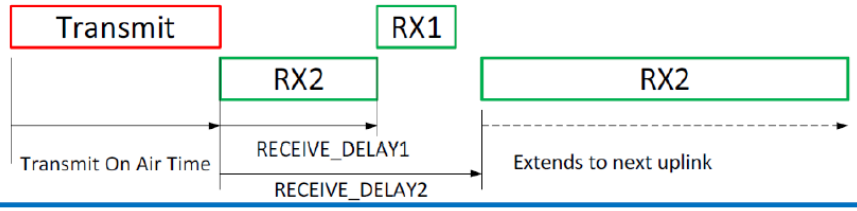
Network may send downlink packet to node at any Rx slot

END DEVICE



BASE STATION

Class C: Continuous Listening



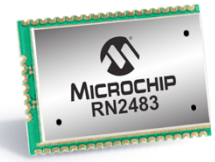
Latency constrained applications

Power Efficiency

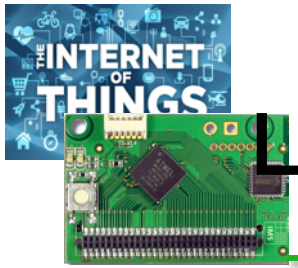
LoRa Alliance

Wide Area Networks for IoT

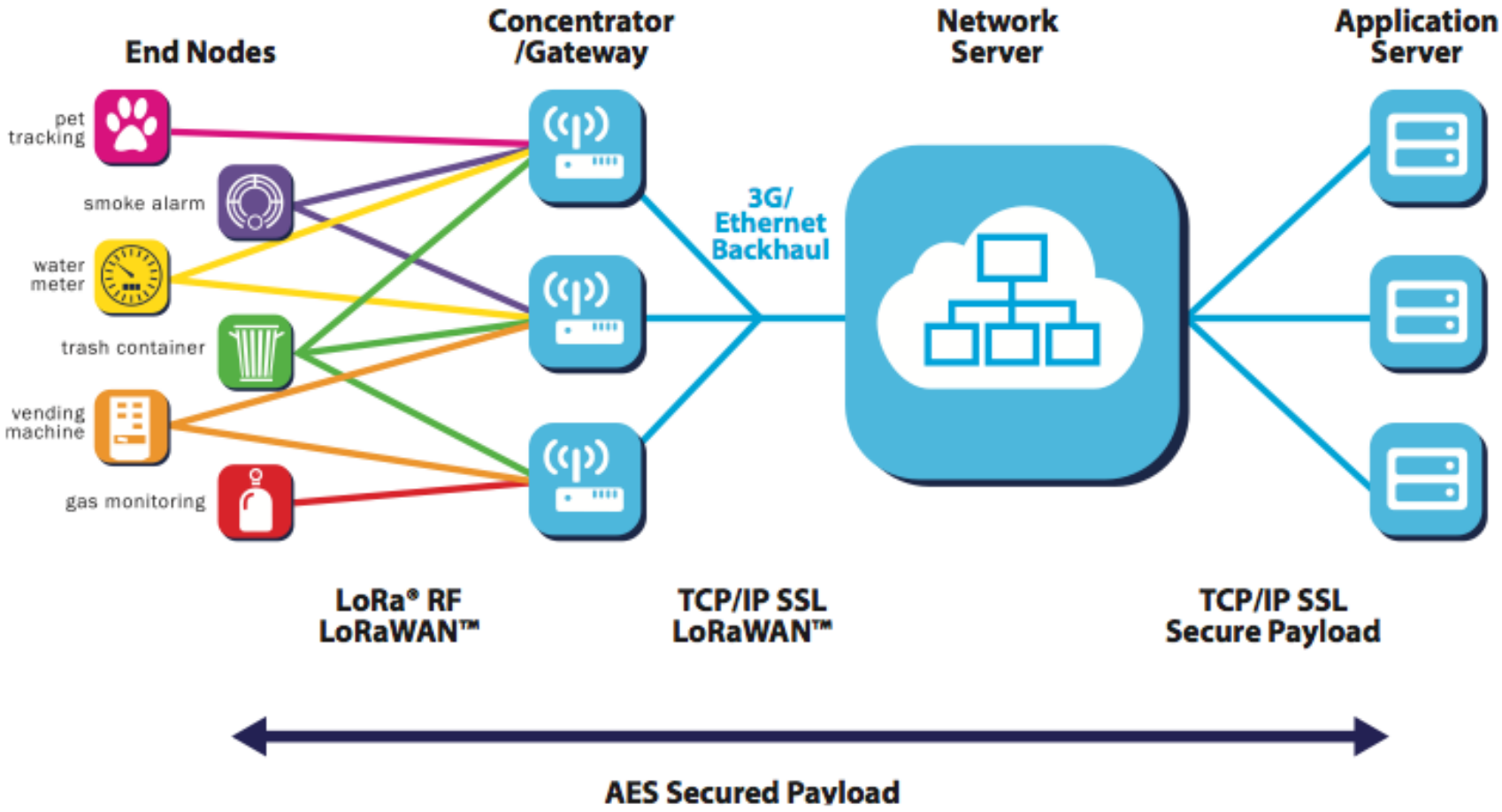
Application				
LoRa® MAC				
MAC options				
Class A (Baseline)	Class B (Baseline)	Class C (Continuous)		
LoRa® Modulation				
Regional ISM band				
EU 868	EU 433	US 915	AS 430	—

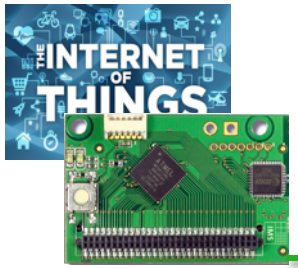


LoRa™ Long-Range Sub-GHz Module (Part # RN2483)



LoRaWAN ARCHITECTURE

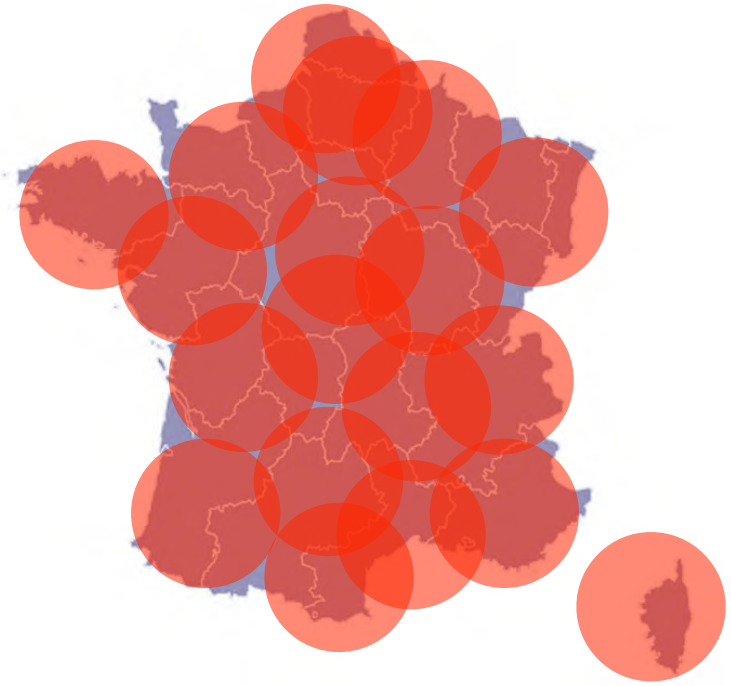




Will main market be operator based?

Long Range

- Greater than cellular
- Deep indoor coverage
- Star topology

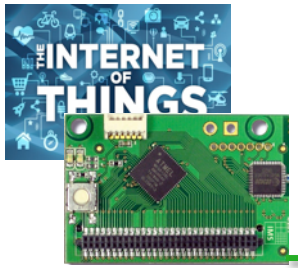


bouygues TELECOM

orange™

swisscom

kpn



...COMMUNITY BASED?

THE THINGS NETWORK

...LOR FROM LOCAL ACTORS?

Irrigation

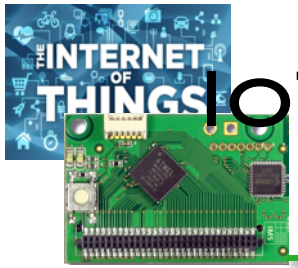
Livestock farming

Fish farming & aquaculture

Storage & logistic

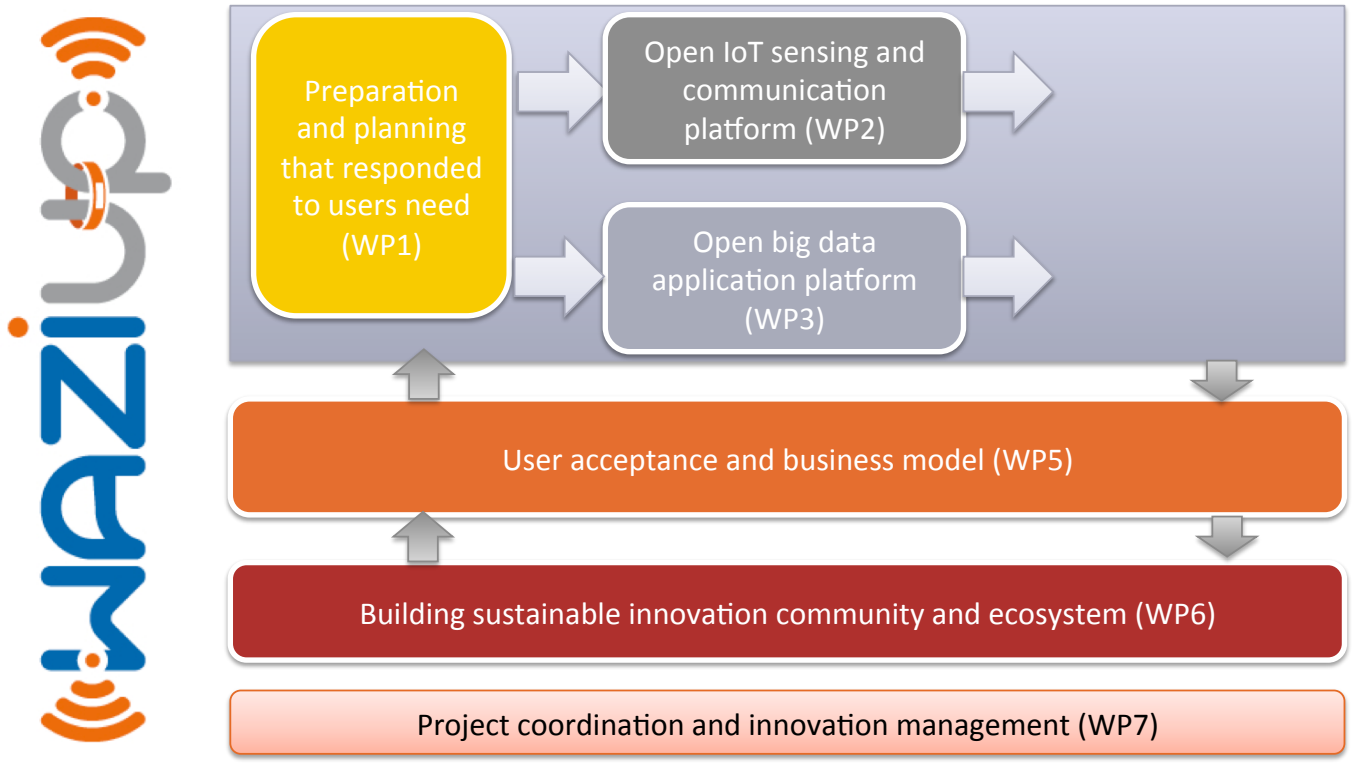
Agriculture

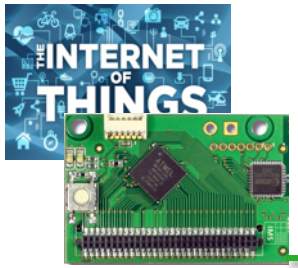
Fresh water



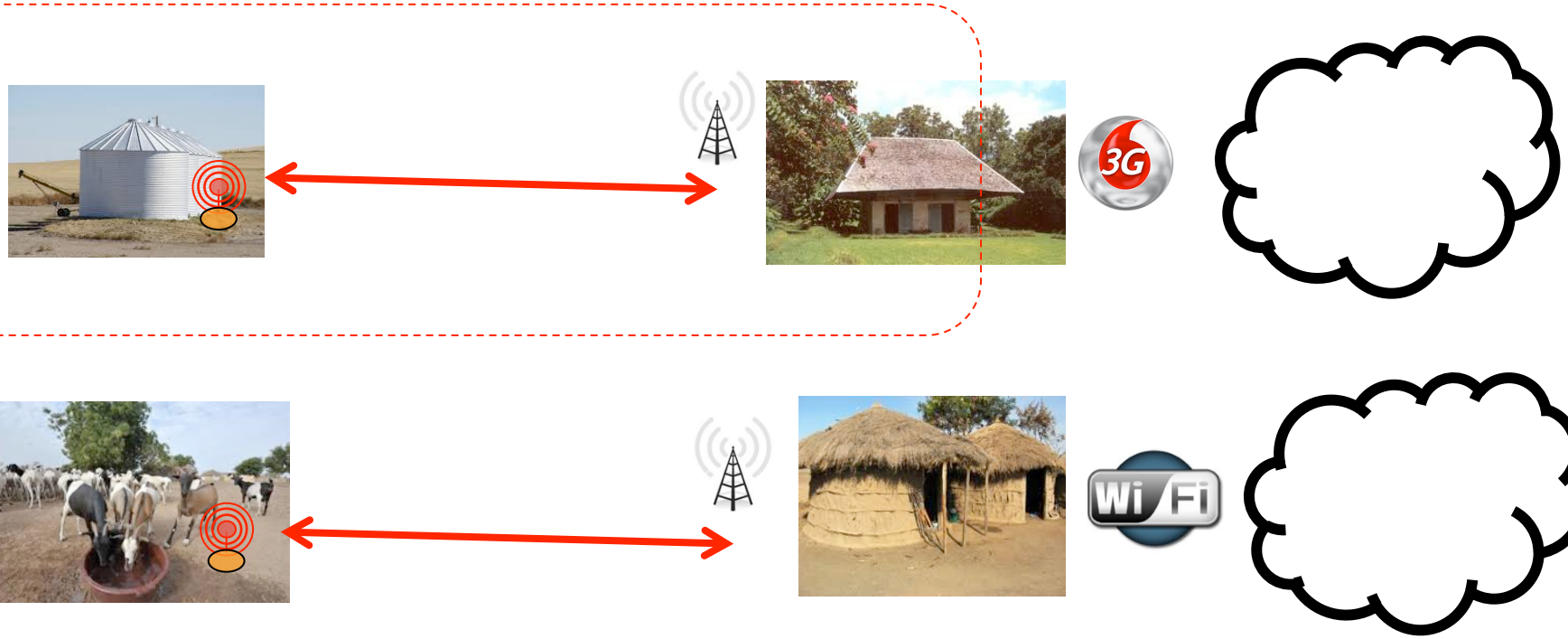
IoT FOR RURAL APPLICATIONS IN DEVELOPPING COUNTRIES

- WAZIUP is an EU H2020 project (2016-2019)
- contributes to long-range networks for rural applications with WP2

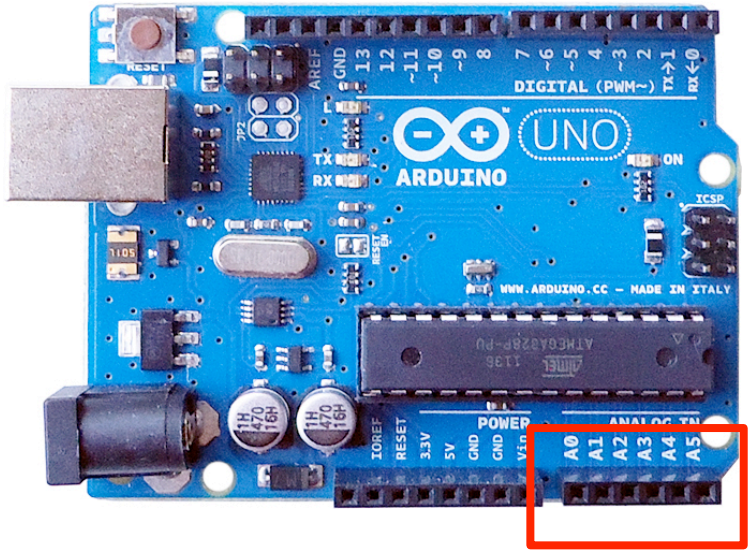




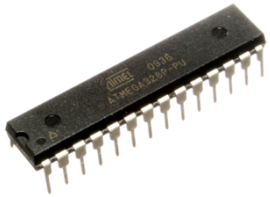
Typical scenarios

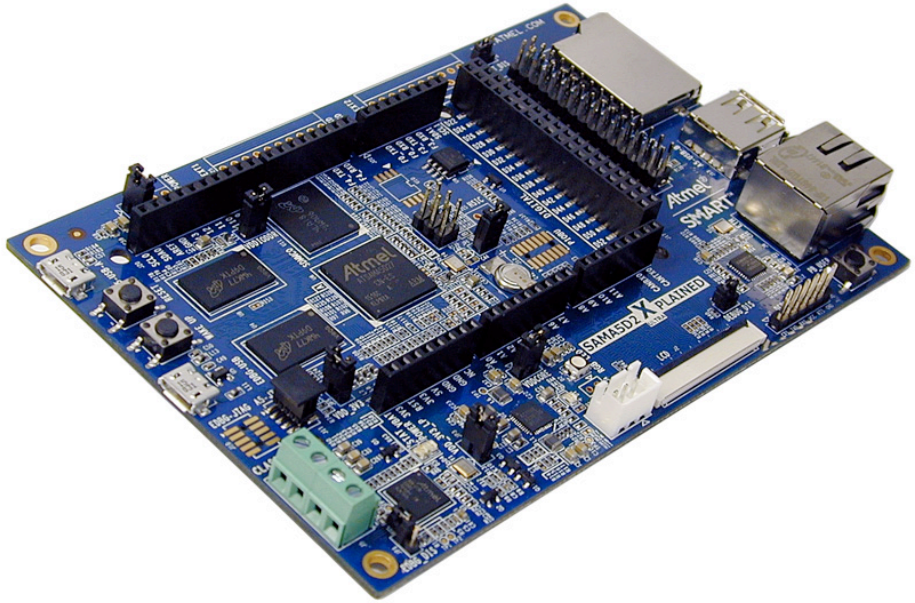


Powerfull micro-controller boards...



Analog pins

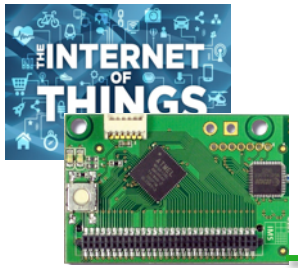




Atmel | SMART SAMA5D2

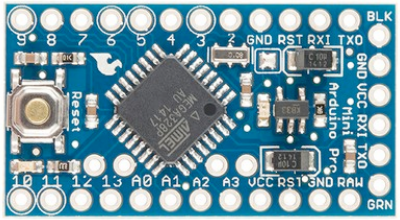
Come with build-in analog-to-digital converter (ADC) which usually have 10-bit resolution:

0V means 0
3.3V or 5V means 1024 = 2^{10}



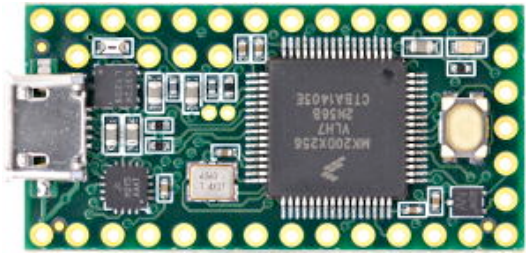
...GETTING SMALLER AND SMALLER !!

Arduino Pro Mini

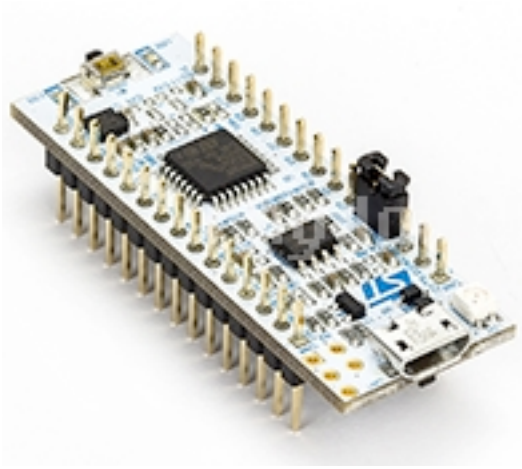


http://blog.atmel.com/2015/12/16/rewind-50-of-the-best-boards-from-2015/

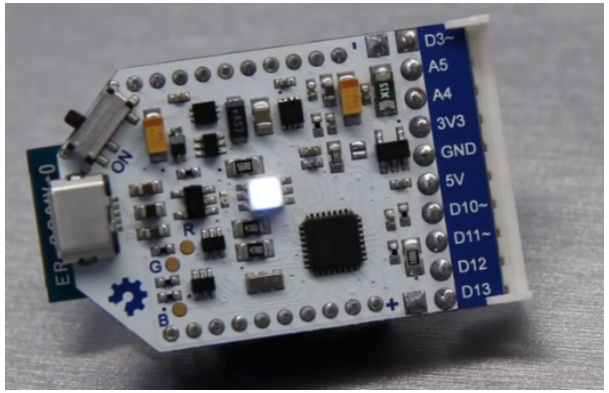
http://blog.atmel.com/2015/04/09/25-dev-boards-to-help-you-get-started-on-your-next-iot-project/



Teensy 3.2

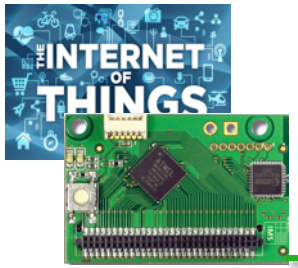


STM32 Nucleo-32



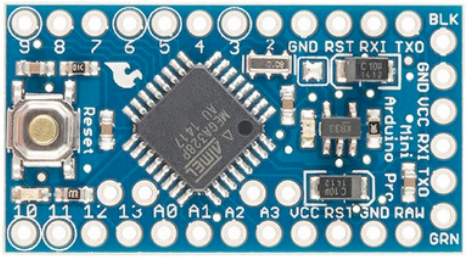
Theairboard on kickstarter

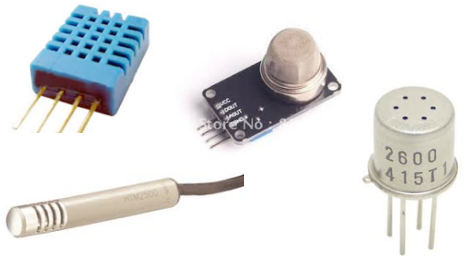
Tinyduino



Design and adaptation

- Build low-cost, low-power, Long-range enabled generic platform
- Methodology for low-cost platform design
- Technology transfers to user communities, economic actors, stakeholders,…





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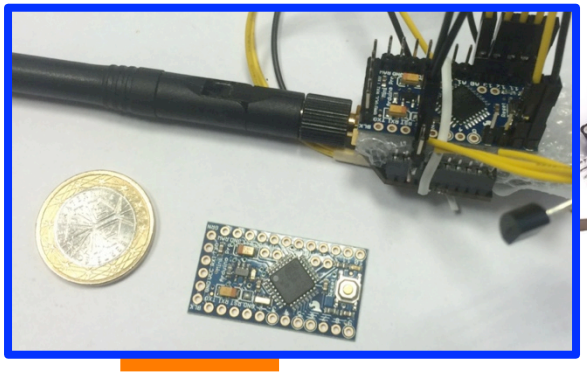
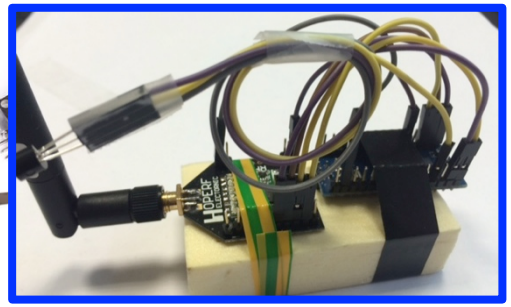
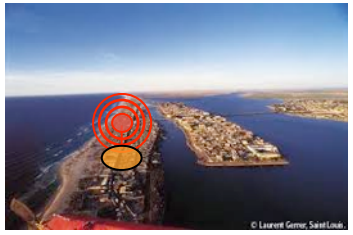
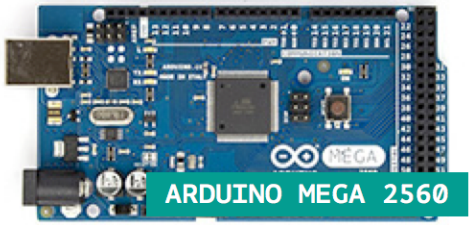
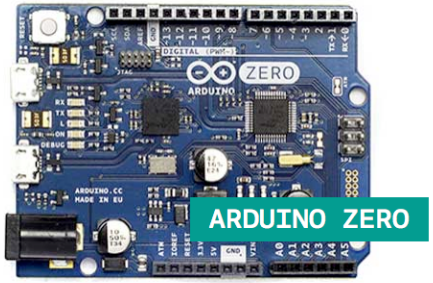


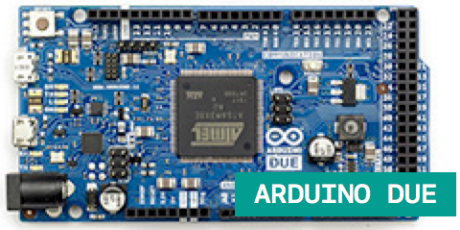


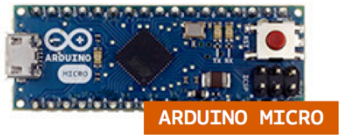


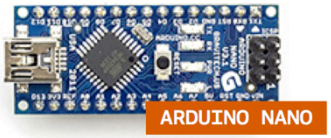
SW/HW BUILDING BLOCKS



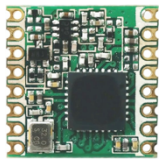








LoRa radios that our library already supports



HopeRF RFM92W/95W

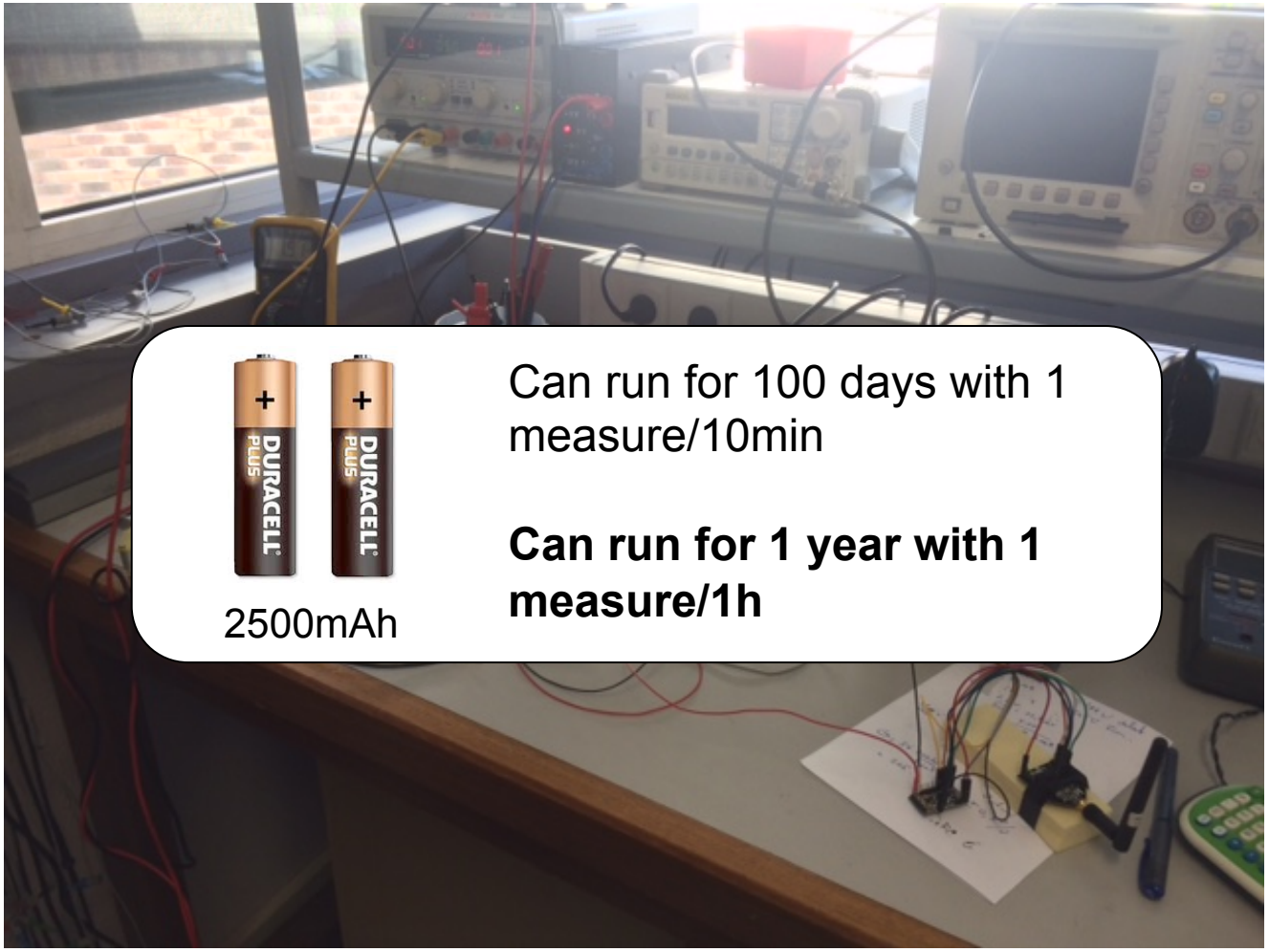
Libelium LoRa

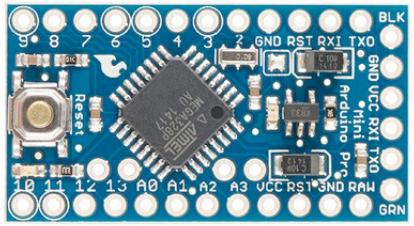
Modtronix inAir9/9B

Long-Range communication library
(mostly sending functions)

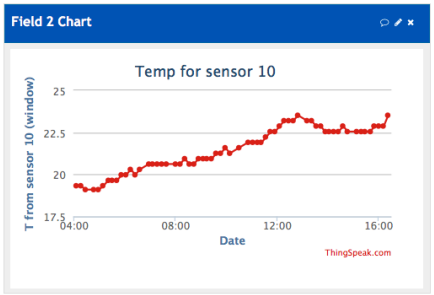
Running for 1 year

Low-Power library from RocketScream





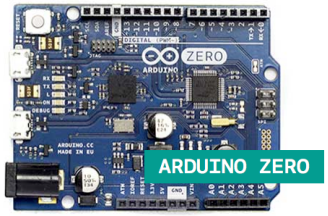
Wakes-up every 10min, take a measure (temp) and send to GW

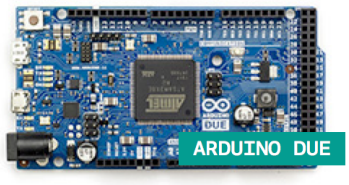


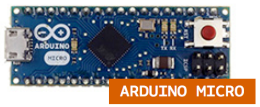
146µA in deep sleep mode, 93mA when active and sending

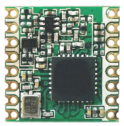
Thanks to T. Mesplou and P. Plouraboué for their help

Communication to gateway is straightforward for developers









HopeRF
RFM95W

Libelium LoRa

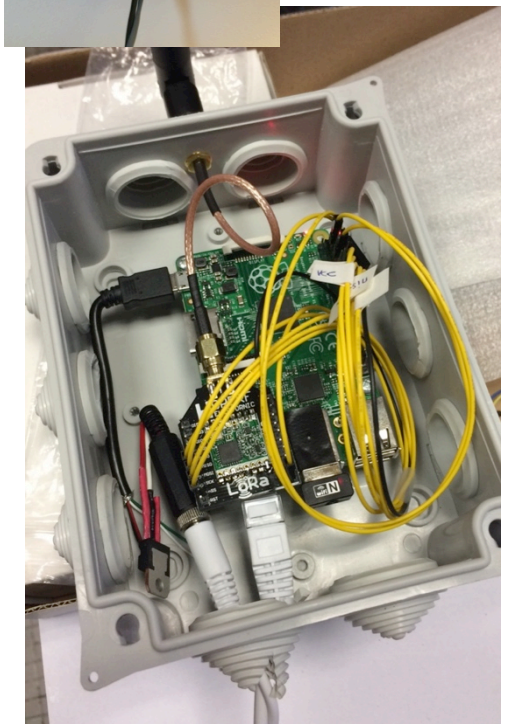
Modtronix
inAir9/9B

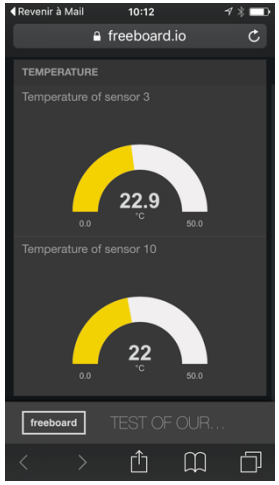
LoRa™

```
sendPacketTimeout(1, "18.5", 4);
// 1: sends to gateway
// 18.5 : temperature message
// 4 : message size
```

1 send function!

Low-cost LoRa gateway: less than 50€

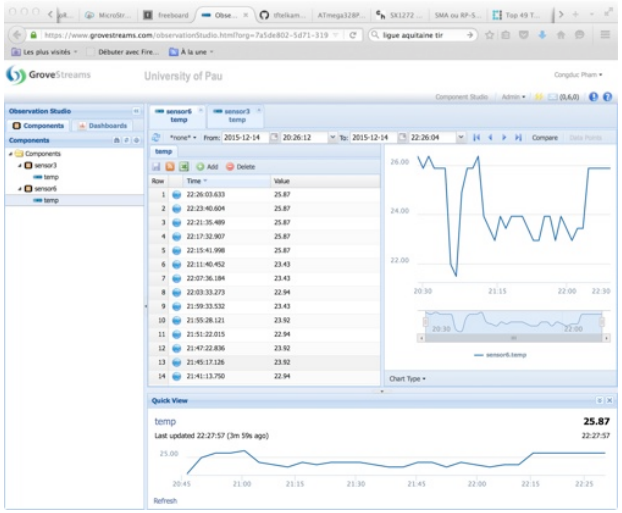




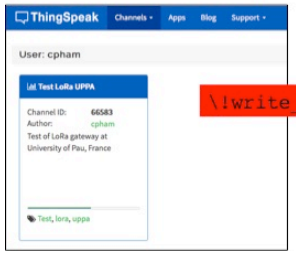
Dropbox

freeboard

FIWARE



ThingSpeak



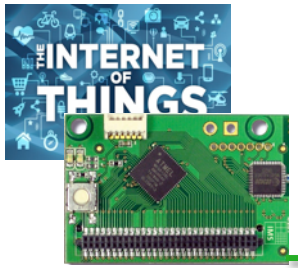
\!##19.6

Node 10

\!write_key#field_index#19.6

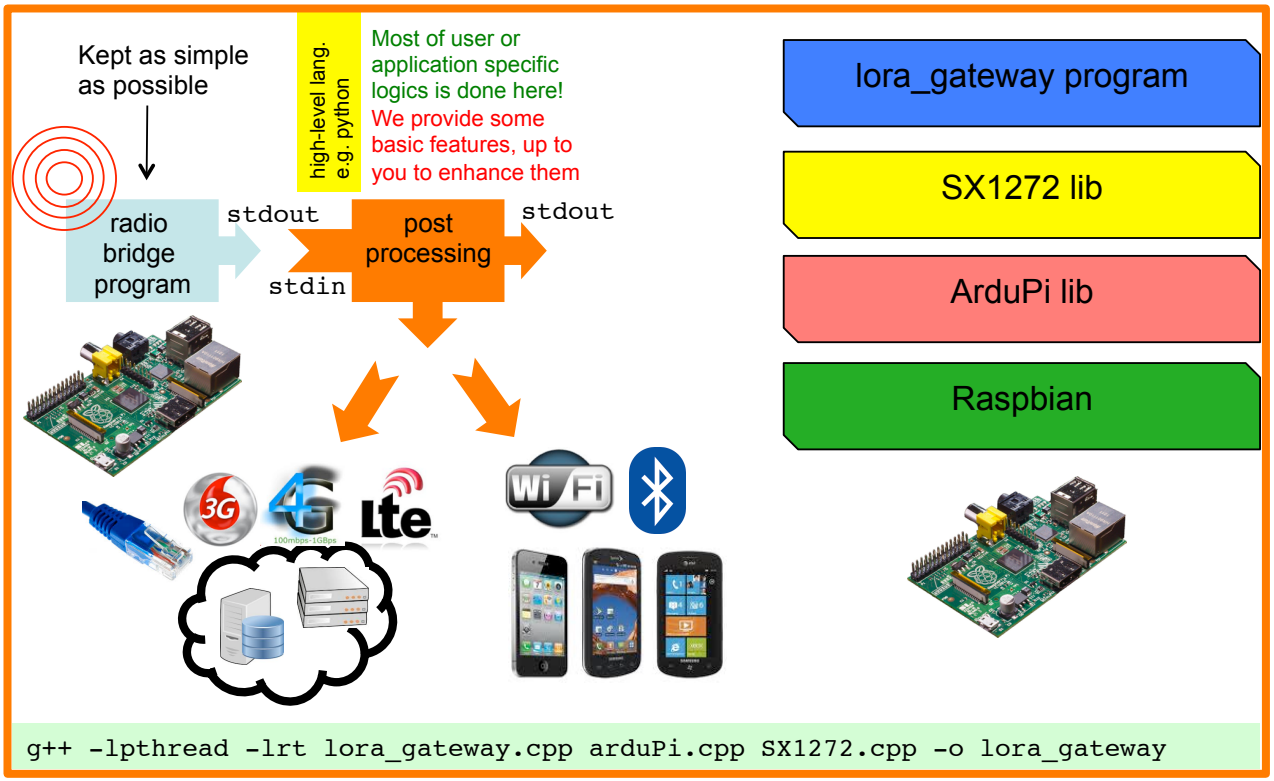
GroveStreams

SensorCloud™



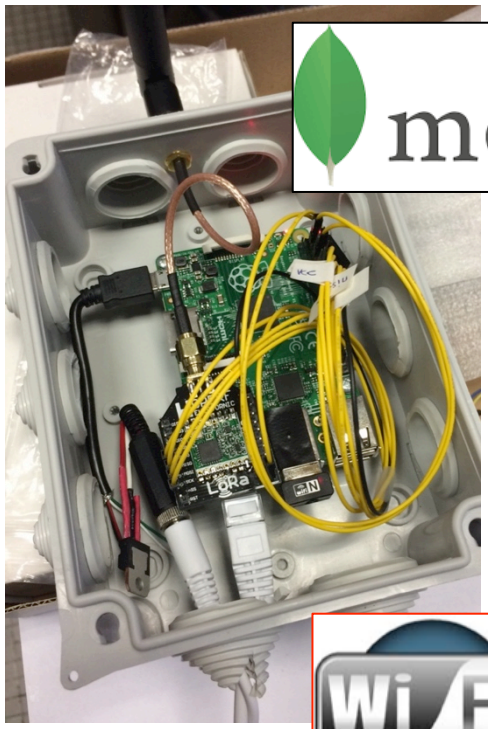
From GW to Cloud platforms

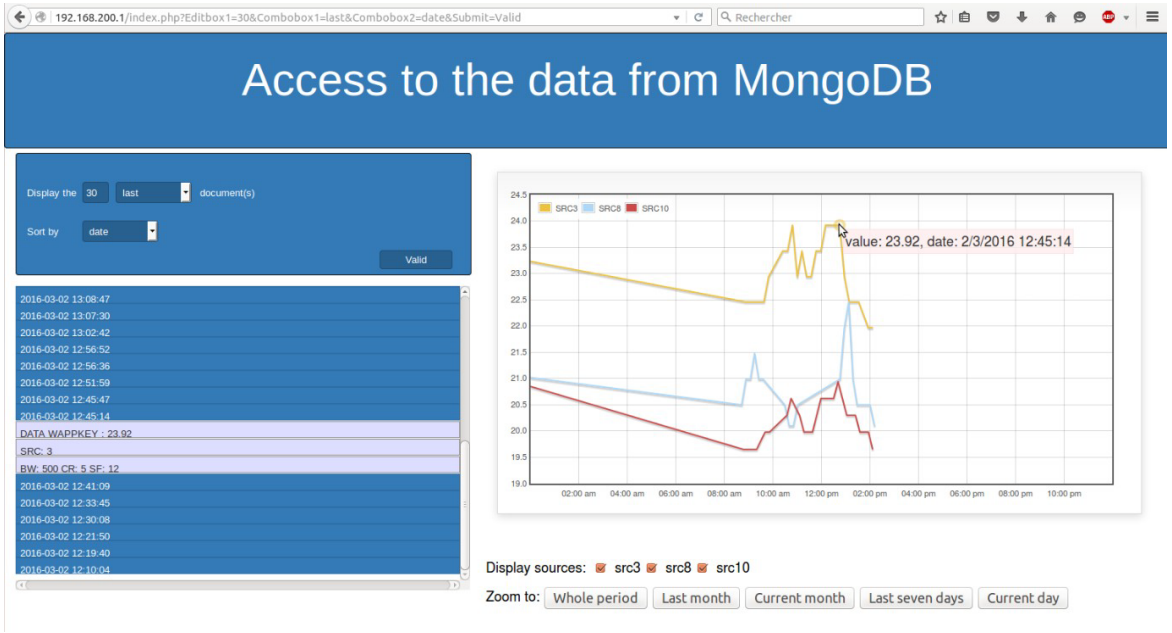
Once data is received at gateway, traditional Internet tools can be used to push data to cloud



- High-level scripting language provides connectivity to any cloud platforms depending on end-user needs

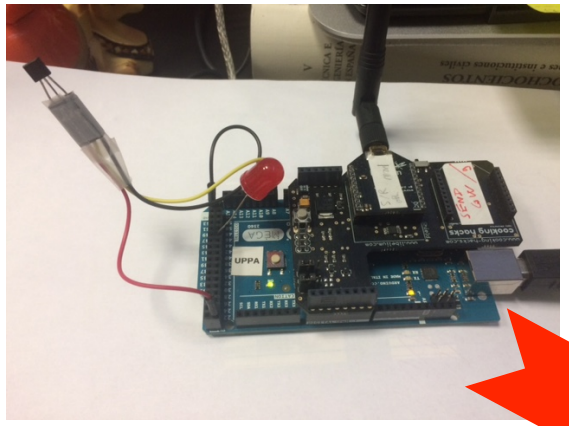
Running without Internet access





Internship of N. Bertuol, collaboration with ConnectingNature (F. Duvignac)

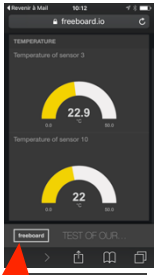
FULL EXAMPLE IS PROVIDED

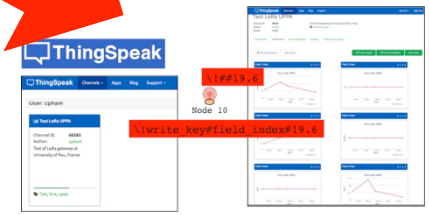


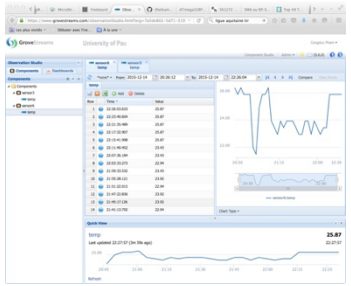
Source code available

Source code available

Python scripts available

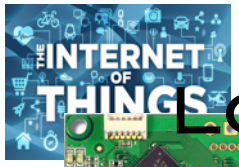


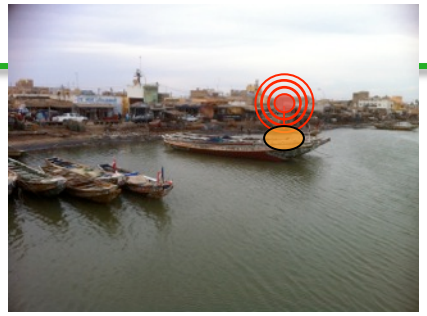


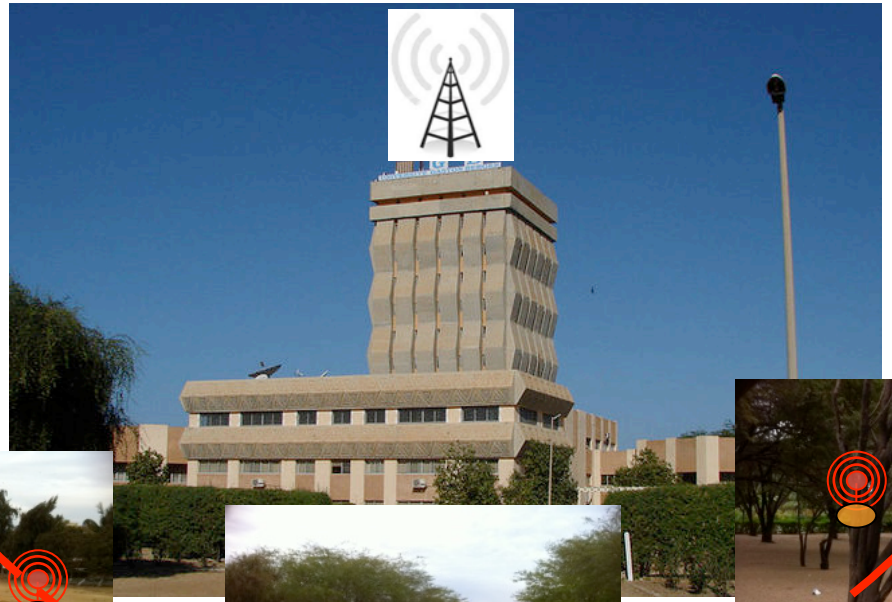


https://github.com/CongducPham/LowCostLoRaGw

LONG-RANGE TEST-BED & BENCHMARK



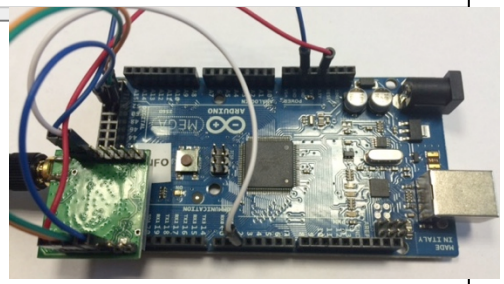


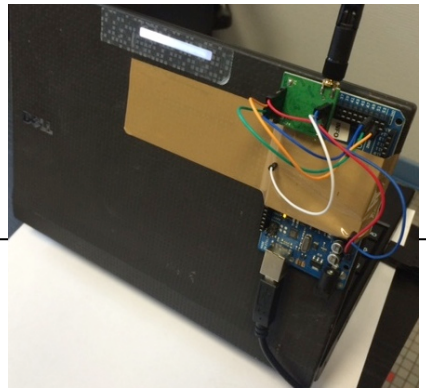


Build your own low-cost test-bed (1)

- Interactive end-device

```
/dev/cu.usbmodemFA131 (Arduino/Genuino M
Hello world
6477 bytes of free memory.
SX1276 detected, starting
SX1276 LF/HF calibration
...
^$**********Power ON: state 0
^$Default sync word: 0x12
^$LoRa mode 4
^$Setting mode: state 0
^$Channel CH_10_868: state 0
^$Set LoRa Power to x
^$Power: state 0
^$Get Preamble Length: state 0
^$Preamble Length: 8
^$LoRa addr 6: state 0
^$SX1272/76 configured as device. Waiting serial input for serial-RF bridge
Rcv serial: hello world
Sending. Length is 11
hello world
Payload size is 11
ToA is w/5B Libelium header 322
Packet number 0
LoRa Sent in 545
LoRa Sent w/CAD in 545
Packet sent, state 0
```





Command	Action
/@M1#	set LoRa mode 1
/@C12#	use channel 12
/@PL/H/M/x/X#	set power to Low, High, Max, extreme (PA_BOOST), eXtreme (+20dBm)
/@A9#	set node addr to 9
/@ACK#hello w/ac	sends "hello w/ack" and request an ACK
/@ACKON#	enables ACK (for all messages)
/@ACKOFF#	disables ACK
/@CAD#	performs an SIFS CAD, i.e. 3 or 6 CAD depending on the LoRa mode
/@CADON3#	uses 3 CAD when sending data (normally SIFS is 3 or 6 CAD, DIFS=3SIFS)
/@CADOFF#	disables CAD (IFS) when sending data
/@RSSI#	toggles checking of RSSI before transmission and after CAD
/@EIFS#	toggles for extended IFS wait
/@T5000#	send a message at regular time interval of 5000ms. Use /@T0# to disable periodic sending
/@TR5000#	send a message at random time interval between [2000, 5000]ms.
/@Z200#	sets the packet payload size to 200 for periodic sending
/@S50#	sends a 50B user payload packet filled with '#'. The real size is 55B with the protocol header
/@D56#	set the destination node to be 56, this is permanent, until the next D command
/@D56#hello	send "hello" to node 56, destination addr is only for this message
/@D1#/@M1#	send the command string "/@M1#" to node 1 (i.e. gateway)

/@ACK#hello

You can get SNR of both uplink and downlink

/@ACK#/@M2#

Switch yourself to 250KHz,SF12

/@M1#

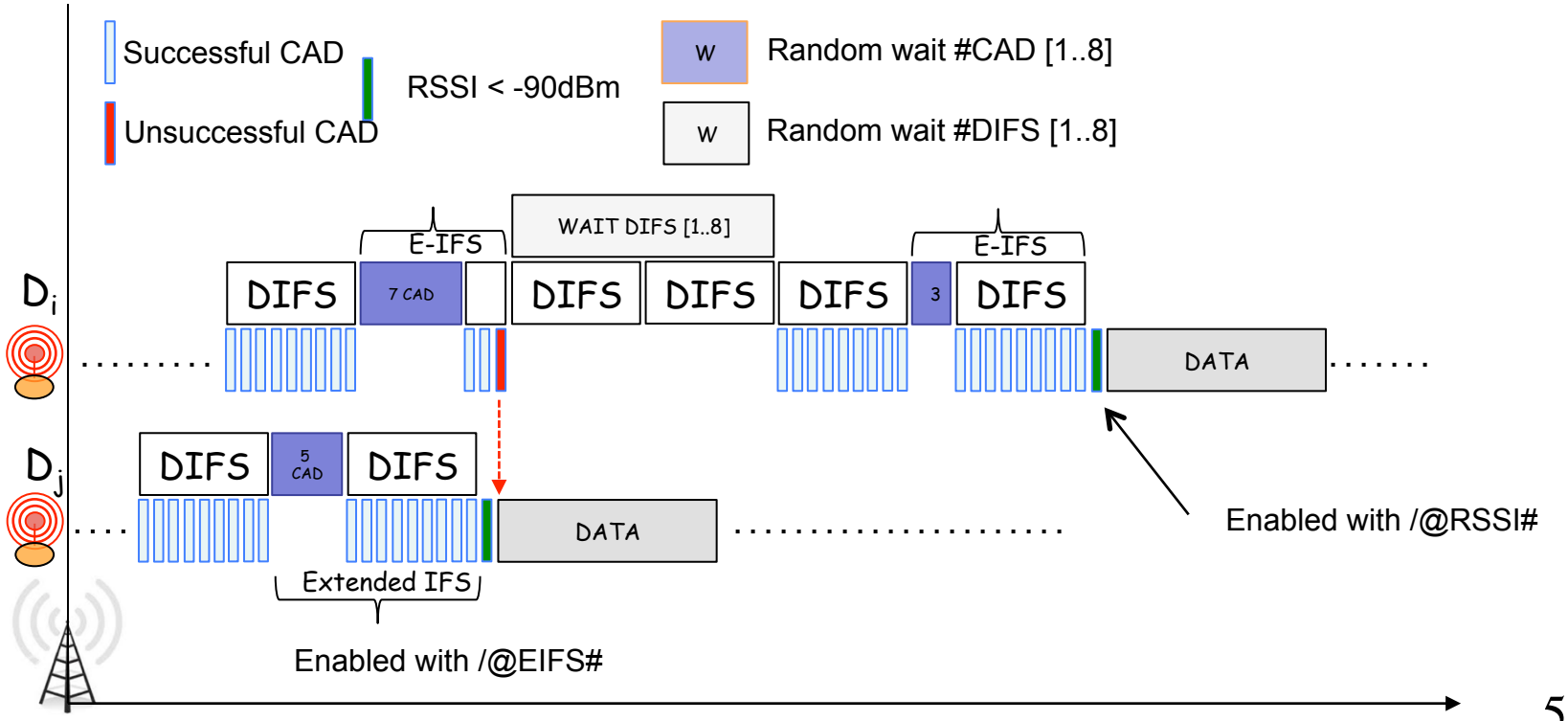
GW switches to 250KHz,SF12

/@ACK#hello

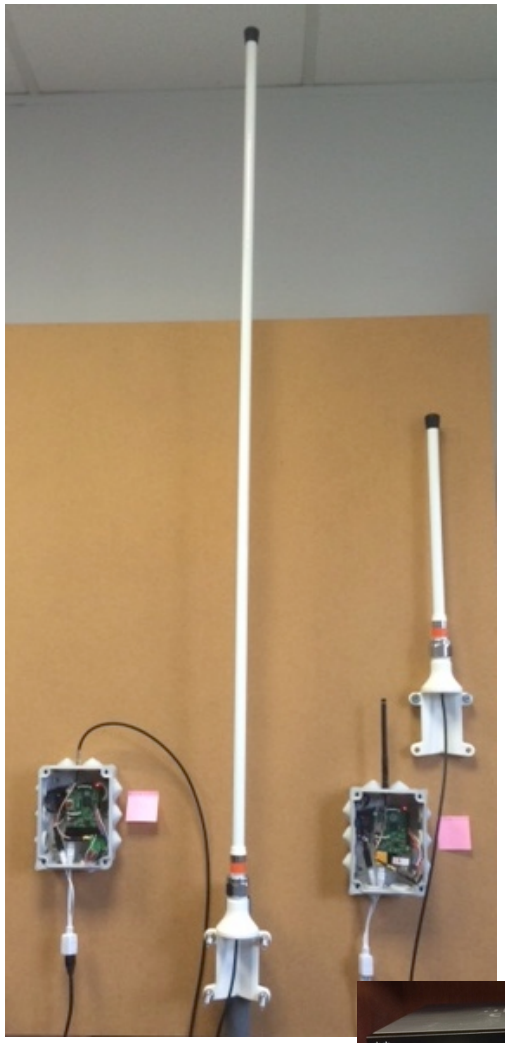
Test whether GW is still reachable

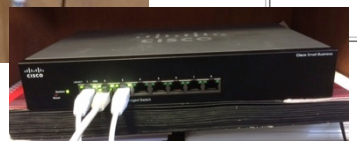
Build your own low-cost test-bed (2)

- Implement & test channel access methods
  - SIFS=xCAD; DIFS=3SIFS; set x with /@CADONx#
  - Use background traffic generator devices
  - /@T2000# or /@TR5000#

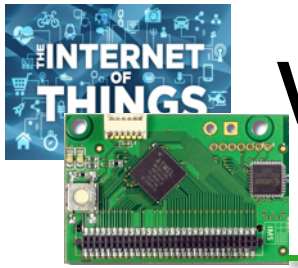


Build your own low-cost test-bed (3)





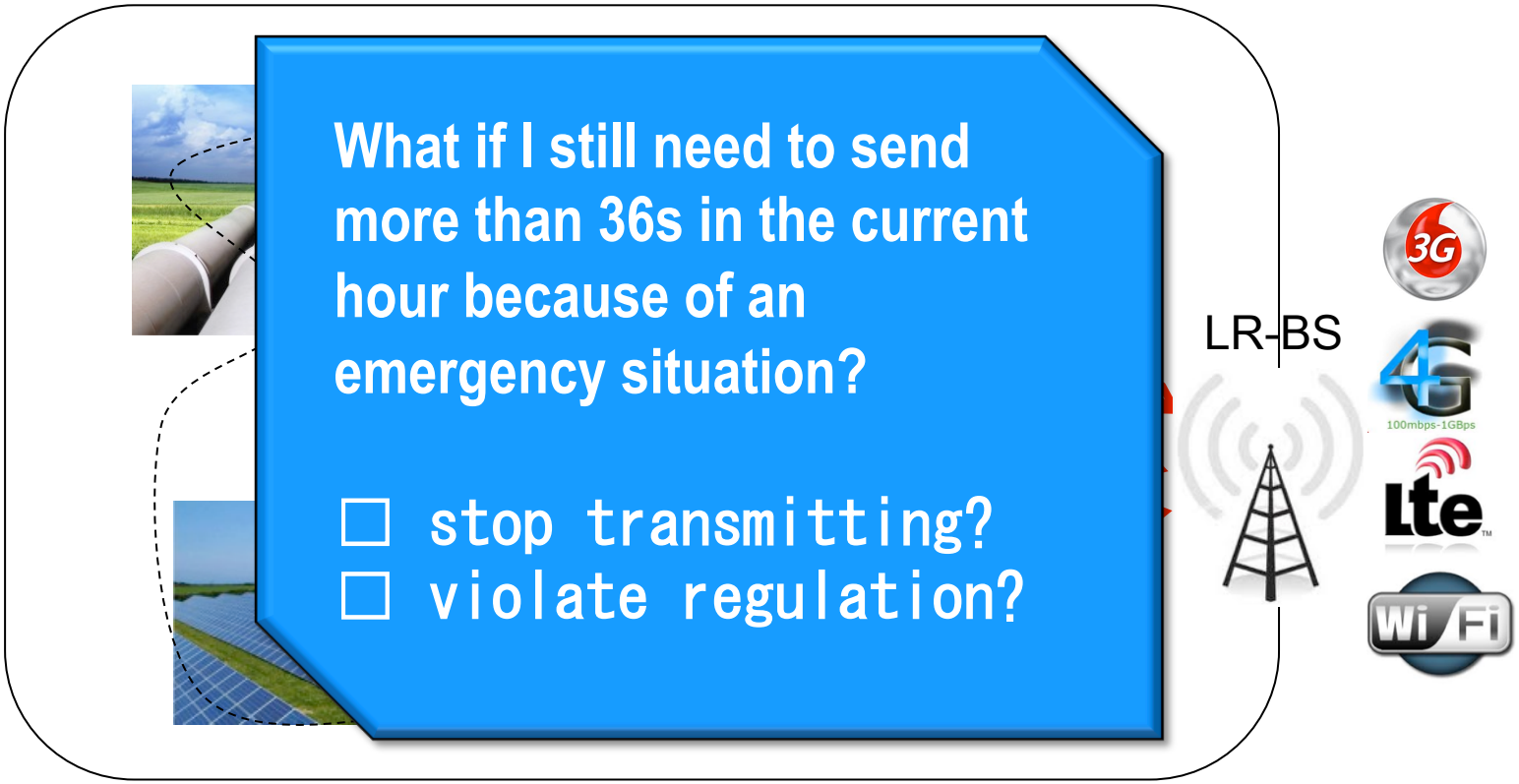
University Gaston Berger, Saint-Louis, Senegal The gateway will be used to deploy low-cost IoT solutions in the context of the H2020 WAZIUP project.	
Easy Global Market, Nice, France The gateway will be used to deploy LoRa service for various demonstration purposes	
As part of the WAZIUP project, a starter kit with a gateway will be deployed at project's partner's site: 1- Farmerline (Ghana) 2- iSpace (Ghana) 3- CTIC (Senegal)	
IIDRE SAS The gateway will be used to deploy LoRa service for various demonstration purposes	
Connecting Nature The gateway will be used to deploy and test LoRa-based telemetry services for various agriculture applications	
Chuck Swiger from West Virginia (US)... has a ds18b20 temp probe ThinkSpeak channel using our gateway	
The Oceanographic Observatory of Banuyls/mer (part of University of Paris 6) The gateway will be used to deploy and test LoRa-based telemetry services for various environmental surveillance applications	
Matthew Way from New Zeland Develops great LoRa-based pest surveillance system. He is testing our solution as well as his own custom design solutions.	



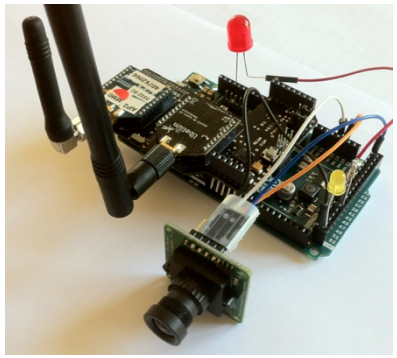
What about Quality of Service?

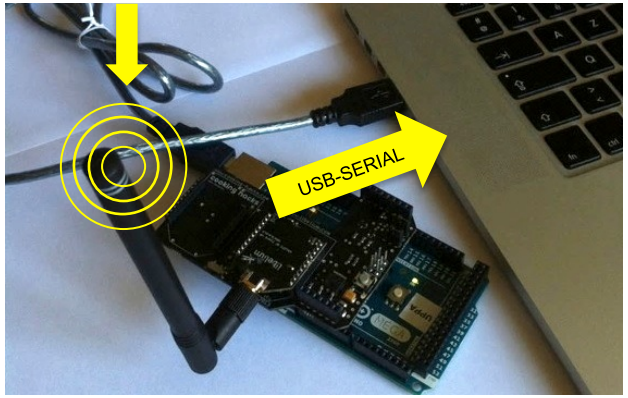
Regulations stipulate that radio activity duty-cycle should be enforced at devices and that end-users should not be able to modify it « easily ».

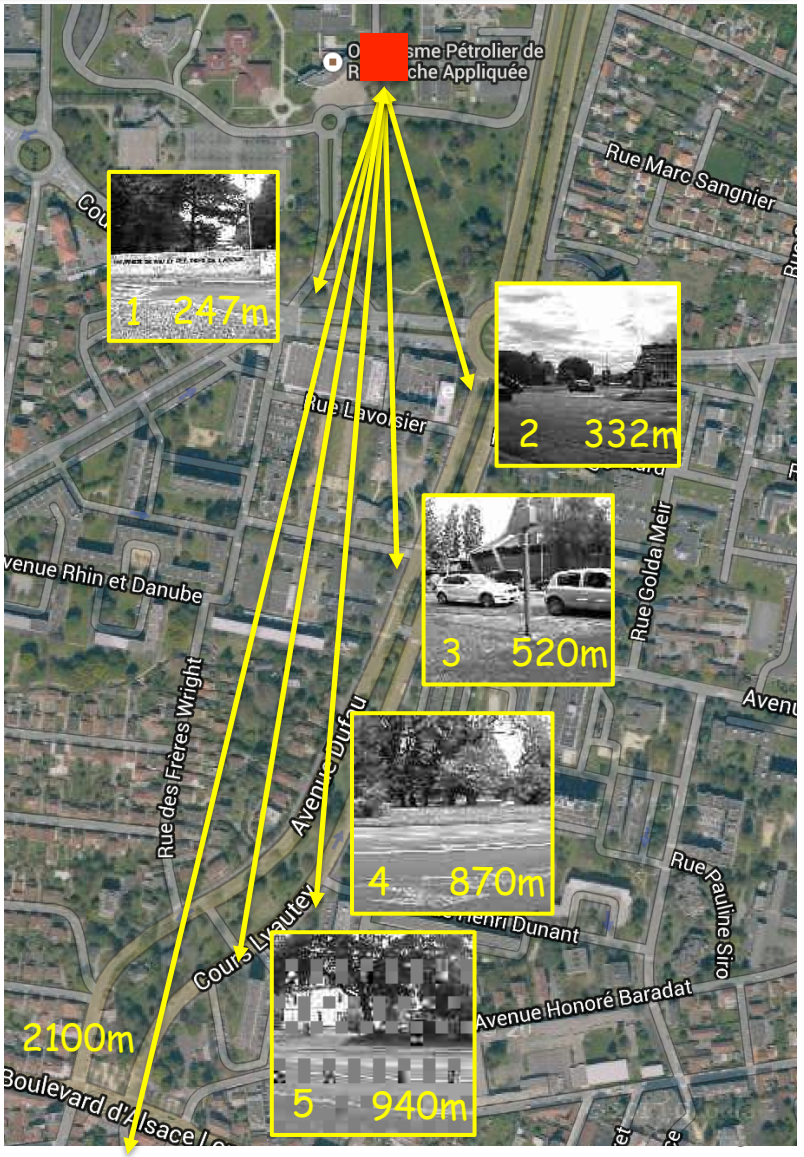
LoRaWAN specification from LoRa Alliance is a first attempt to standardize LoRa networks but no issues on quality of service.

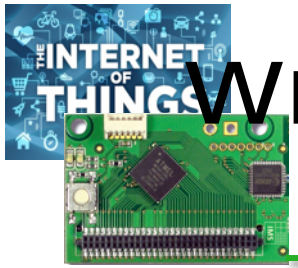


Long-range version of our image sensor









WHAT IF I WANT TO TRANSMIT IMAGES?

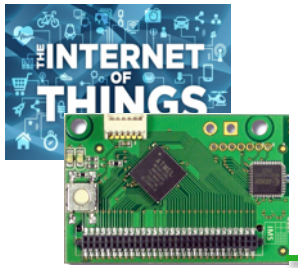
				time on air in second for payload size of					
LoRa mode	BW	CR	SF	5 bytes	55 bytes	105 bytes	155 Bytes	205 Bytes	255 Bytes
1	125	4/5	12	0.95846	2.59686	4.23526	5.87366	7.51206	9.15046
2	250	4/5	12	0.47923	1.21651	1.87187	2.52723	3.26451	3.91987
3	125	4/5	10	0.28058	0.69018	1.09978	1.50938	1.91898	2.32858
4	500	4/5	12	0.23962	0.60826	0.93594	1.26362	1.63226	1.95994
5	250	4/5	10	0.14029	0.34509	0.54989	0.75469	0.95949	1.16429
6	500	4/5	11	0.11981	0.30413	0.50893	0.69325	0.87757	1.06189
7	250	4/5	9	0.07014	0.18278	0.29542	0.40806	0.5207	0.63334
8	500	4/5	9	0.03507	0.09139	0.14771	0.20403	0.26035	0.31667
9	500	4/5	8	0.01754	0.05082	0.08154	0.11482	0.14554	0.17882
10	500	4/5	7	0.00877	0.02797	0.04589	0.06381	0.08301	0.10093

Optimized image encoding at medium quality: 16384b down to 1366b (ratio 12).

Will generate 7 pkts using 250 max payload

7*9.15= 64.05s

7*1.96 = 13.72s



Deploying your LoRa network

Operator-based approach (w… subscriptio…

Privately-based …oach

…Tech Conduit

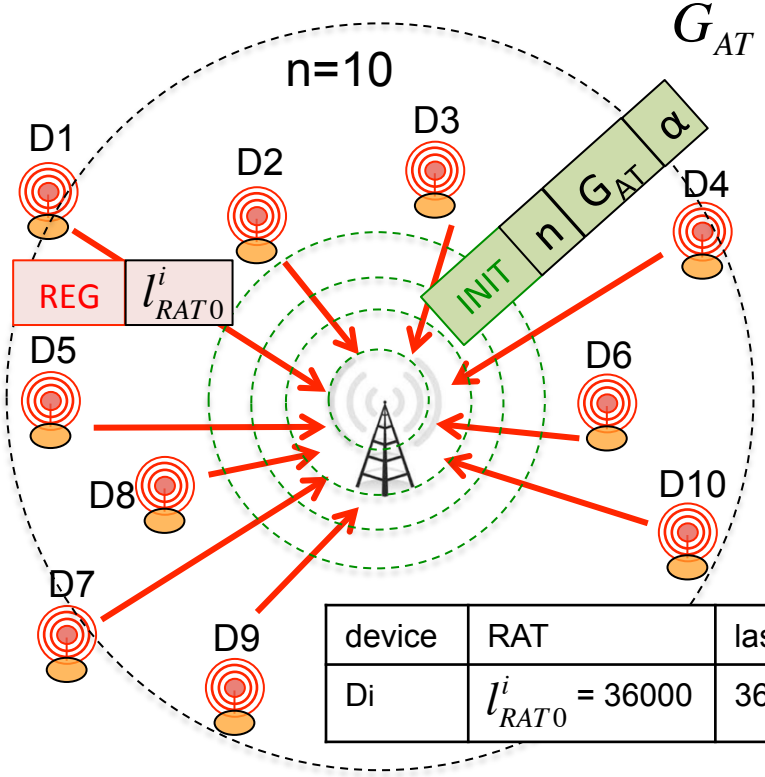
Our low-cost gateway

…IoT Station

Whatever the deployment approach, the gateway knows how many devices are deployed by a given organization

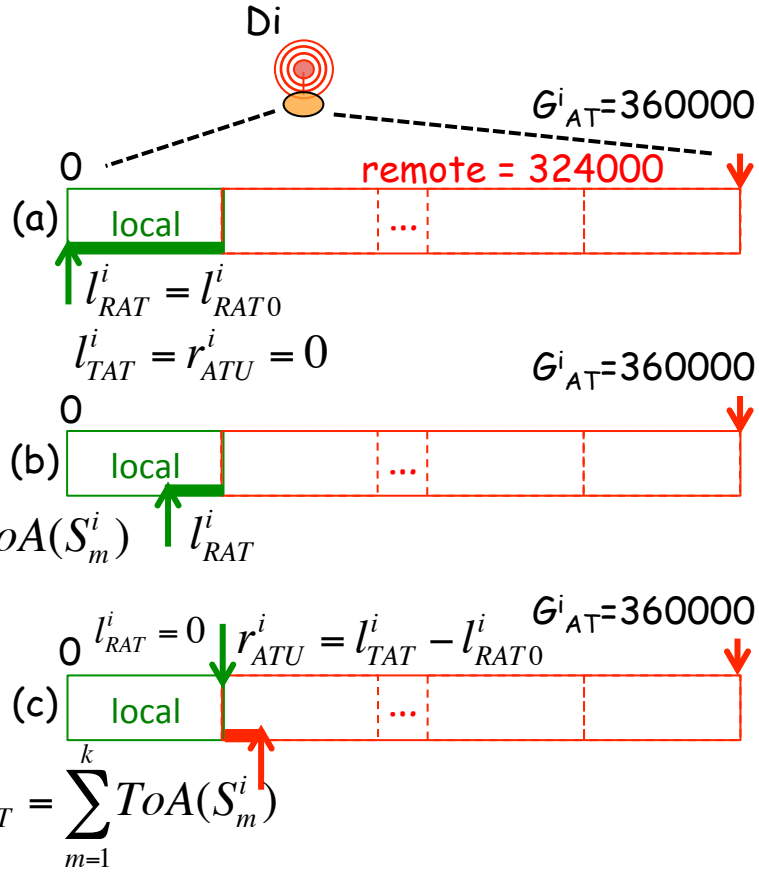
Our proposition is to view all device' activity time in a global manner, with the gateway taking care of radio time usage consistency

Long-range Activity Sharing (LAS)

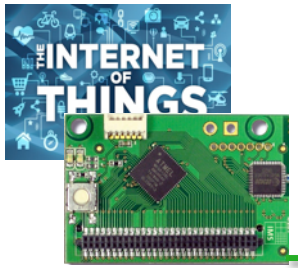


device	RAT	lastRAT
Di	l^i_{RAT0} = 36000	36000

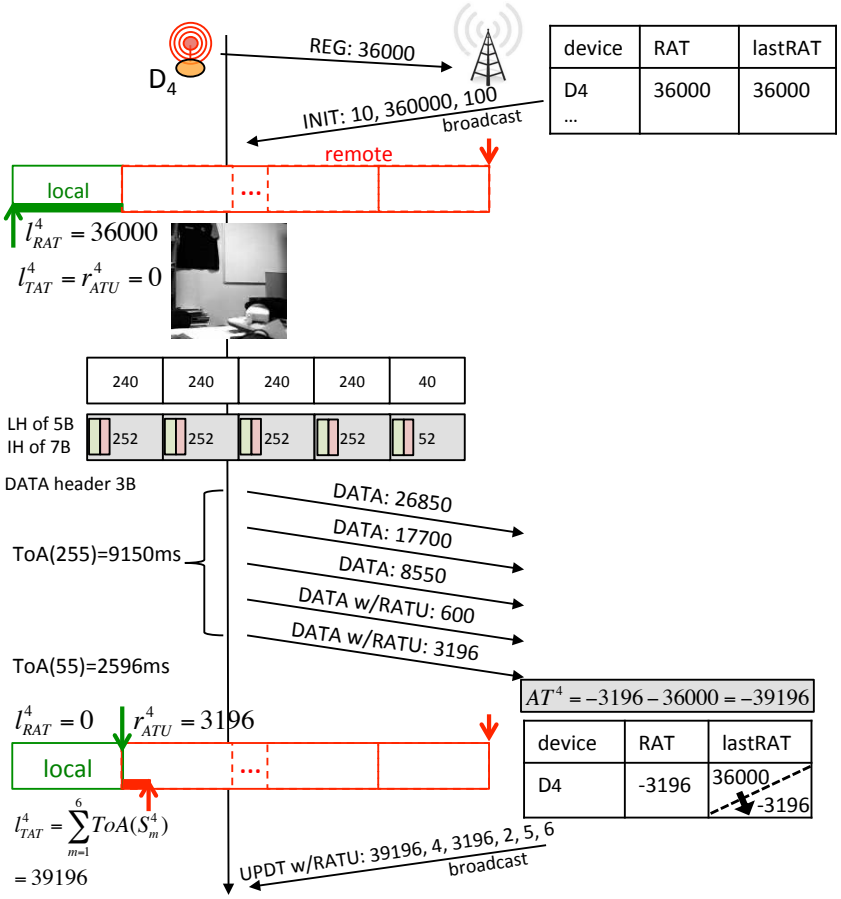
$$G_{AT} = \sum_{i=1}^{n} l^i_{RAT0}$$

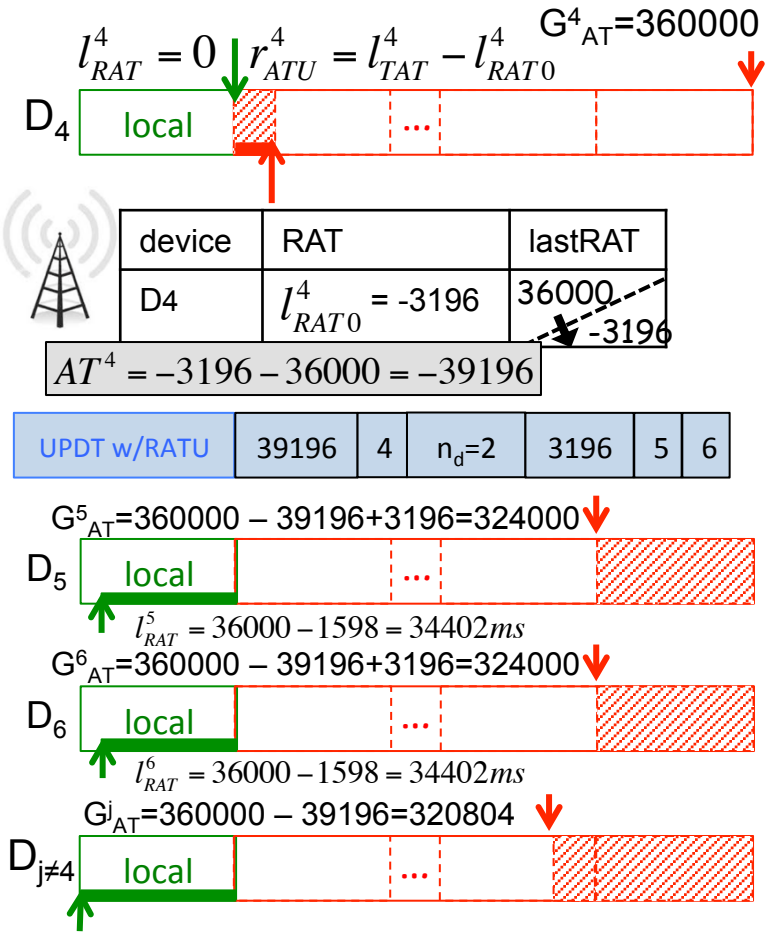


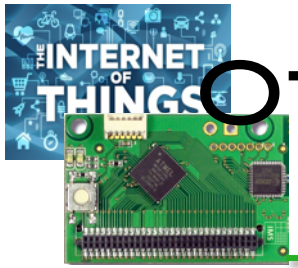
A device can transmit more if needed, provided that other devices will decrease their radio activity time accordingly.



Distributing Remote Activity Time Usage



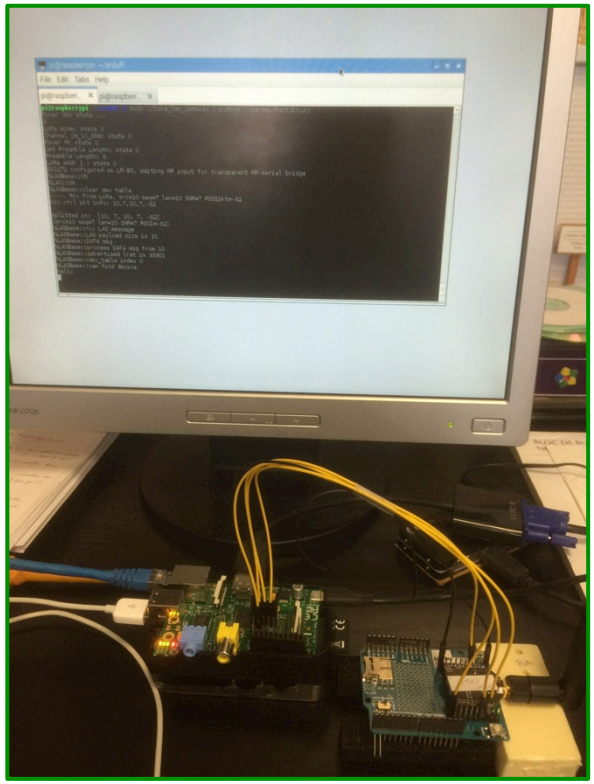




OTHER ISSUES TO TAKE INTO ACCOUNT

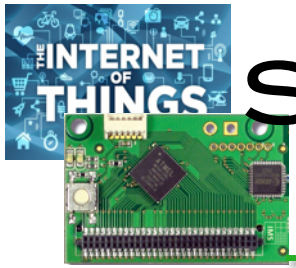
- Minimise the number of UPDT messages sent by the gateway because the gateway's radio time is also limited
  - UPDT can have cumulative behavior if no remote activity time has been used
- Support sleep periods of end-devices
  - The network is synchronized for control messages (REG, INIT, UPDT). UPDT msg that can not use cumulative behavior are queued for transmission at next transmission slot. At rcv, UPDT have to be applied sequentially.
- Maintain (loose) synchronization
  - If no UDPT are scheduled, the gateway periodically sends a BEACON. Clock drift is limited to a BEACON period
- Dynamic insertion of new end-devices
  - New devices can either stay out of the managed pool (then only 36s of activity time/h is allowed), or join by waiting for the next UPDT/BEACON msg
  - Every hour, end-devices decide if they want to join the pool or not
- Give priority to control msg
  - SIFS/DIFS mechanism are implemented using LoRa Channel Activity Detection
- Avoid interleaving of several image transmissions
  - Use DIFS for first image packet, then SIFS
- Improve LoRa network efficiency
  - Move from pure ALOHA to CSMA mechanism with CAD+RSSI tests prior to any transmission

IMPLEMENTATION AVAILABLE

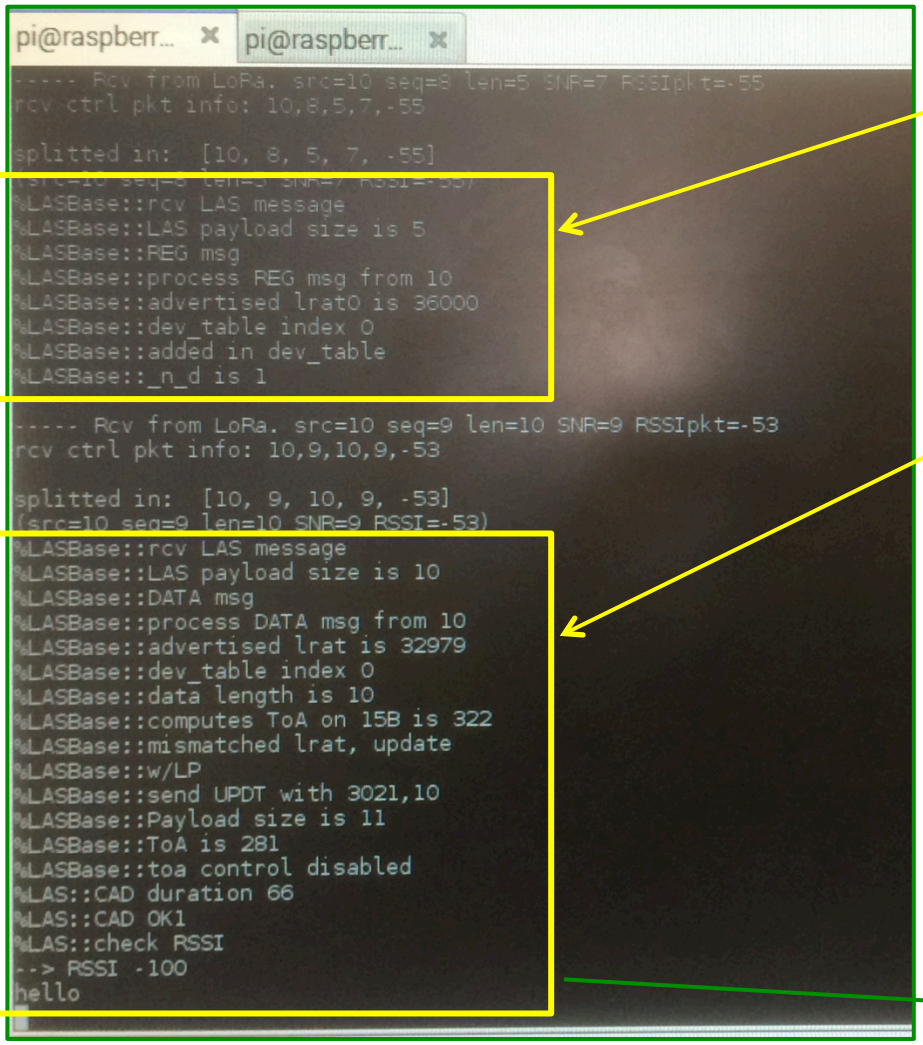


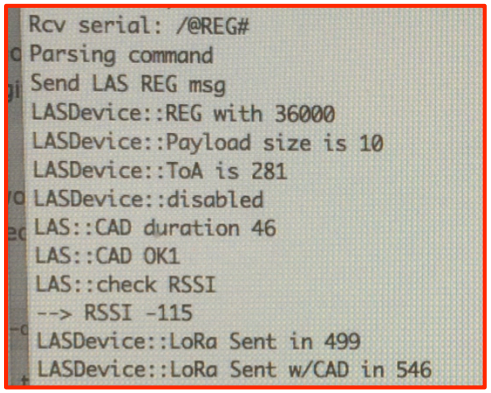
```
pi@raspberr...  pi@raspberr...
pi@raspberrypi
Power ON: state ...
0
LoRa mode: state 0
Channel CH_10_868: state 0
Power M: state 0
Get Preamble Length: state 0
Preamble Length: 8
LoRa addr 1 : state 0
SX1272 configured as LR-BS. Waiting RF input for transparent RF-serial bridge
%LASBase::ON
%LAS::ON
%LASBase::clear dev table
----- Rcv from LoRa. src=10 seq=7 len=10 SNR=7 RSSIpkt=-62
rcv ctrl pkt info: 10,7,10,7,-62

splitted in:  [10, 7, 10, 7, -62]
(src=10 seq=7 len=10 SNR=7 RSSI=-62)
%LASBase::rcv LAS message
%LASBase::LAS payload size is 10
%LASBase::DATA msg
%LASBase::process DATA msg from 10
%LASBase::advertised lrat is 33301
%LASBase::dev_table index 0
%LASBase::can find device
hello
```

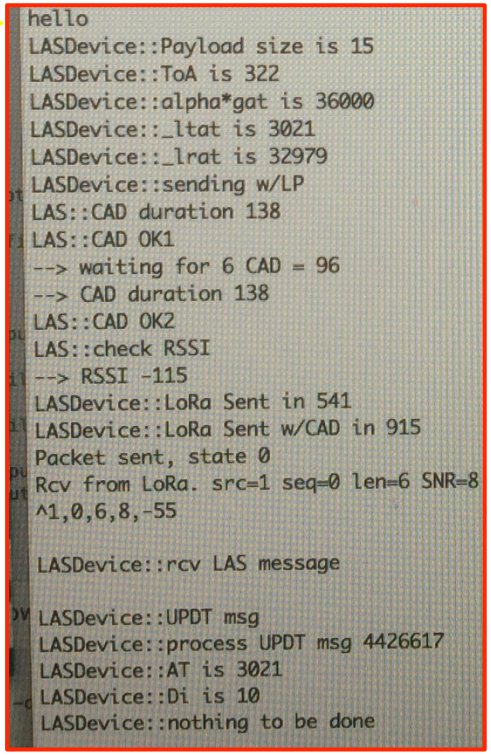
```
Rcv serial: hello
Sending. Length is 5
hello
LASDevice::Payload size is 15
LASDevice::ToA is 322
LASDevice::alpha*gat is 36000
LASDevice::_ltat is 2699
LASDevice::_lrat is 33301
LASDevice::sending w/LP
LAS::CAD duration 138
LAS::CAD OK1
--> waiting for 6 CAD = 96
--> CAD duration 138
LAS::CAD OK2
LAS::check RSSI
--> RSSI -114
LASDevice::LoRa Sent in 541
LASDevice::LoRa Sent w/CAD in 916
Packet sent, state 0
```

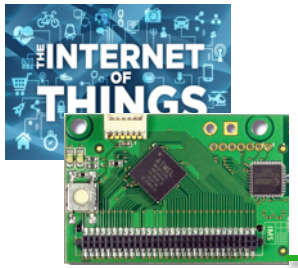


Sending message under LAS services









Conclusions

- Low-power, long-range (LR) transmission is a break-through technology for IoT and large-scale deployment of wireless (sensor) devices
- With a large variety of applications, products & actors the low-power WAN (LPWAN) eco-system is becoming mature
- New technologies will certainly emerge but the LPWAN « philosophy » is now settled firmly: out-of-the-box connectivity is now the standard and multi-hop scenarios based on short-range technologies is questionable.