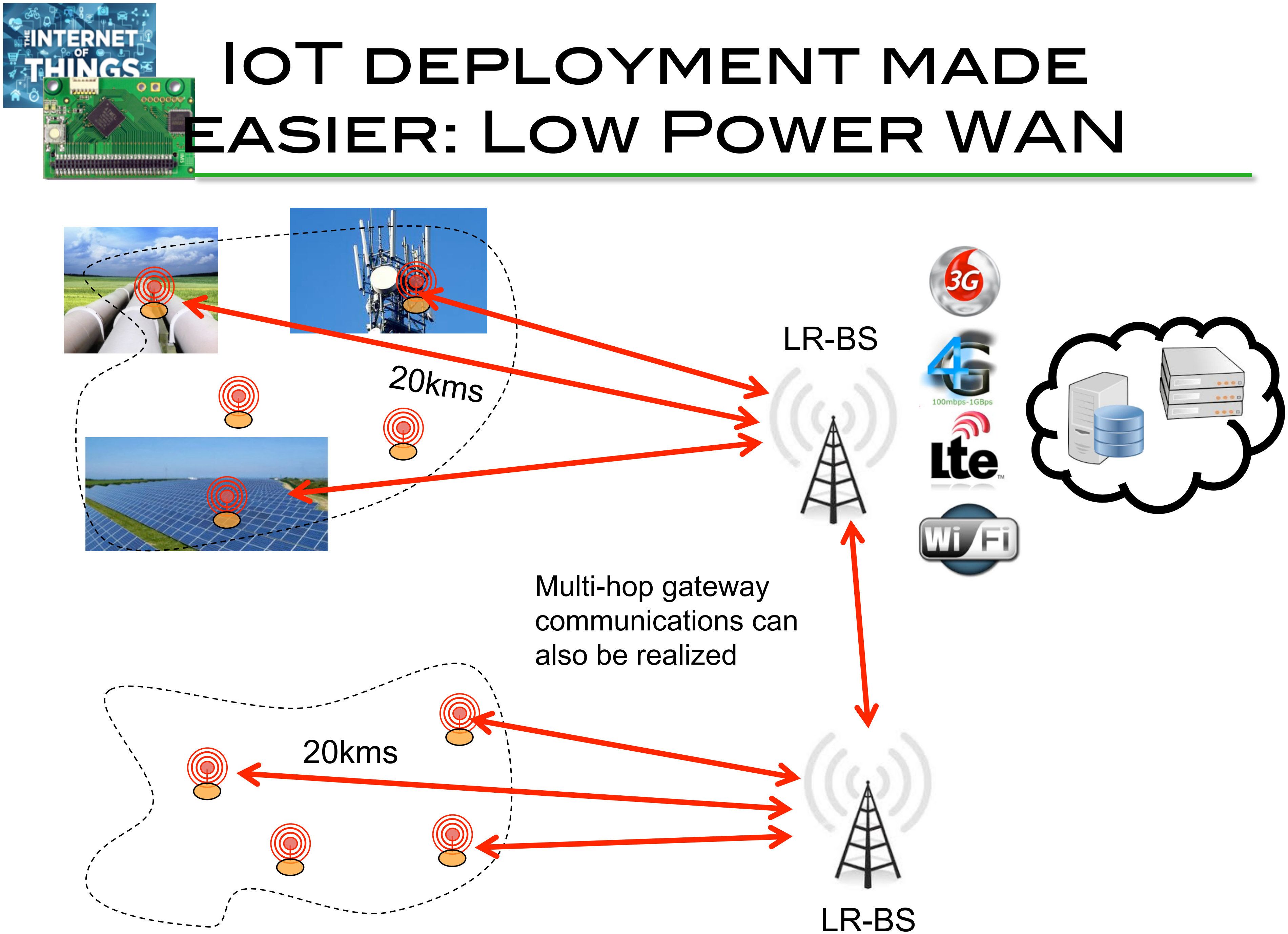
Long-Range technology overview

last update: 22nd december, 2015

Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France

IoT deployment made easier: Low Power WAN



Typical scenarios

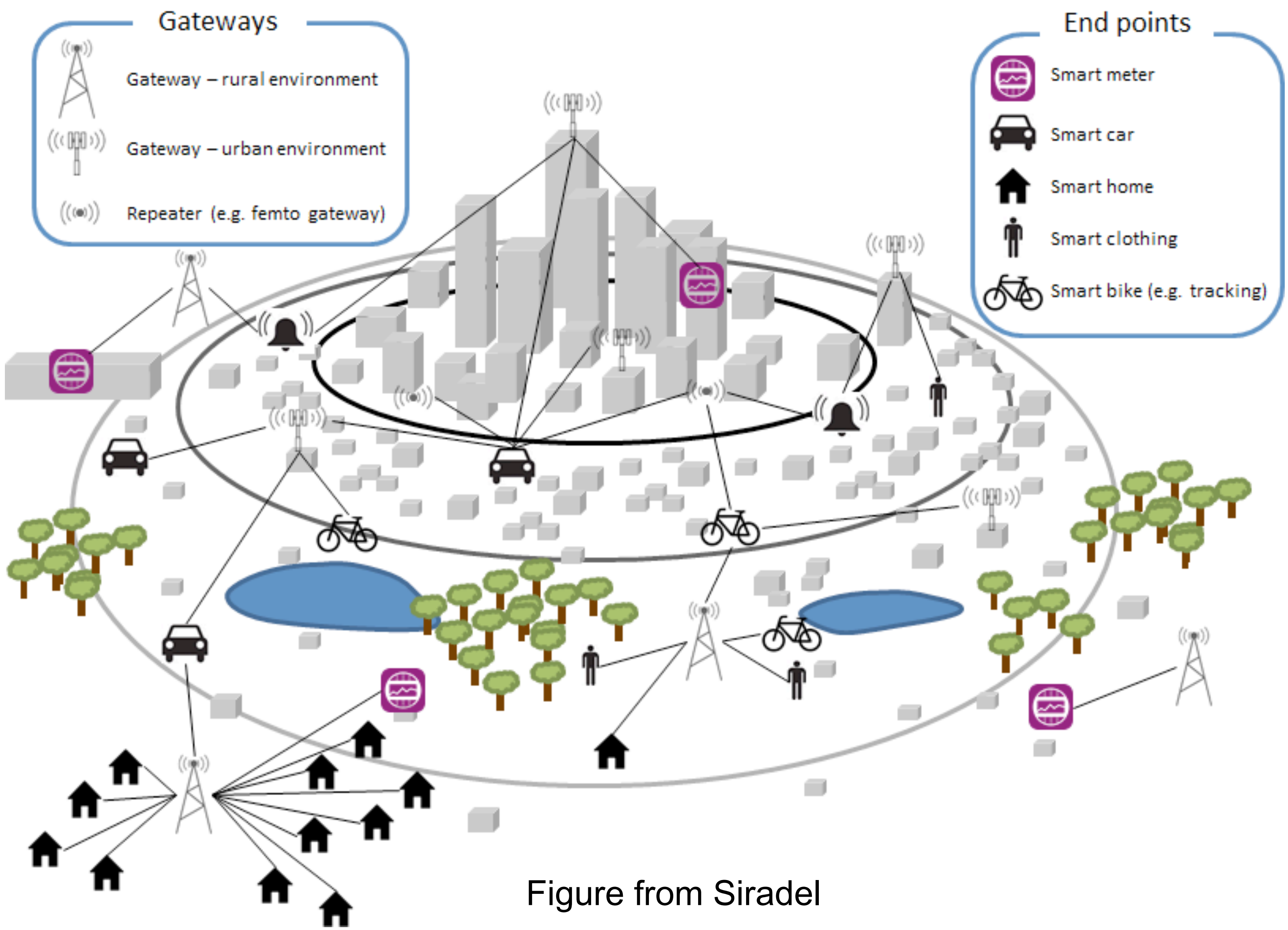
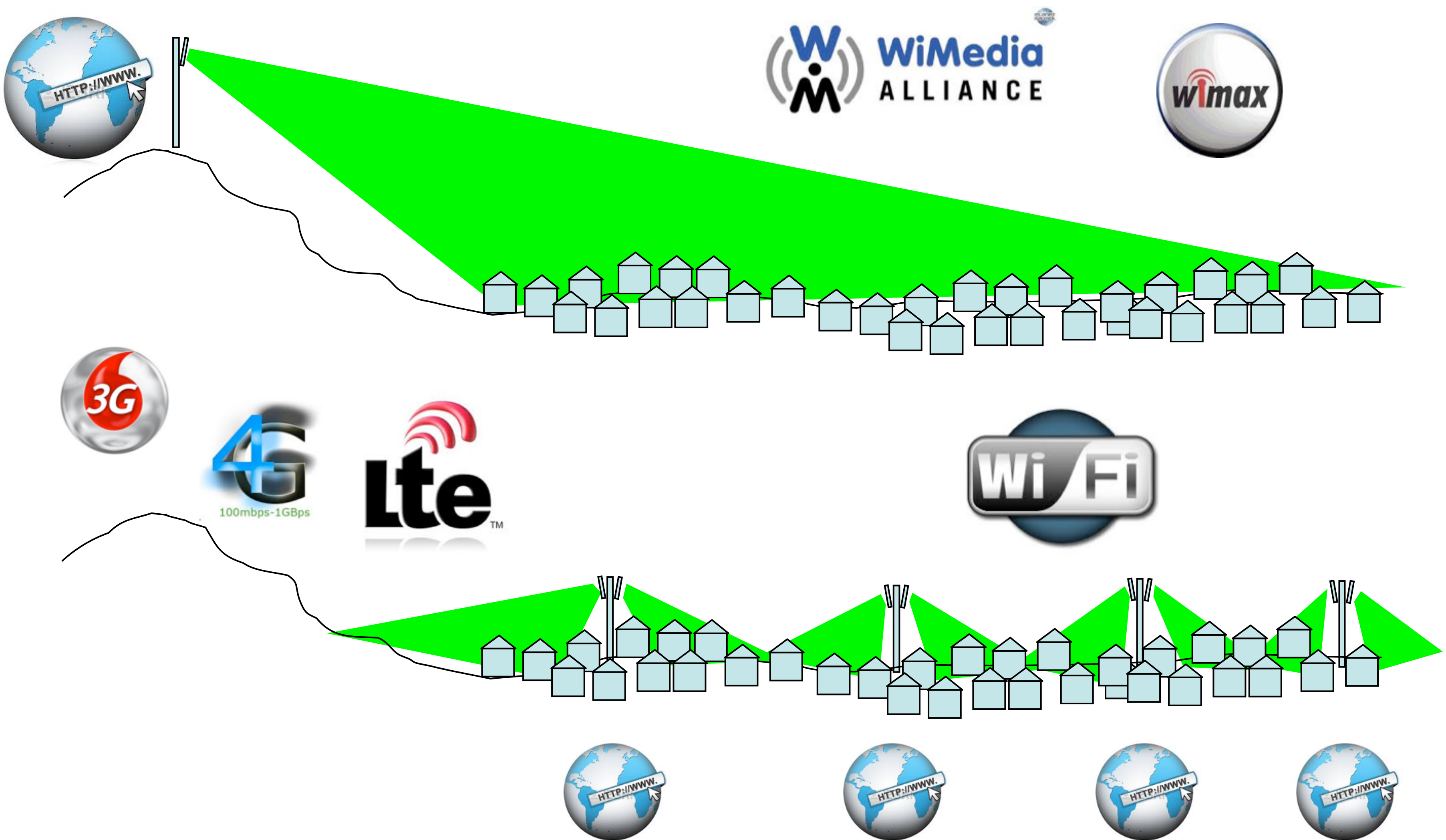
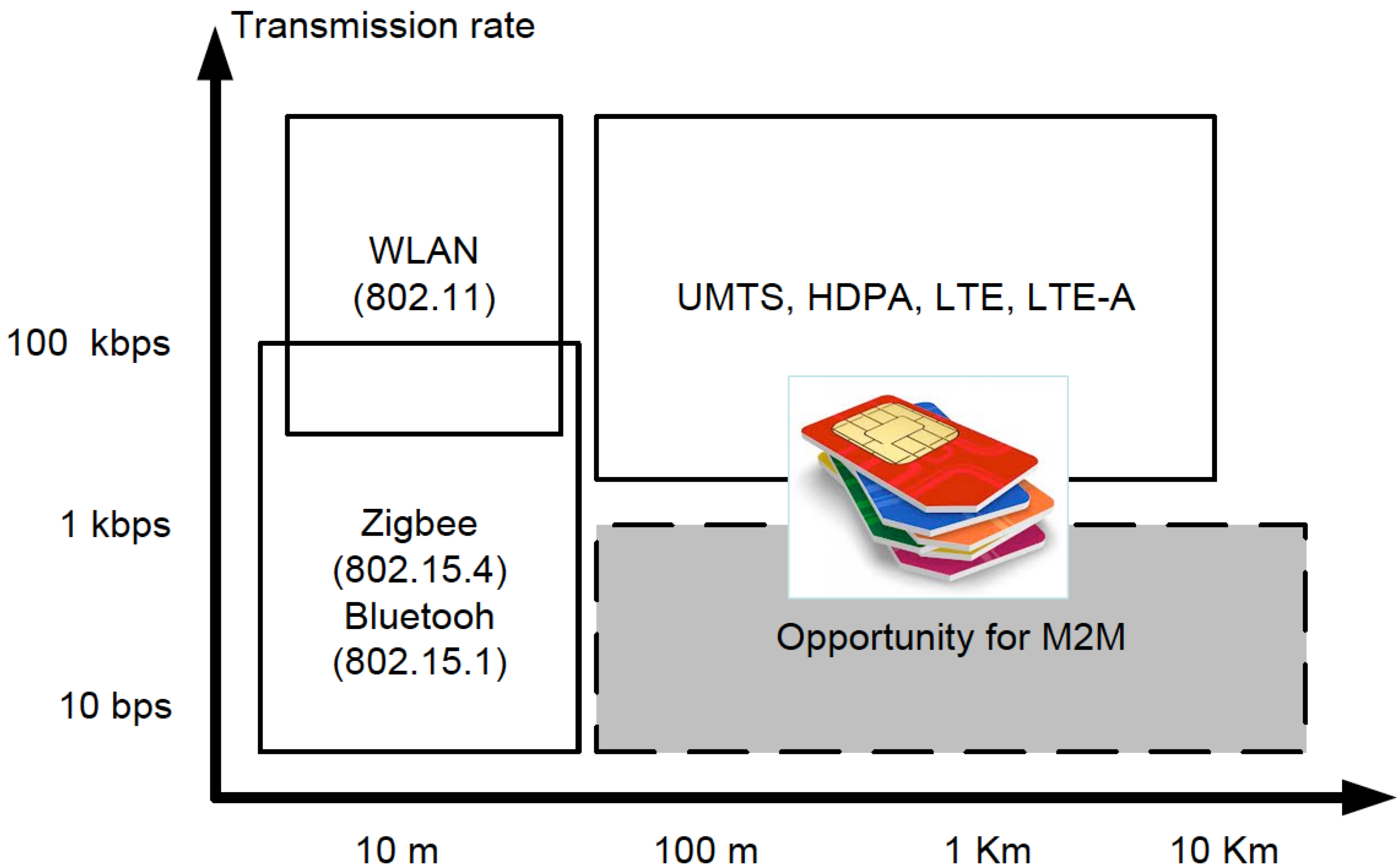


Figure from Siradel

Basically a Cellular model

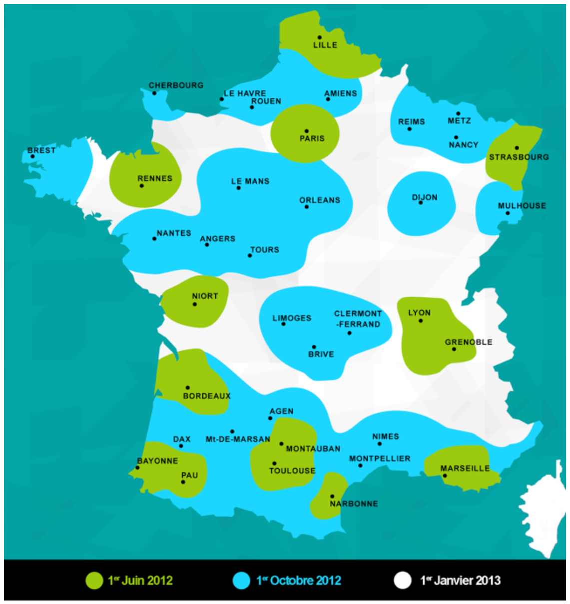


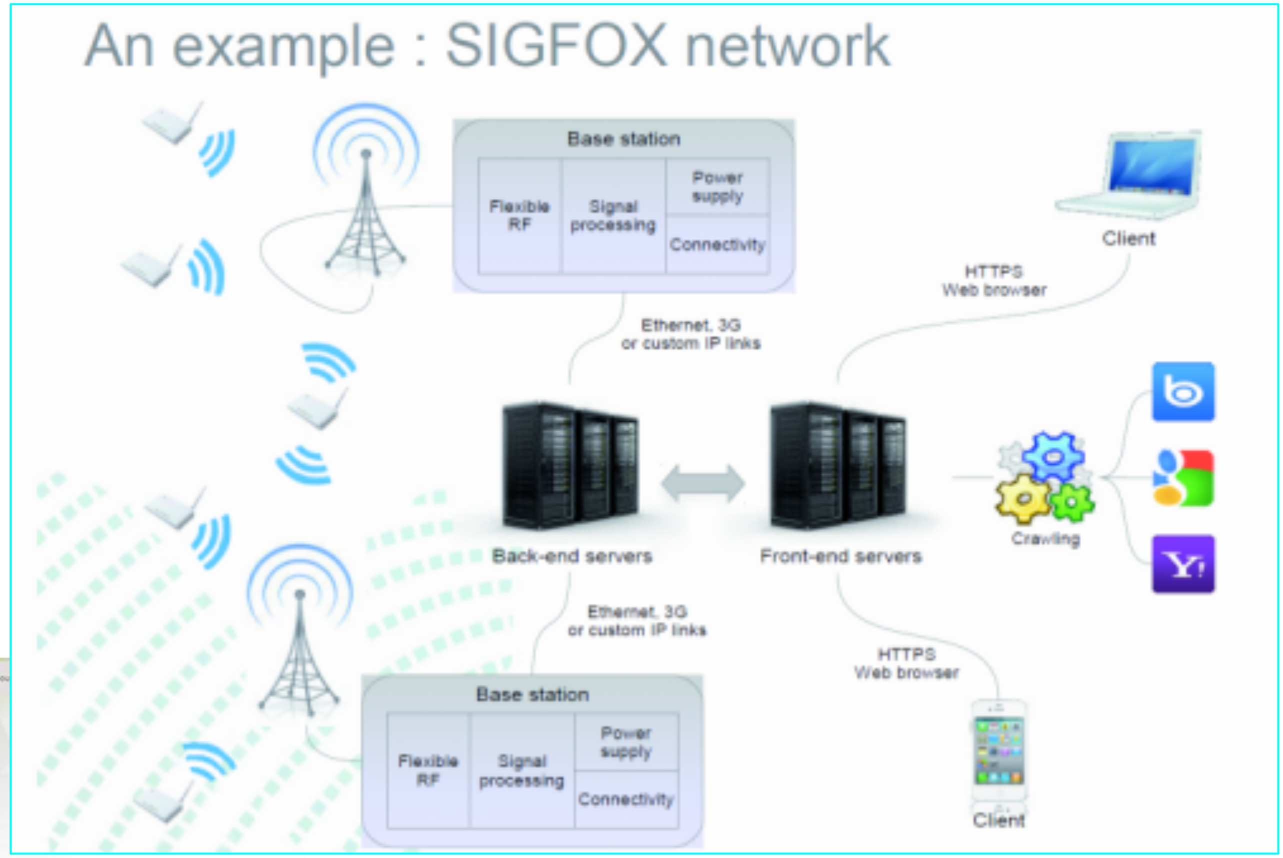
Opportunities for Telco operators & more...



Enhanced from M. Dohler "M2M in SmartCities"

Sigfox model for M2M: the operator approach



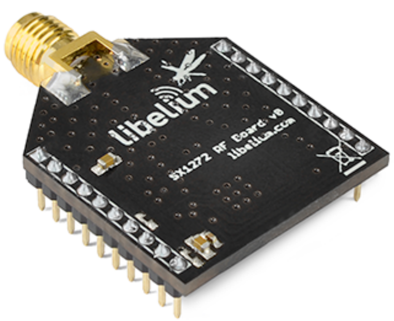


Figures from SigFox

Private long range communications

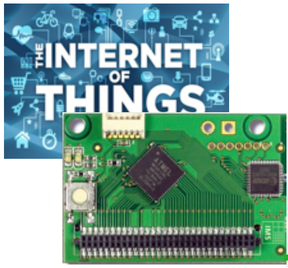
License-free sub-GHz band

Several kilometers (20-80kms)
can be achieved in a single hop!

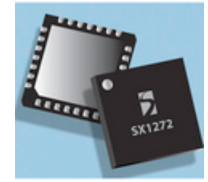


Libelium LoRa is based on Semtech SX1272 LoRa 863-870 MHz for Europe Data rate from 200bps to 20kbps

DORJI DRF1278DM is based on Semtech SX1278 LoRa 433MHz



Semtech's LoRa technology



dBm – **power referred to 1 mW,**

$P_{dBm}=10\log(P/1mW)$

- Parameters
  - Bandwidth: 125kHz, 250kHz, 500kHz
  - Coding rate: 4/5, 4/6, 4/7, 4/8
  - 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	$\boxed{-137}$
250	6	18750	-119
250	12	586	-134
500	6	3750	-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

LoRa vs Sigfox

Sigfox uses ultra-narrow band (UNB) of about 100Hz!

Figure show Semtech LoRa band of 125kHz

Sigfox's band is 1000 time smaller! Can create less interference, « hide » in noise at the cost of much lower data rate, i.e 100bps

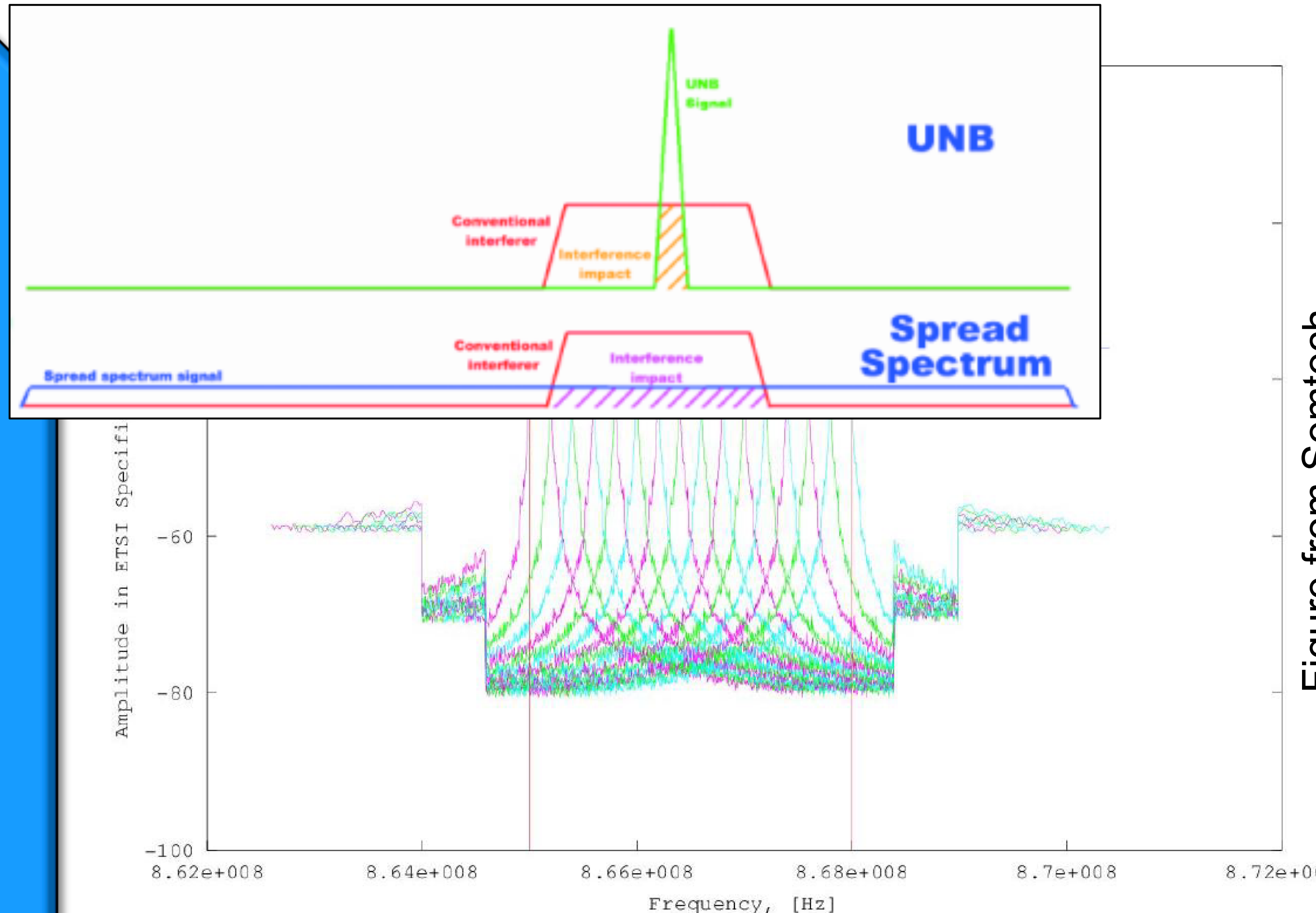


Figure 3. Band G (Note 7) 6 dBm RF Output Power 125 kHz Bandwidth

Figure from Semtech

Simple loss in signal strength model

- Free Space Path Loss model

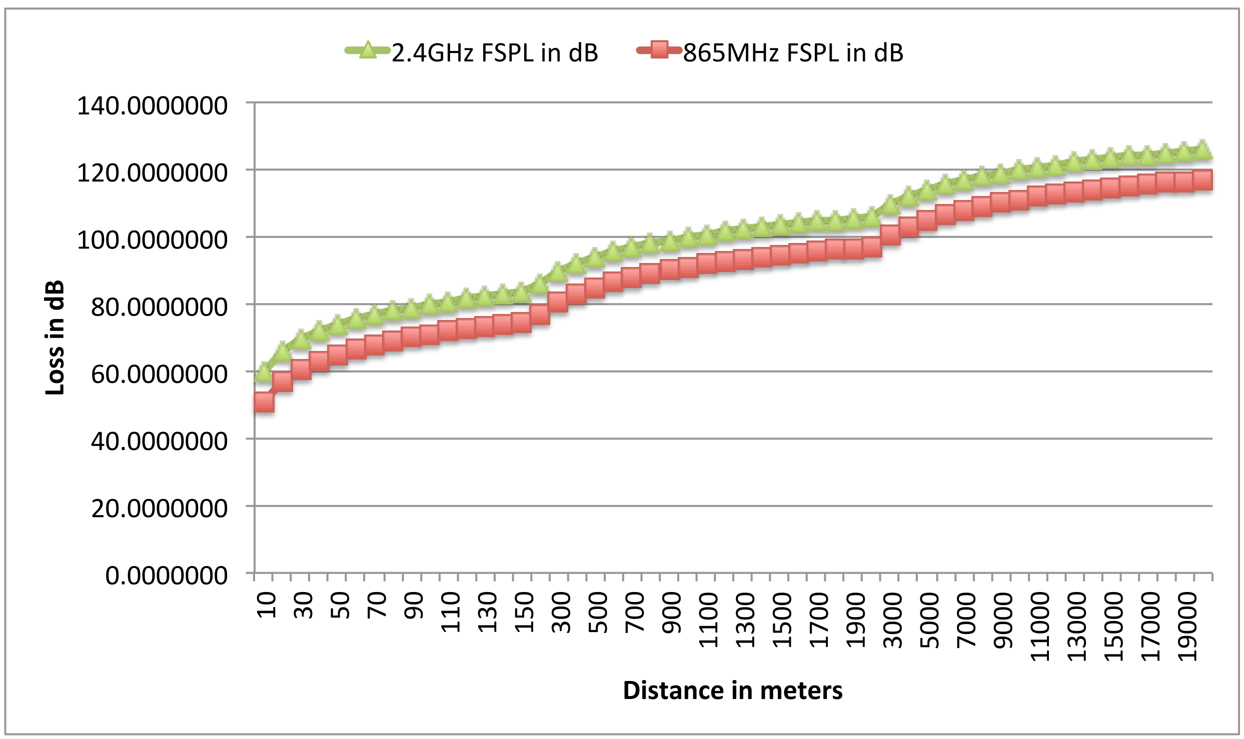
$$\mathrm{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2$$

$$FSPL = \frac{P_t}{P_r} G_t G_r$$

FSPL assume Gt=Gr=1

$$L_{(dB)} = 10\log\left(\frac{P_t}{P_r}\right) = 20\log\left(\frac{4\pi d}{\lambda}\right) = 20\log\left(\frac{4\pi fd}{c}\right)$$

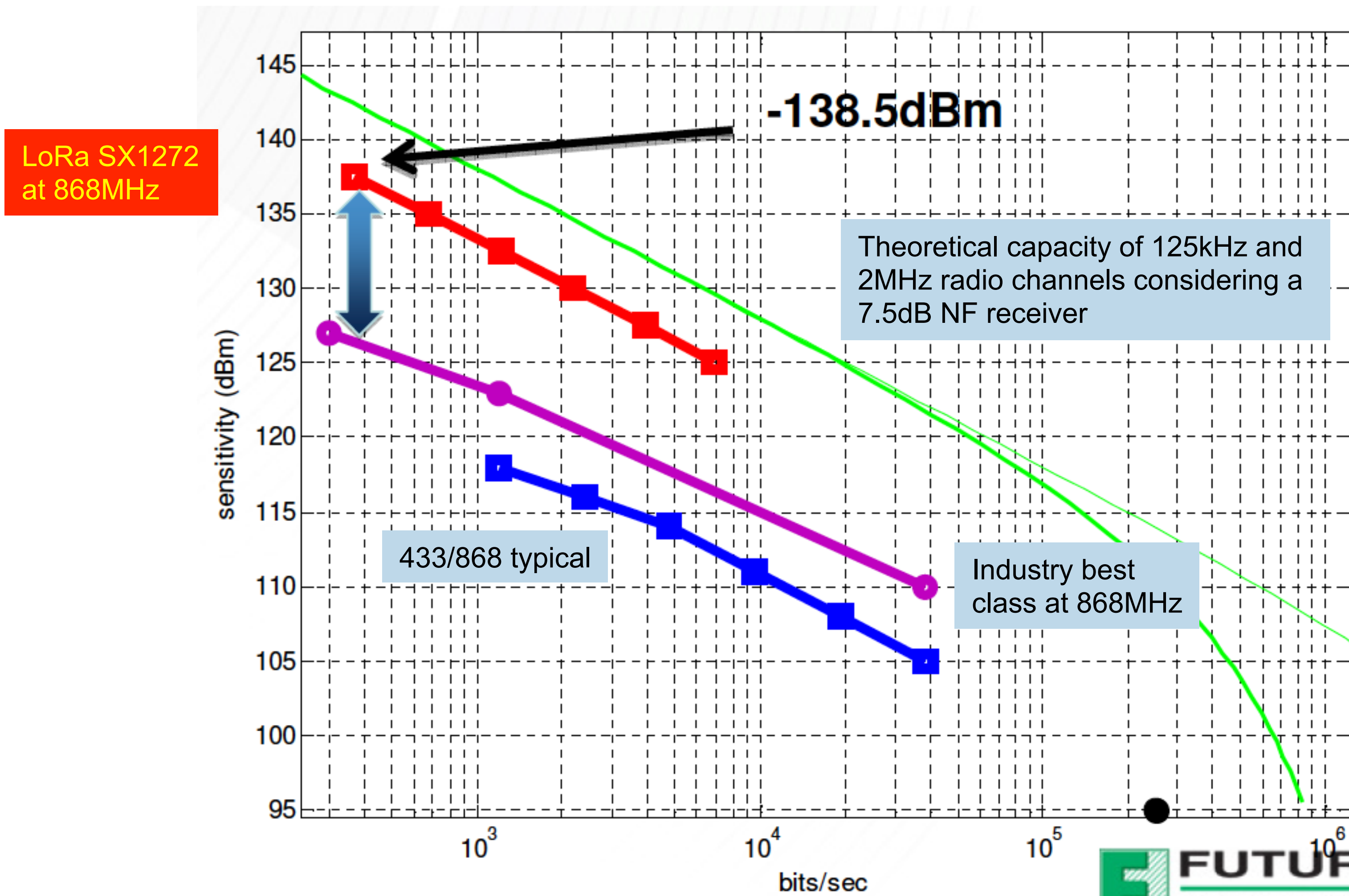
$$L_{(dB)} = 20\log(f) + 20\log(d) - 147{,}55\ dB$$



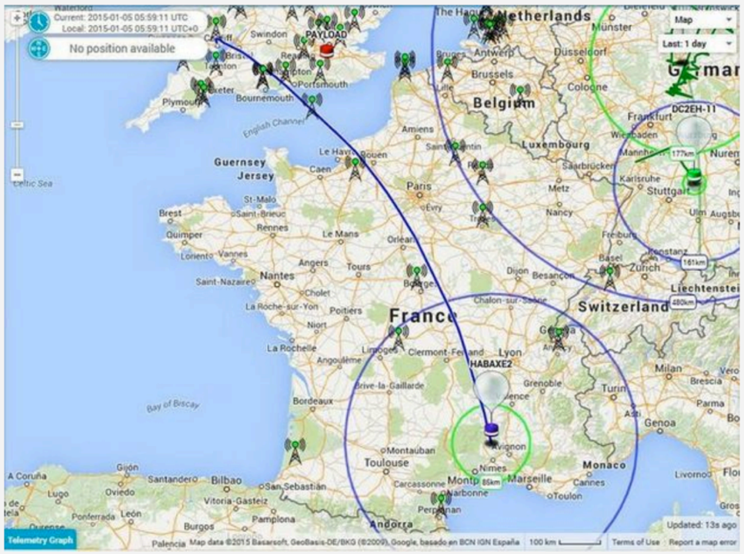
Link budget broad concepts

- Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) – Losses (dB)
- Example
  - Transmitted power is +14dBm (25mw)
  - Losses (FSPL) is 120dB (received power is 10^{12} less than transmitted power)
  - Then Receiver Power (dBm) is -106dBm
- If you have a receiver sensitivity of -137dBm you can handle FSPL up to 151dB, i.e. 1.15×10^{15} less power than transmitted power!
- You can be well under the noise floor
- In a conventional WLAN system, signal-to-noise ratio (SNR) is 20 dB or greater in order to achieve the maximum data rate

WHY THE LORA REVOLUTION?



Extreme long-range!

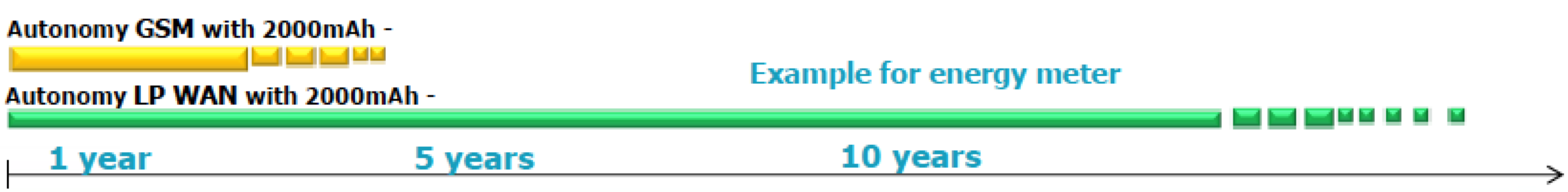


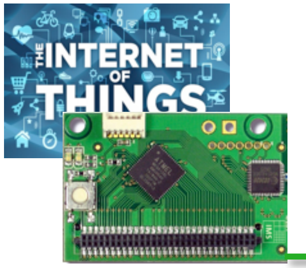
UK HAB (High Altitude Ballooning) trials gave 2 way LoRa™ coverage at up to 240 km. Lowering the data rate from 1000bps to 100bps should allow coverage all the way to the radio horizon, which is perhaps 600 km at the typical 6000-8000m soaring altitude of these balloons. Balloon tracking can be made

Power consumption rough comparison

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	200mA-500mA	500mA – 1000mA	50mA	35mA	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 $





FROM SCOOP.IT

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

From www.businesswire.com - November 4, 3:25 PM

" SIGFOX and Glen Canyon, a provider of low-cost smart meters ... ric

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

From intelilight.eu - July 10, 7:40 AM

" Brasov, ROM... 2015

Tata Communication... world's largest IoT n... India

devic...

The c... of Lo... conne... Beng...

Cofely Services, a subsidiary of ENGIE (SUEZ group), integrates SIGFOX solution to expand services it provides for buildings

From m2mworldnews.com - May 28, 2:26 PM

" Cofely Services opens a new era in driving energy efficiency of buildings and smart metering by connecting its service offering to the SIGFOX energy-efficient, cost-effective network. Through this new partnership with the provider of the world's premier...

...ourg Is 8th Cou... ...ide Internet of ... from SIGFOX

From m2mworldne...

" POST Luxemb... Digital ID and N... Dedicated IoT I... Continuing the... wireless Intern... SIGFOX and tw... RMS.lu, today announced the deplo... Luxembourg. POST Luxembourg is...

Samsung Invests in Sigfox. Is the Race Over for Long-Range Low-Power Wireless Competitors?

From blog.vdcresearch.com - June 16, 7:56 AM

" A preliminary market battle has been brewing over the past year between technologies to connect IoT devices via wireless wide area networks. These cellular-type networks allow very low power battery devices to transmit small amounts of data over several miles, a solution...

A... IoT city network

METERING & SMART ENERGY INTERNATIONAL

From www.meterin...

determine the "best" wireless network...

Bouygues picks Semtech's Lo... for French M2M network - Ret... Wireless

Satellite Phones: Will Dual Mode Help the Phoenix Rise from the Ashes?

From www.... April 3, 11:2...

" French ... Telecom ... LoRa radio technology for its own domestic IoT and M2M network."

Smart City waste logistics provider Enevo joins LoRa™ Alliance at Mobile World Congress in Barcelona - Enevo

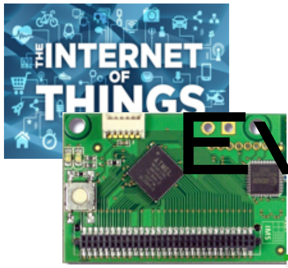
From www.enevo.com - March 6, 4:12 PM

T-Mobile to cover the Czech Republic with the SIGFOX network for the Internet of Things

From www.theinternetofthin... 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.

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.



EVERYBODY WANTS TO BE IN!

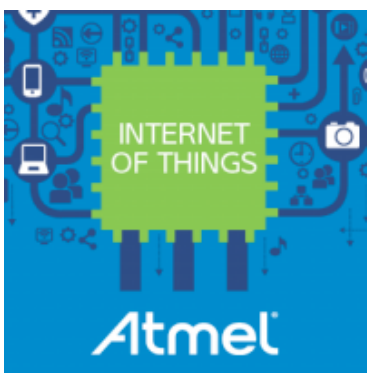
SIGFOX

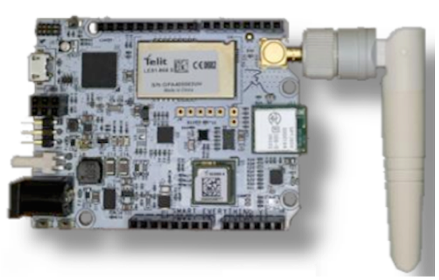
SIGFOX OPERATOR

TST

TEXAS INSTRUMENTS

libelium





LoRa

SEMTECH

MULTITECH

LoRa Alliance
Wide Area Networks for IoT

IBM

Froggy FACTORY

actility
Making Things Smart

Wi6LABS

ThingPark Wireless

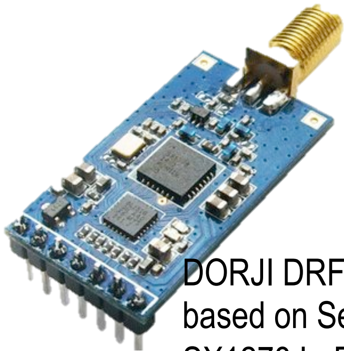
Bouygues Telecom

IMST

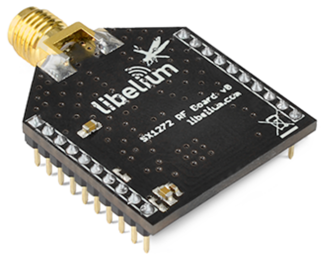
kerlink
m2m technologies

LinkLabs

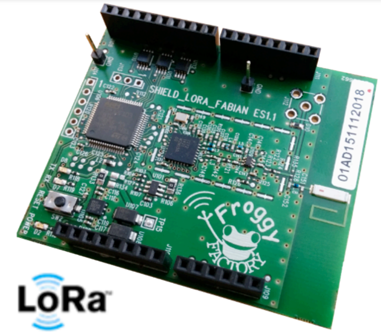
LoRa radios (mostly based on SX1272/76 chip)



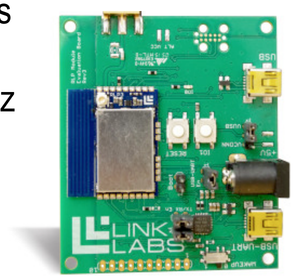
DORJI DRF1278DM is based on Semtech SX1278 LoRa 433MHz



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

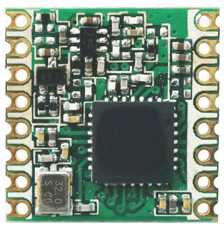


Froggy Factory LoRa module (Arduino)

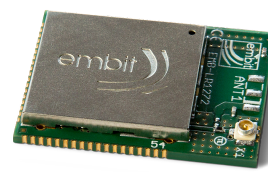


LinkLabs Symphony module

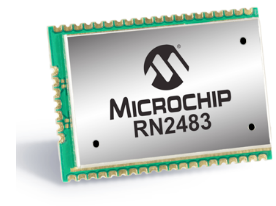
IMST IM880A-L is based on Semtech SX1272 LoRa 863-870 MHz for Europe



HopeRF RFM series



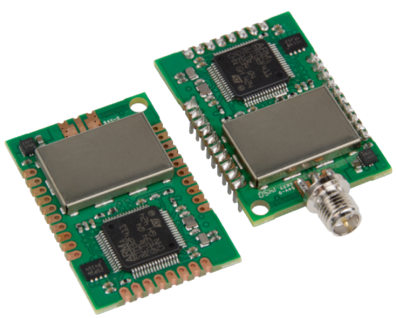
Embit LoRa



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

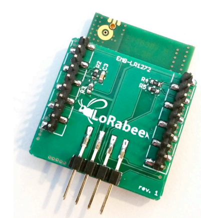
Microship RN2483

habSupplies



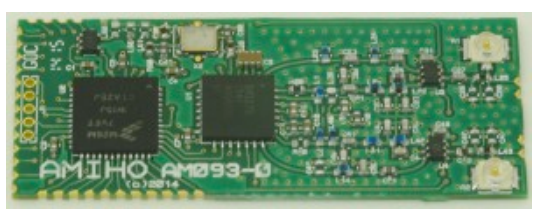
Multi-Tech MultiConnect mDot

Adeunis ARF8030AA- Lo868



SODAQ LoRaBee Embit

SODAQ LoRaBee RN2483



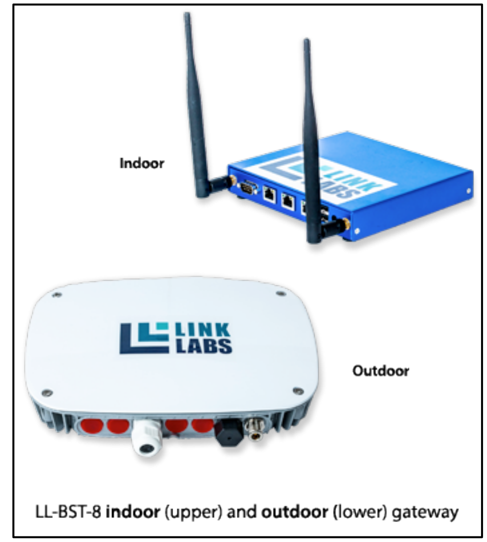
AMIHO AM093

LoRa Gateways
(non exhaustive list)

Multi-Tech Conduit

Embedded Planet
EP-M2M-LORA

Ideetron Lorank 8



LinkLabs Symphony

PicoWAN from Archos

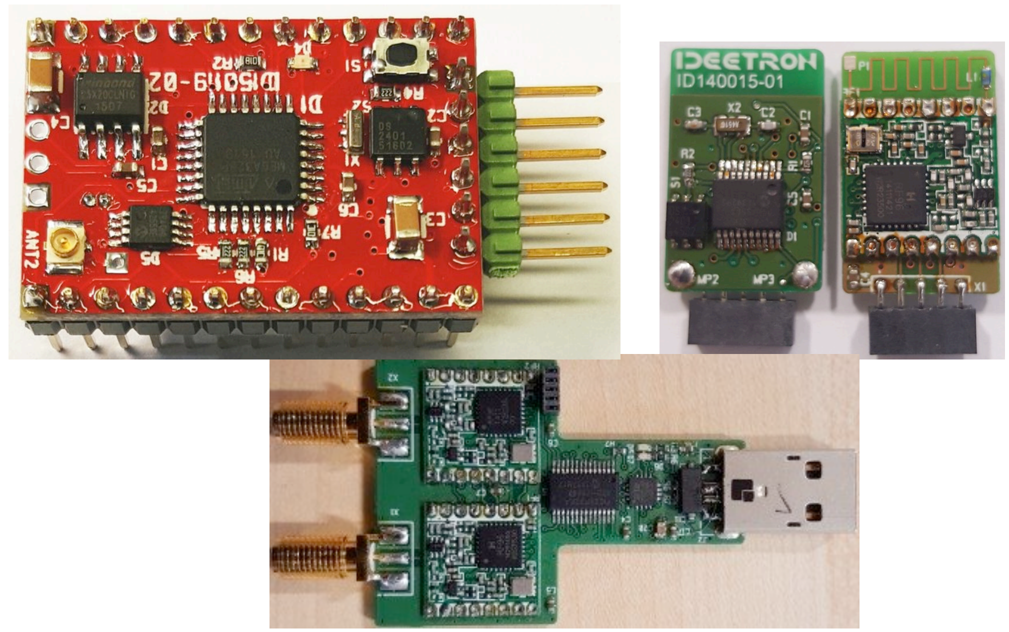
TheThingNetwork

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

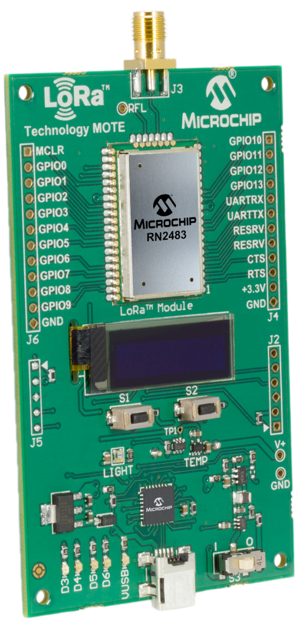
Kerlink IoT Station

Ready-to-use LoRa devices

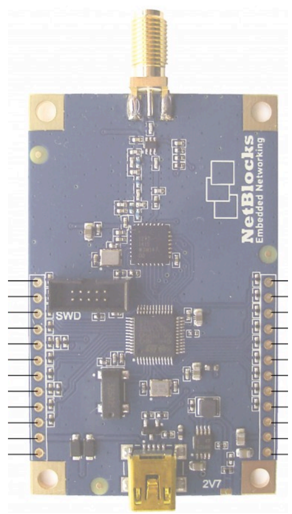
LoRa Mote from Semtech



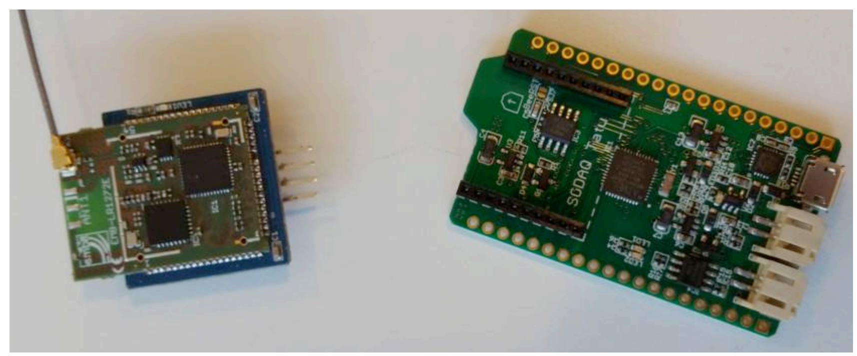
HopeRF/Ideetron motes



Microchip LoRa mote



NetBlocks
XRange



SODAQ Tatu with LoraBee (Embit)

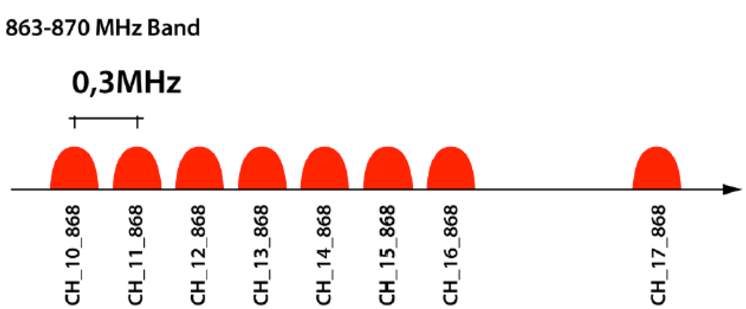
Some other long-range technologies

	LoRa	NWave	OnRamp	Platanus	SIGFOX	Telensa	Weightless -N	Weightless -P	Amber Wireless	M2M Spectrum
Range (km) (Caveat)	15-45 flat; 15-22 suburban; 3-8 urban	10	4 (but claims 25x competition)	Several hundred meters	50 rural; 10 urban	Up to 8	5+	2+ urban	Up to 20	
Band (MHz)	Spread; varies by region	Sub-GHz	2.4 GHz	Sub-GHz	868; 902	868/915 470 (China)	Sub-GHz	Sub-GHz	434, 868, 2.4 GHz	800/900
ISM?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Symmetric up/down?	No	No	No (4:1)	No	No	Yes	Uplink only	Not yet determined		
Data rate (Caveat)	0.3-50 kbps (adaptive)	100	8 bps – 8 kbps	500 kbps	100	Low	30 kbps-100 kbps	Up to 200 kbps (adaptive)	Up to 500 kbps**	
Max nodes	Depends; 200K-300K/hub	Million/ base	"10s of 1000s"	50,000	Millions/ hub	150,000/ Server (moving to 500,000)	No real claim (due to "it depends")	No real claim (due to "it depends")	255 networks of 255 nodes	
OTA upgrades?	Yes	Yes	Yes	Yes	Doubtful	Yes	No	Yes		
Handoff?	No; no node/hub association	No; it's being considered	Yes	Yes	Doubtful	Yes	Yes	Yes		
Operational model	Public or private (expect 80% public)	Public or private	Public or private	Public or private	Public	Public	Public or private	Public or private		Public
Standard status (if any)	No	Weightless-N	IEEE; in process	Weightless-P	No	No (perhaps in future)	Yes	In process; spec later this yr		

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% to 1% duty-cycle depending on frequency: 3.6s to 36s/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



Channel Number	Central Frequency
CH_10_868	865.20 MHz
CH_11_868	865.50 MHz
CH_12_868	865.80 MHz
CH_13_868	866.10 MHz
CH_14_868	866.40 MHz
CH_15_868	866.70 MHz
CH_16_868	867 MHz
CH_17_868	868 MHz

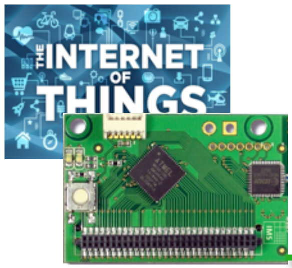
LBT+AFA

- Listen Before Talk and Adaptive Frequency Agility can remove the duty-cycle constraints…

- … but still

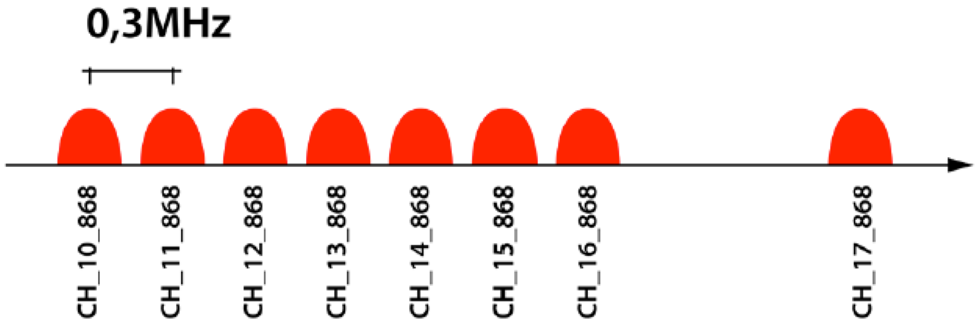
  - 100s / hour on every 200kHz BW
  - no more than 1s for a single transmission

- … so may not be that interesting in some cases!



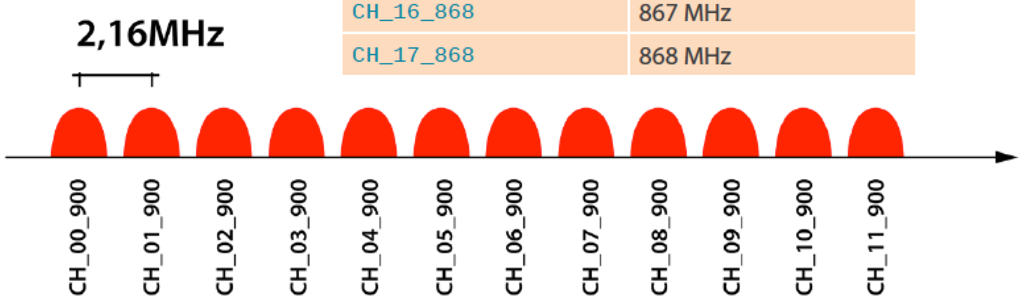
Libelium LoRa

863-870 MHz Band



Channel Number	Central Frequency
CH_10_868	865.20 MHz
CH_11_868	865.50 MHz
CH_12_868	865.80 MHz
CH_13_868	866.10 MHz
CH_14_868	866.40 MHz
CH_15_868	866.70 MHz
CH_16_868	867 MHz
CH_17_868	868 MHz

902-928 MHz Band



Mode	BW	CR	SF	Sensitivity (dB)
1	125	4/5	12	-134
2	250	4/5	12	-131
3	125	4/5	10	-129
4	500	4/5	12	-128
5	250	4/5	10	-126
6	500	4/5	11	-125,5
7	250	4/5	9	-123
8	500	4/5	9	-120
9	500	4/5	8	-117
10	500	4/5	7	-114

Figures and table from Libelium

Tests from Libelium

Pictures from Libelium

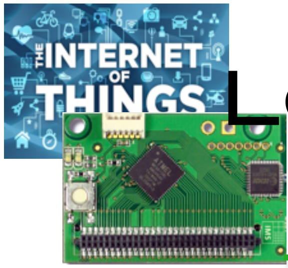
HTTP://WWW.LIBELIUM.COM

Time on air for various Libelium LoRa mode

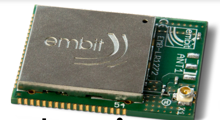
				time on air in second for payload size of					
LoRa mode	BW	CR	SF	5 bytes	55 bytes	105 bytes	155 Bytes	205 Bytes	255 Bytes
1	125	4/5	12	0.95846	2.59686	4.23526	5.87366	7.51206	9.15046
2	250	4/5	12	0.47923	1.21651	1.87187	2.52723	3.26451	3.91987
3	125	4/5	10	0.28058	0.69018	1.09978	1.50938	1.91898	2.32858
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

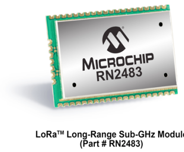
Range

Throughput



LoRaWAN R1.0 Specification: The Need for Standard





LoRa Alliance
Wide Area Networks for IoT

- Class A - bi-directional end-devices

  LoRaWAN class A endpoint devices provide bidirectional communications. To achieve this, each endpoint transmission is followed by two short downlink receive windows. The transmission slot scheduled by the particular endpoint is based upon the needs of the end point and also there is a small variation determined using a random time basis.

  LoRa Class A operation provides the lowest power option for end points that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time wait until the next scheduled uplink time.

- Class B - bi-directional end-devices with scheduled receive slots:

  LoRa Class B devices provide the Class A functionality and in addition to this they open extra receive windows at scheduled times. To achieve the required synchronisation from the network, the endpoint receives a time synchronized Beacon from the gateway. This allows the server to know when the end-device is listening.

- Class C - bi-directional end-devices with maximal receive slots:

  LoRa Class C devices provide nearly continuously open receive windows. They only closed when the endpoint is transmitting. This type of endpoint is suitable where large amounts of data are needed to be received rather than transmitted.

LoRaWAN MAC protocols

- LoRaMAC protocol developped initially by Semtech. Considers only Class A devices. Open source (github).
- LoRaWAN in C (LMIC) developped later by IBM. Additionally takes into account Class B devices. Open source (IBM Zurich).
- Provide basic MAC operation to create, join and manage a LoRA network
- Mostly use 1% duty-cycle approach

LoRaWAN channels

- EU 863-870MHz ISM Band

DataRate	Configuration	Indicative physical bit rate [bit/s]
0	LoRa: SF12 / 125 kHz	250
1	LoRa: SF11 / 125 kHz	440
2	LoRa: SF10 / 125 kHz	980
3	LoRa: SF9 / 125 kHz	1760
4	LoRa: SF8 / 125 kHz	3125
5	LoRa: SF7 / 125 kHz	5470
6	LoRa: SF7 / 250 kHz	11000
7	FSK: 50 kbps	50000
8..15	RFU	

TXPower	Configuration
0	20 dBm (if supported)
1	14 dBm
2	11 dBm
3	8 dBm
4	5 dBm
5	2 dBm
6..15	RFU

Table 14: Data rate and TX power table

- Minimum set

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%

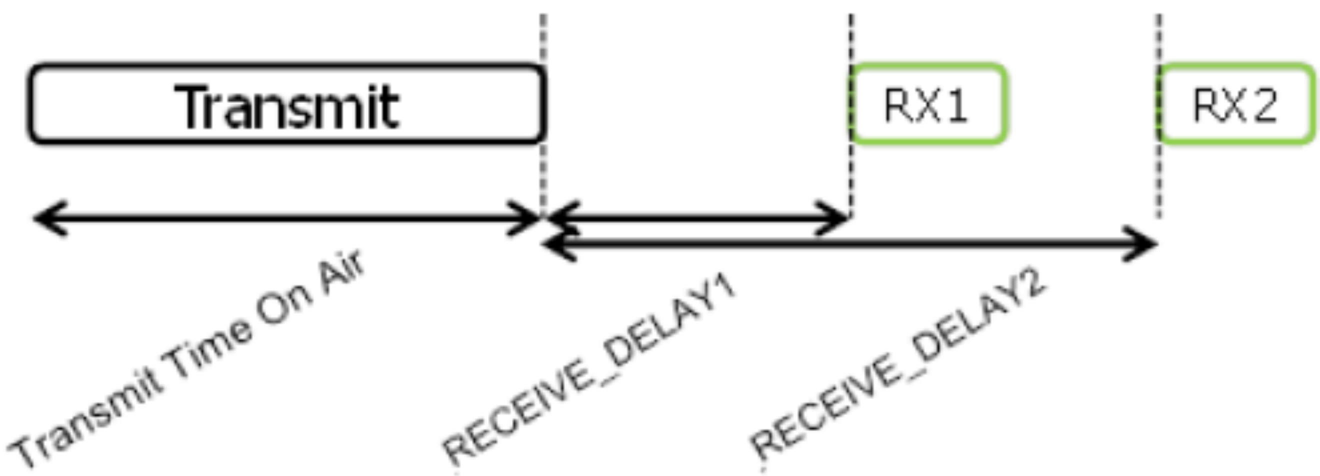
Table 12: EU863-870 default channels

LoRaWAN MAC protocol main features (1)

- "Following each uplink transmission the end-device opens two short receive windows. The receive window start times is a configured periods are the end of the transmission of the last uplink bit."

Same channel than uplink

Configurable channel



LoRaWAN MAC protocol main features (2)

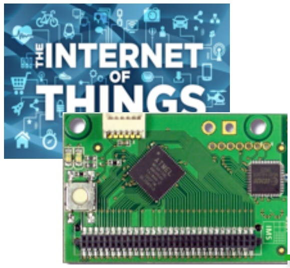
- Adaptive Data Rate, ACKnowlegements, Retransmission procedure, Encryption
- Duty-cycle and channel management
  - The maximum end-device transmit duty cycle is:

$$aggregated\ duty\ cycle = \frac{1}{2^{\mathrm{MaxDCycle}}}$$

  - The valid range for **MaxDCycle** is [0 : 15]. A value of 0 corresponds to —no duty cycle limitation except the one set by the regional regulation (e.g. 1%)

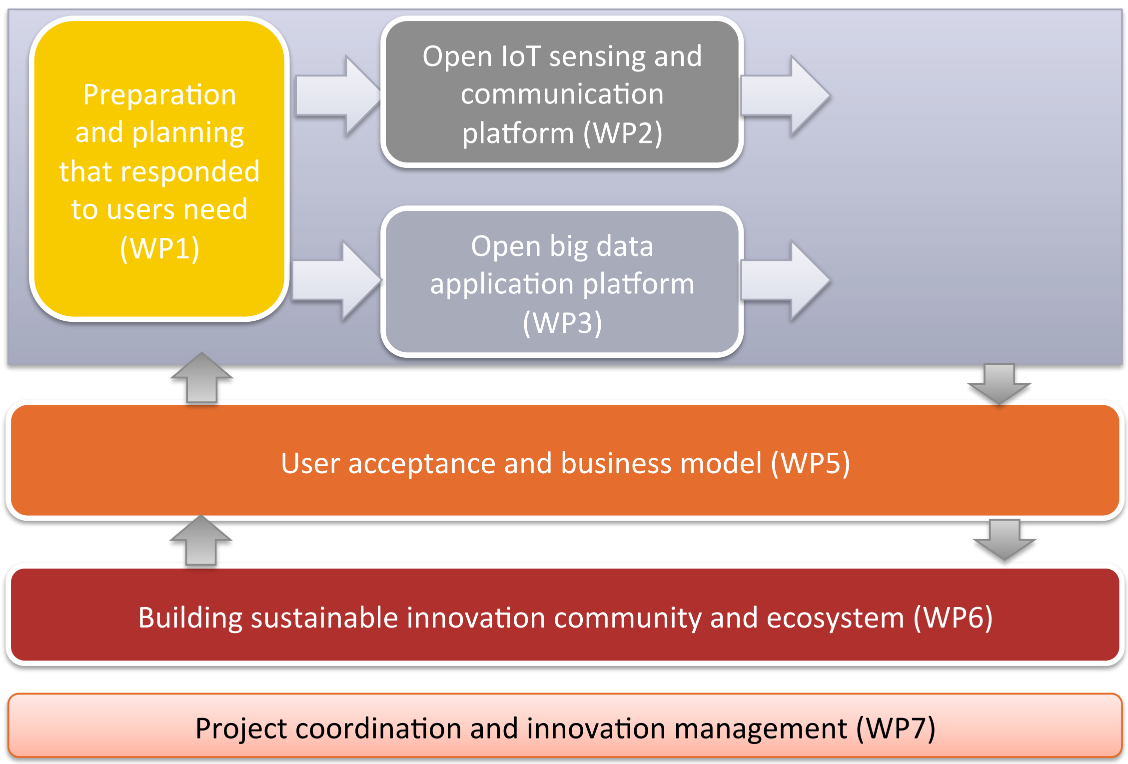
- Channel off-time after transmission

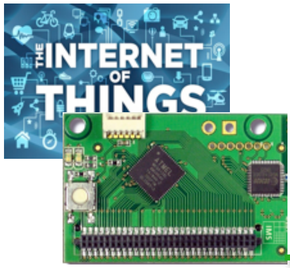
$$\mathrm{Toff}_{\mathrm{subband}} = \frac{\mathrm{TimeOnAir}}{\mathrm{DutyCycle}_{\mathrm{subband}}} - \mathrm{TimeOnAir}$$



WAZIUP CONTRIBUTION

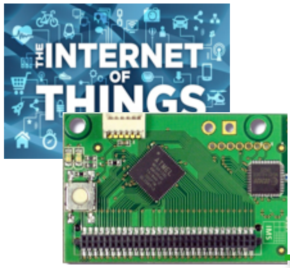
- WAZIUP is an EU H2020 project (2016-2019)
- contributes to long-range networks with WP2





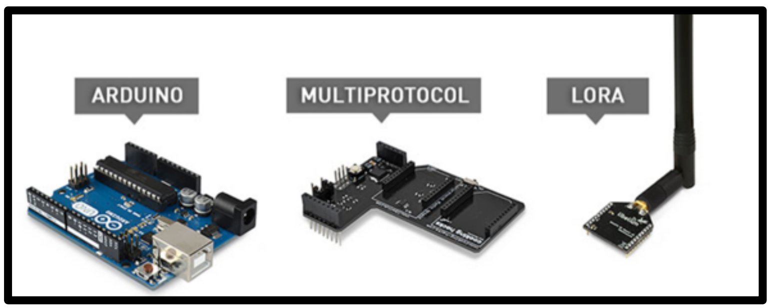
WAZIUP's WP2

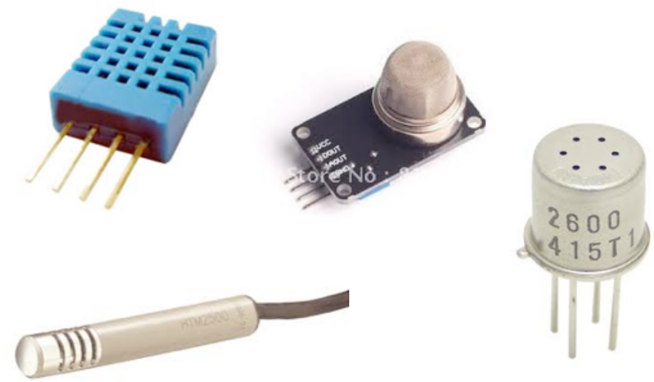
- UPPA (LIUPPA/T2I) leads WP2
  - T.2.1 Design and adaptation of sensing systems considering societal and environmental threat (UI)
  - T2.2 Design and integration of heterogeneous IoT networking (UPPA)
  - T2.3 Low-latency and low-energy MAC protocols (UPPA)
  - T2.4 Open IoT test-bed and benchmark (UGB)
  - T2.5 Multimedia training materials and tools for developer community (CTIC)



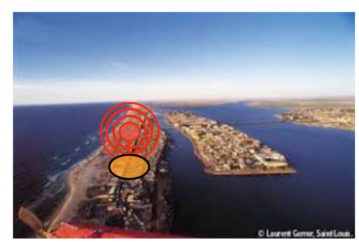
T2.1
Design and adaptation

- Build low-cost, low-power, Long-range enabled generic platform
- Methodology for low-cost platform design



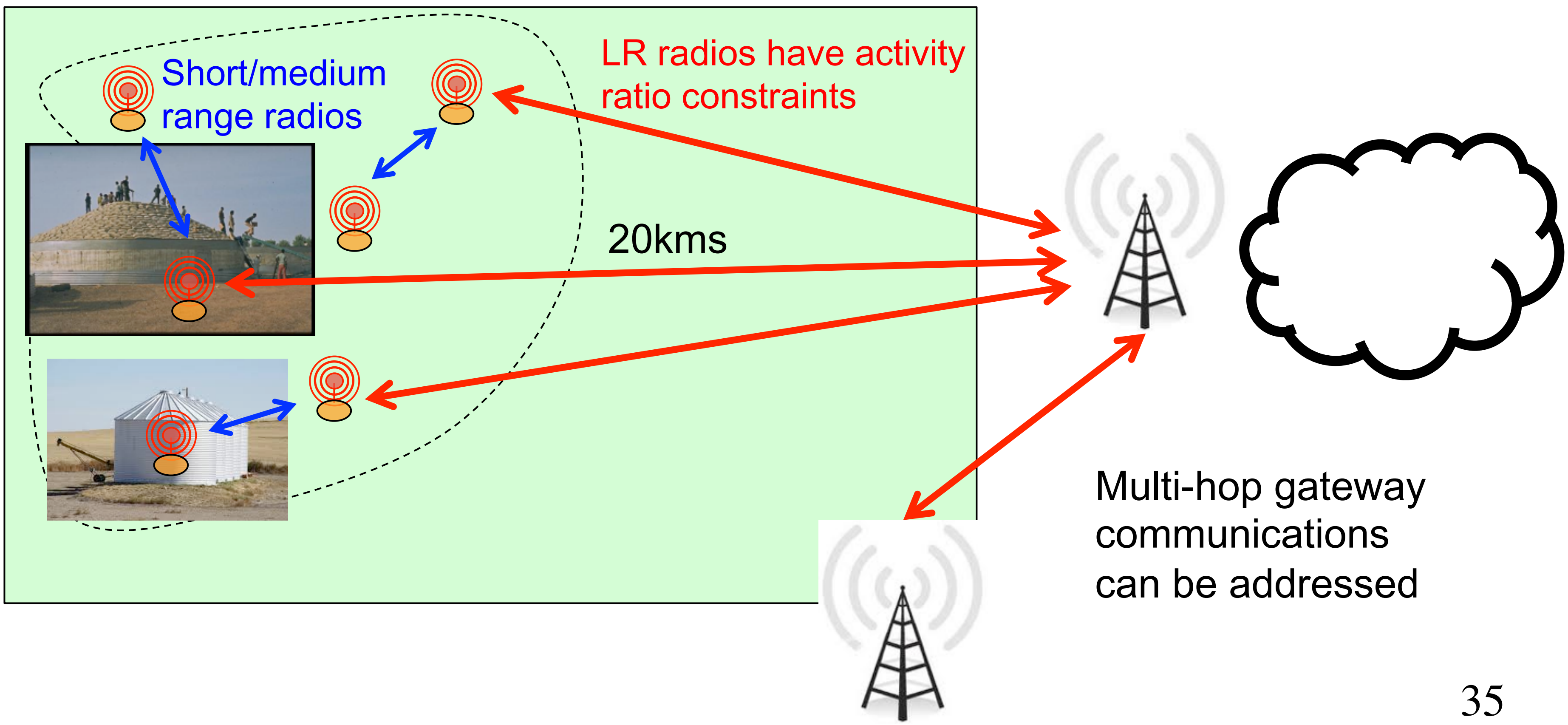




T2.2
Heterogeneous IoT Networking

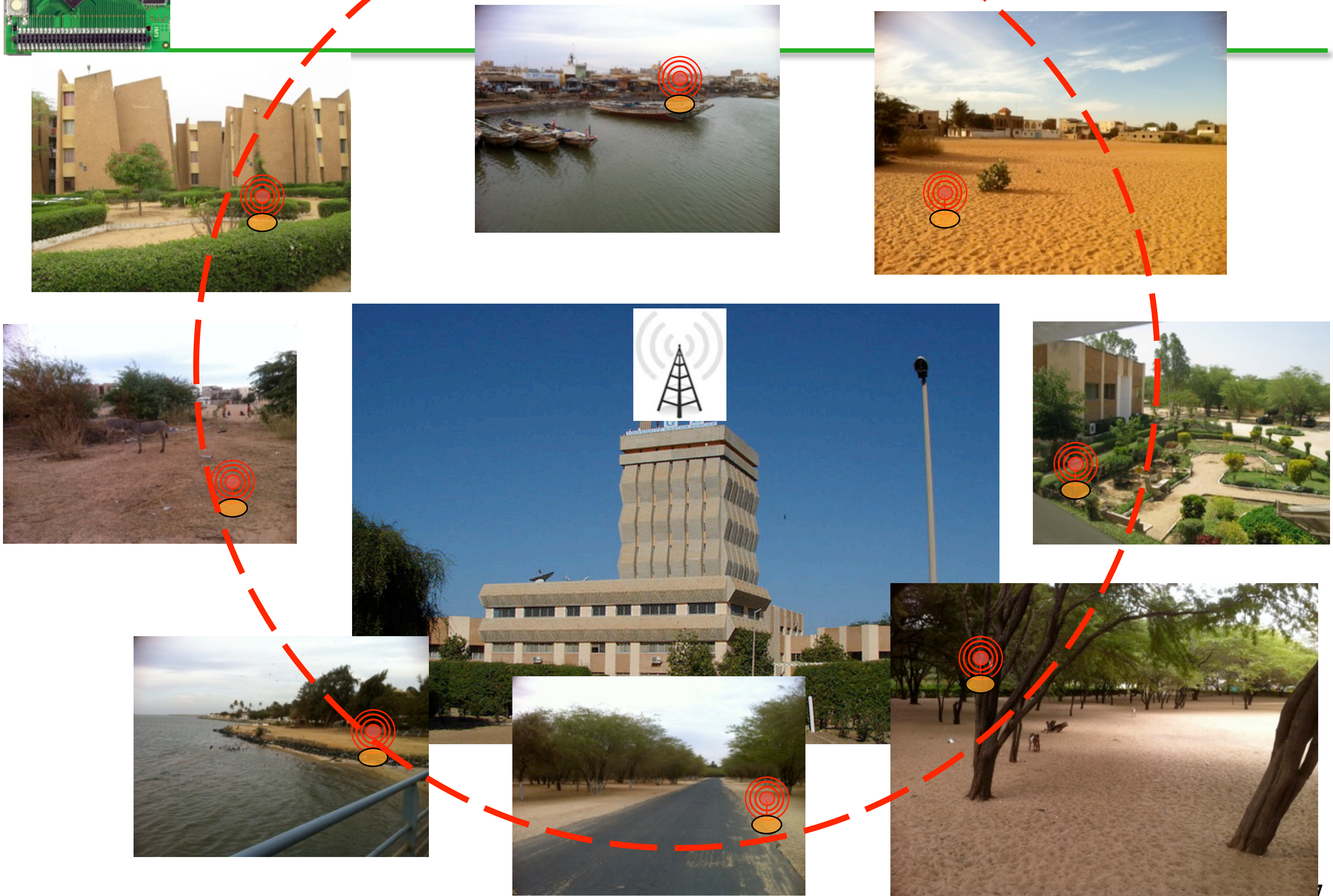
- Seamless integration of short-range & long-range, intermittent connectivity



T2.3
MAC PROTOCOLS

- Can use existing MAC implementation as a starting point
- Contributes on
  - criticality-based scheduling for surveillance applications: how to schedule devices for low-power (activity duty-cycle) mode without degrading the surveillance quality?
  - long-range activity sharing (LAS) for increased quality of service, especially for data-intensive applications: how can we go beyond the 1% radio activity time constraint to provide low-latency communications?

T2.4
Long-range test-bed & benchmark



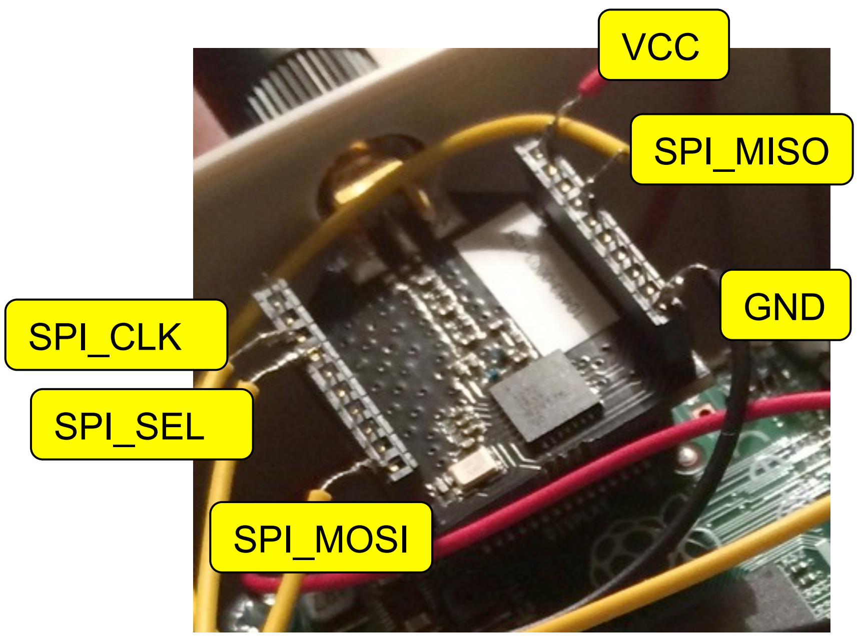
LoRa gateways

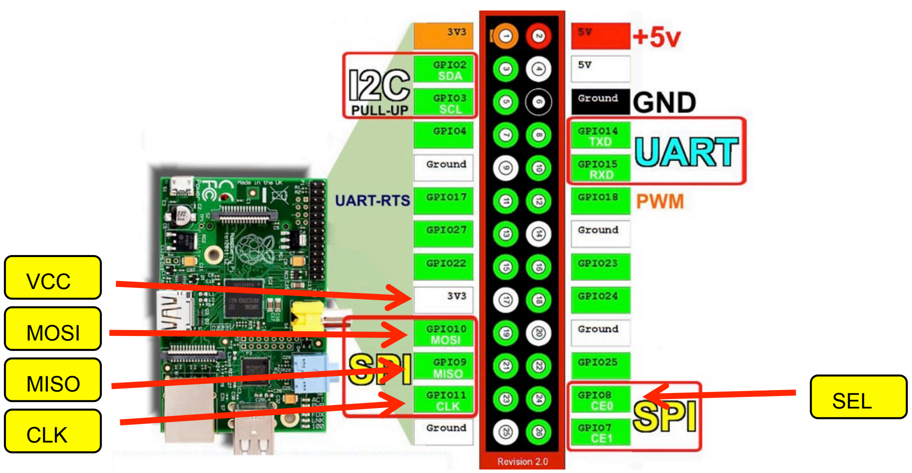
- WAZIUP will deploy already-packaged gateways such as Kerlink and MultiTech gateways
- WAZIUP will also provide low-cost gateways based on off-the-shelves platforms for minimum cost, maximum customization and flexibility
  - Raspberry PI
  - Arduino (MEGA, DUE)
  - Intel Galileo
- Interoperability will be discussed and tested to go towards « roaming » facilities among several LoRa networks (gateways owned by various parties)

Existing LoRa gateways ressources

- Semtech's LoRa gateway code
  - Implements LoRaWAN specification
  - https://github.com/Lora-net/lora_gateway
- TheThingNetwork initiative
- Various DIY initiative
  - LoRaWAN RPI+mCard from Nestor Ayuso
    - https://github.com/mirakonta/lora_gateway/wiki
  - PI-in-the-sky gateway
    - https://github.com/PiInTheSky/lora-gateway
    - http://www.pi-in-the-sky.com/index.php?id=making-a-lora-gateway
- Our low-cost gateway with Activity Time Sharing
  - Arduino and Raspberry PI
  - http://www.univ-pau.fr/~cpham/LORA/RPIgateway.html

Our low-cost LoRa gateway





Conclusions

- Low-power long-range (LR) transmission is a break-through technology for IoT and large-scale deployment of wireless devices
- With a large variety of applications and products, the long-range eco-system is becoming mature
- WAZIUP's WP2 focus in LR technology
  - To develop low-cost platform and software buillding block for managing heterogeneous networks
  - To build a LR test-bed targeted for Africa rural areas and open to end-users
  - To validate the usage IoT for rural applications through real use cases
  - To propose innovative LR control mechanism for increased surveillance quality