Low-power, long-range radio technologies for Internet-of-Things

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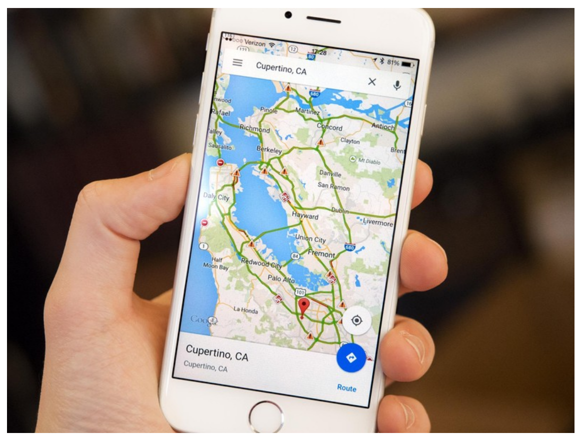
IoT & PHYSICAL WORLD



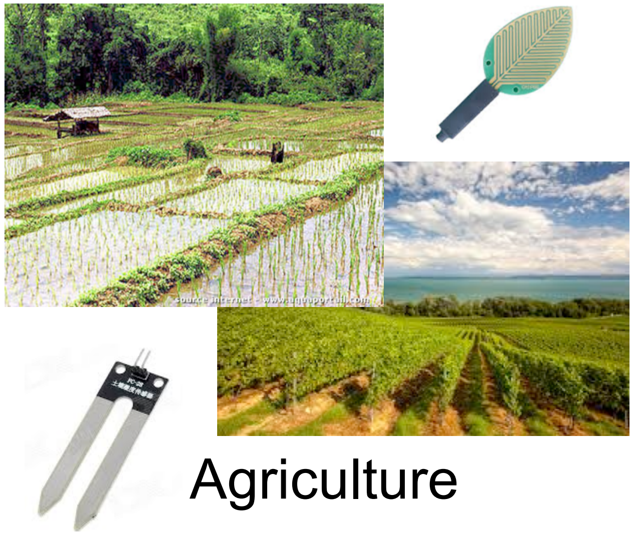
IoT4D
Development for rural areas

Irrigation

Livestock farming

Fish farming & aquaculture

Storage & logistic

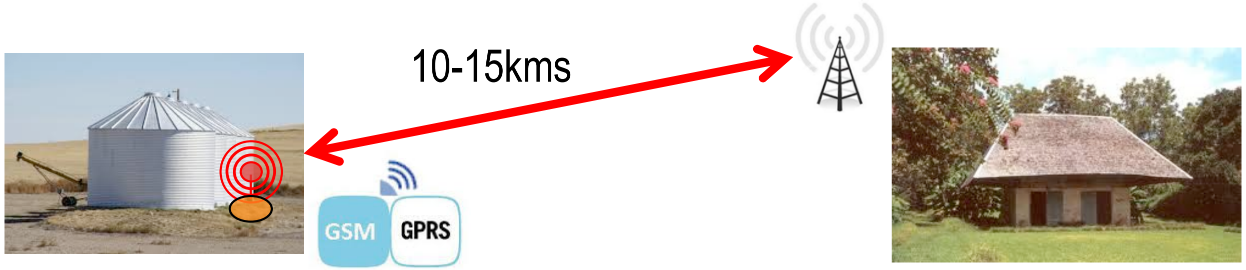


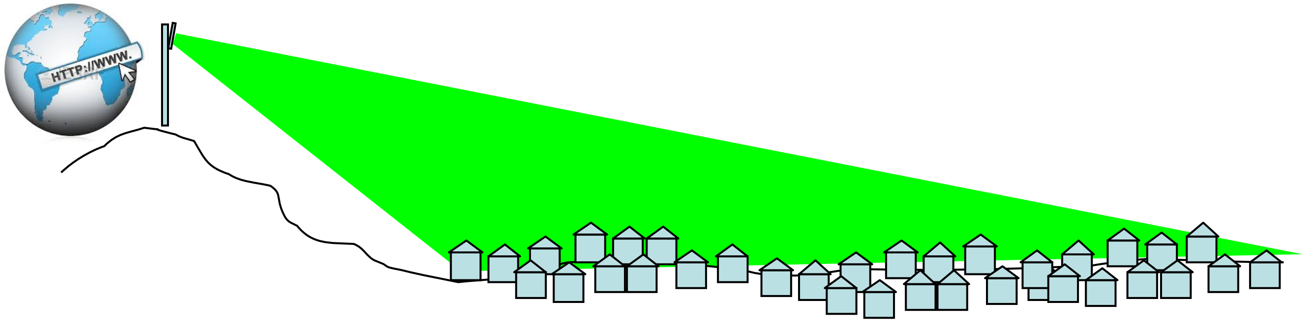
Agriculture

Environment

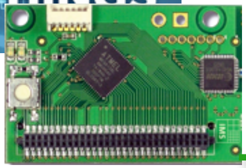
Telemetry and Transmission cost

Moisture/
Temperature of
storage areas



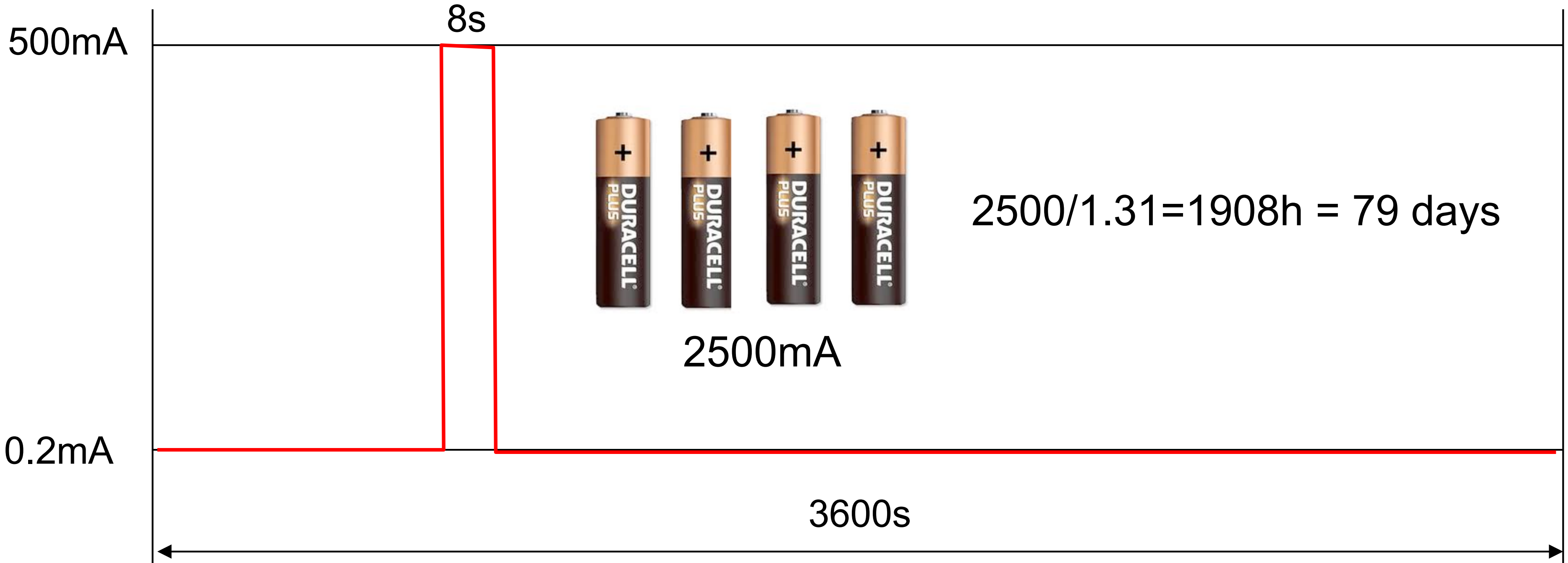


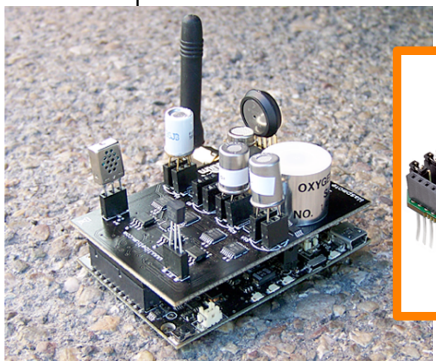
Technology	2G	3G	LAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m
Tx current consumption	200-500mA	500-1000mA	100-300mA
Standby current	2.3mA	3.5mA	NC

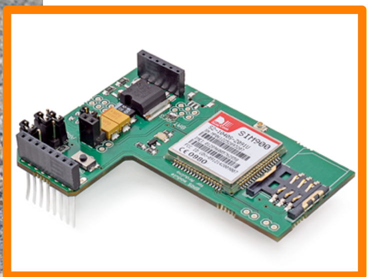


Energy consideration

TX power: 500mA. Mean consumption: (8x500+3592x0.2)/3600=1.31mA







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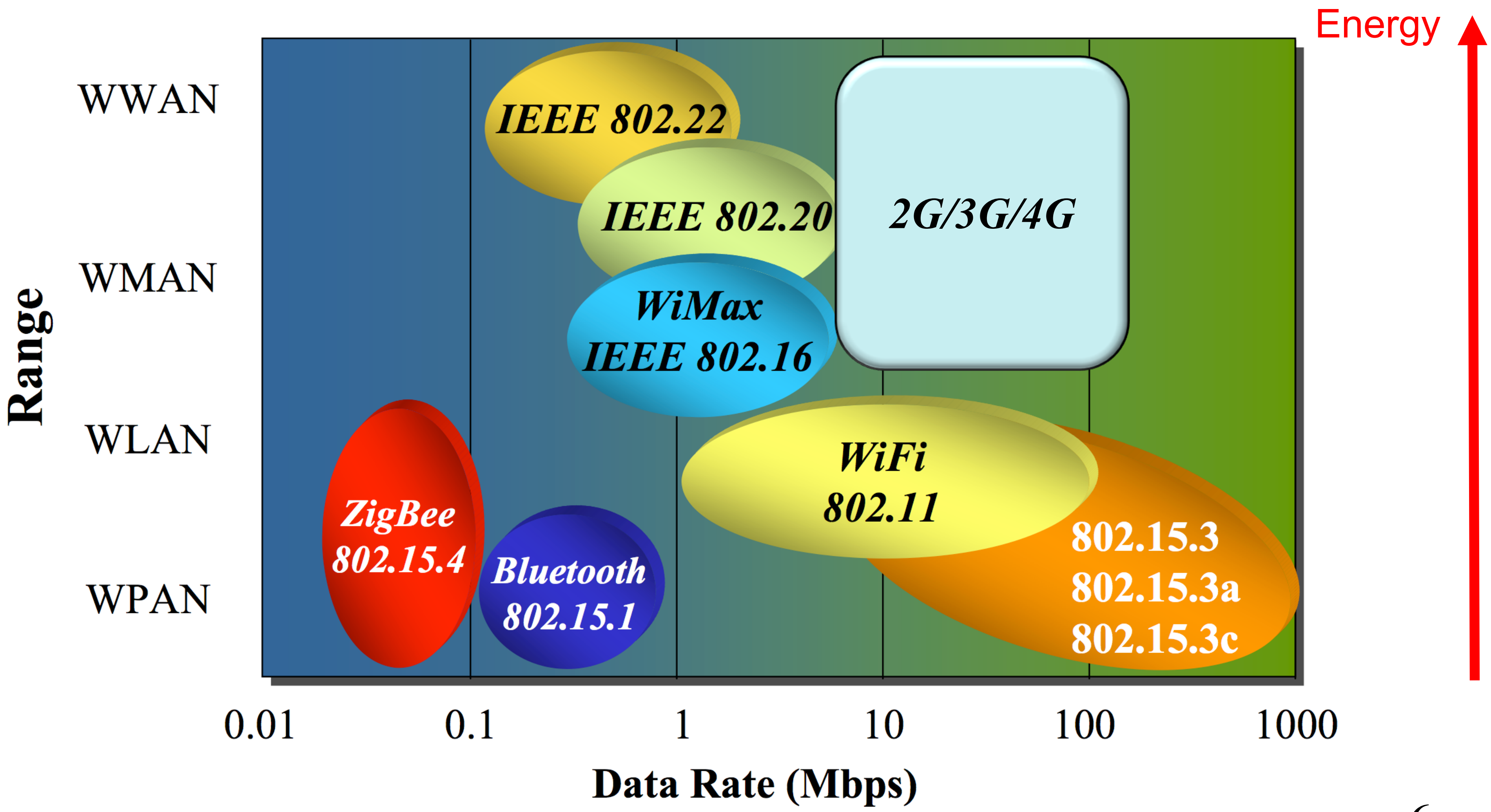
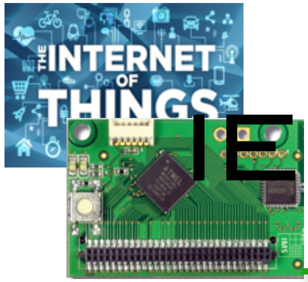
The wireless space

Energy-Range dilemma



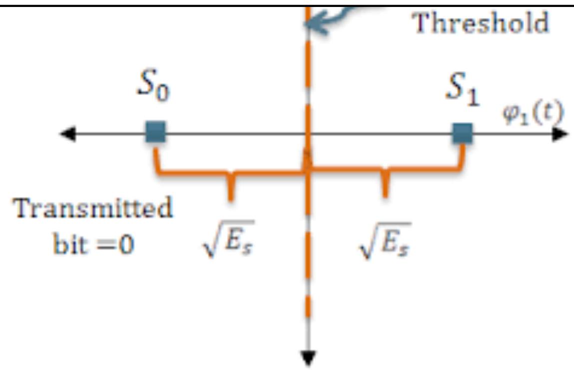


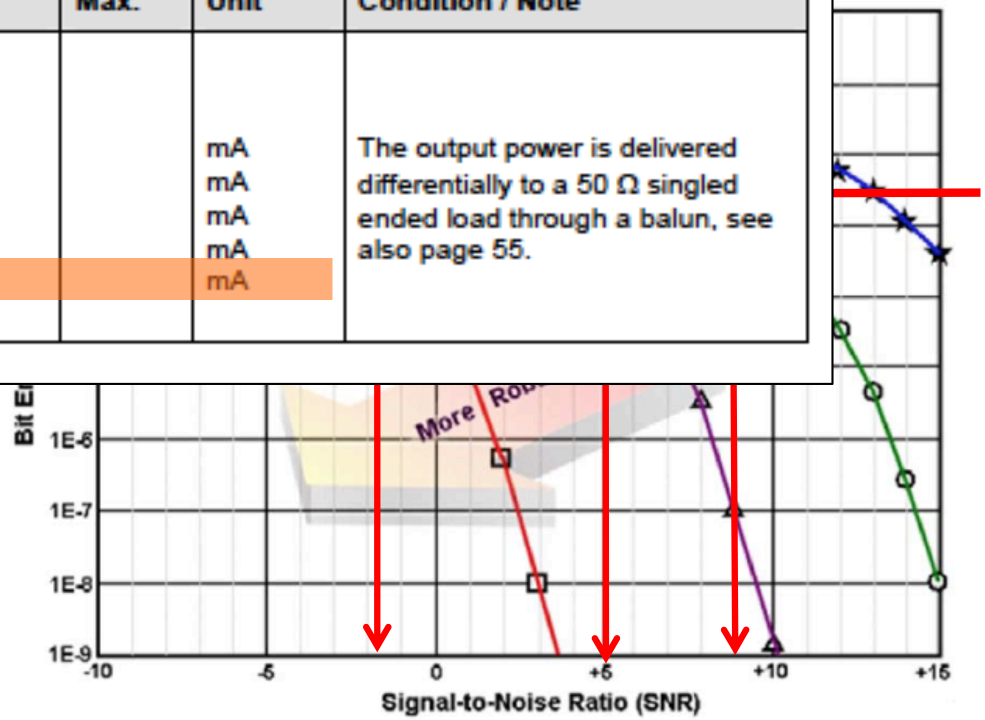
IEEE 802.15.4 in ISM 2.4GHz

- Low-power radio in the 2.4GHz band offering 250kbps throughput at physical layer

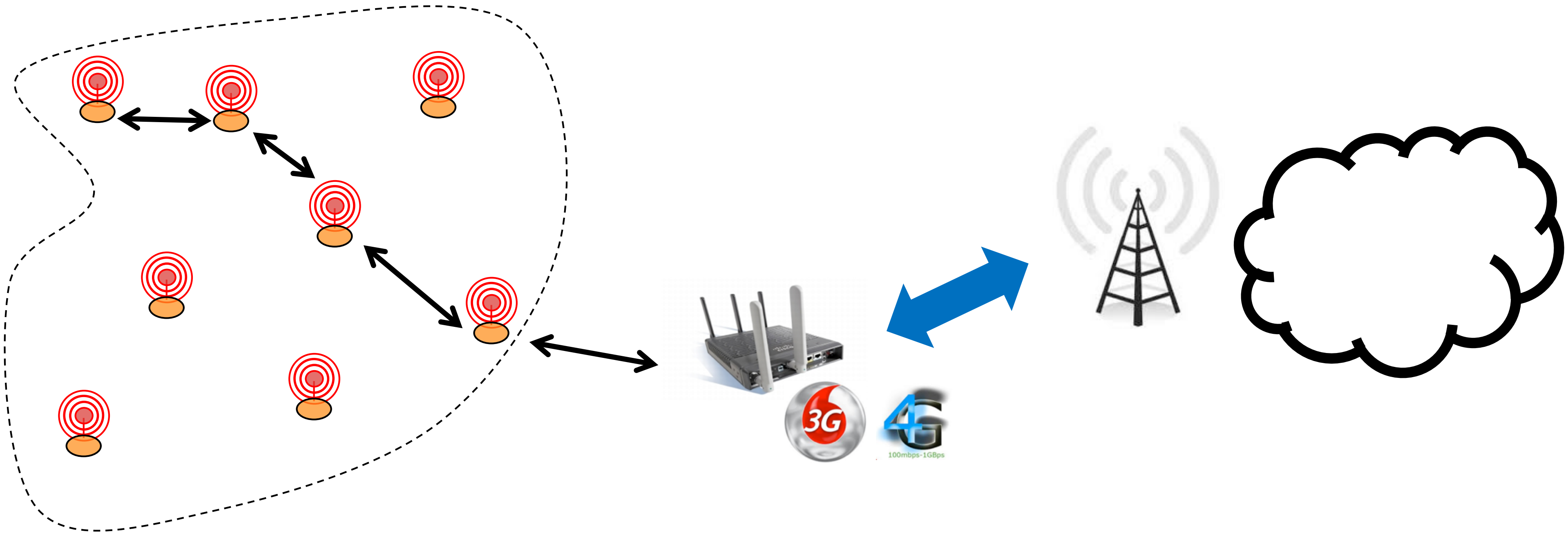
Chipcon Products from Texas Instruments — **CC2420**

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	





Lower energy means shorter range!

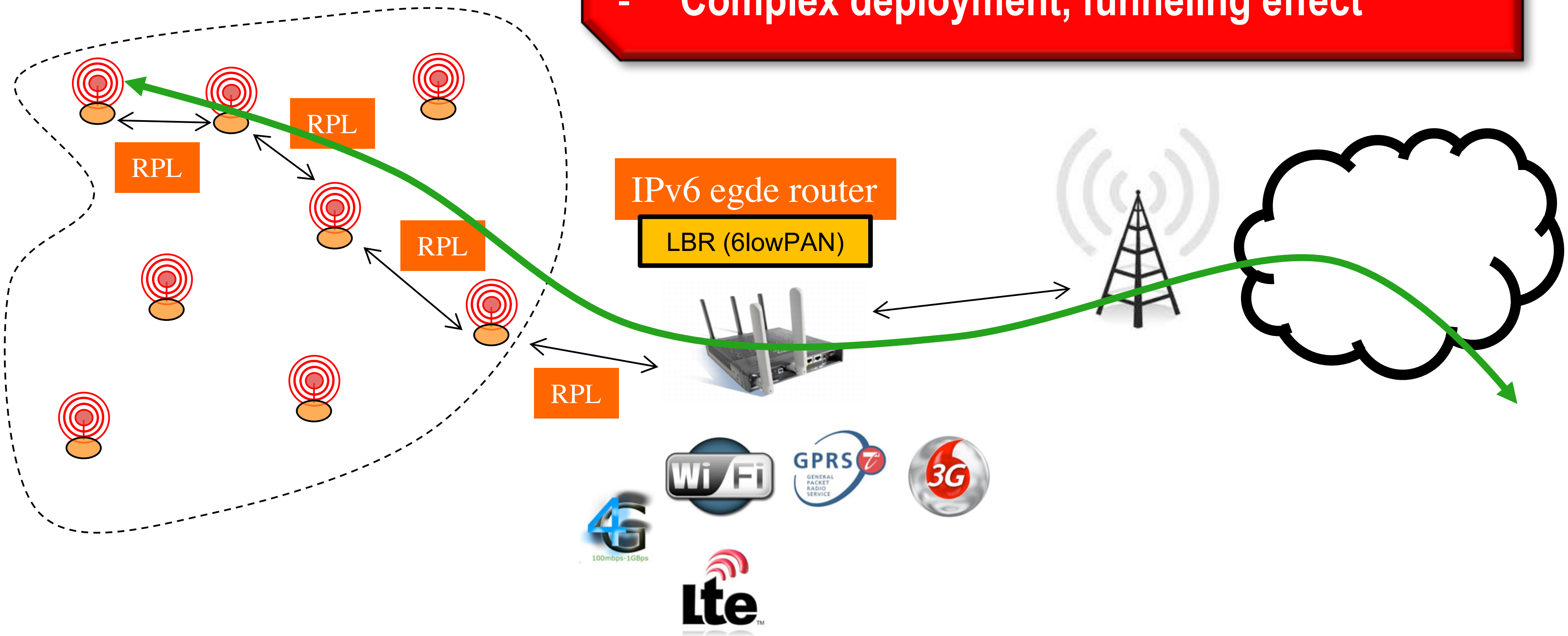


How bad is multi-hop routing?

- Increases packet loss rate
- Increases end-to-end delivery time
- Consumes more energy as intermediate nodes must relay packets
- Limits energy saving mechanism benefits as both sender and intermediate node must be somehow synchronized
- Is impacted by intermediate node failure

15 YEARS OF MULTI-HOP ROUTING?

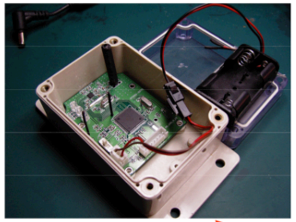
- High packet loss rates
- Needs synchonization when duty-cycling
- Complex deployment, funneling effect

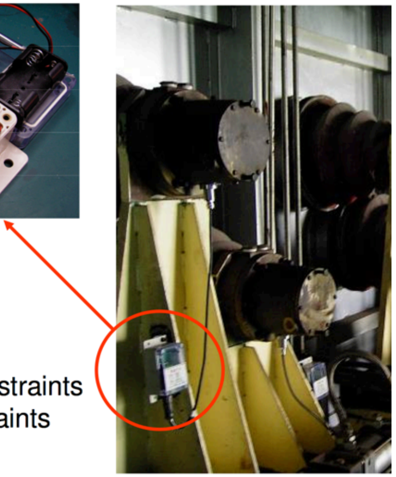


Academics vs Industries
Let's go back to reality!

Millions of sensors, self-organizing, self-configuring, with QoS-based multi-path routing, mobility, and …

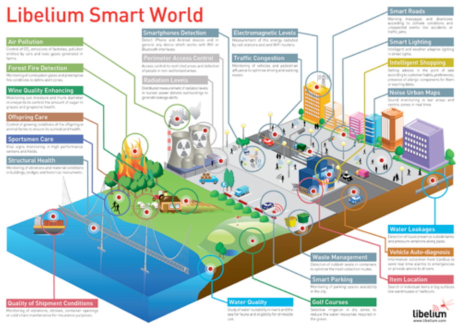
500 sensors, STATIC deployment, but need to have RELIABILITY, GUARANTEED LATENCY for monitoring and alerting. MUST run for 3 YEARS. No fancy stuff! CAN I HAVE IT?





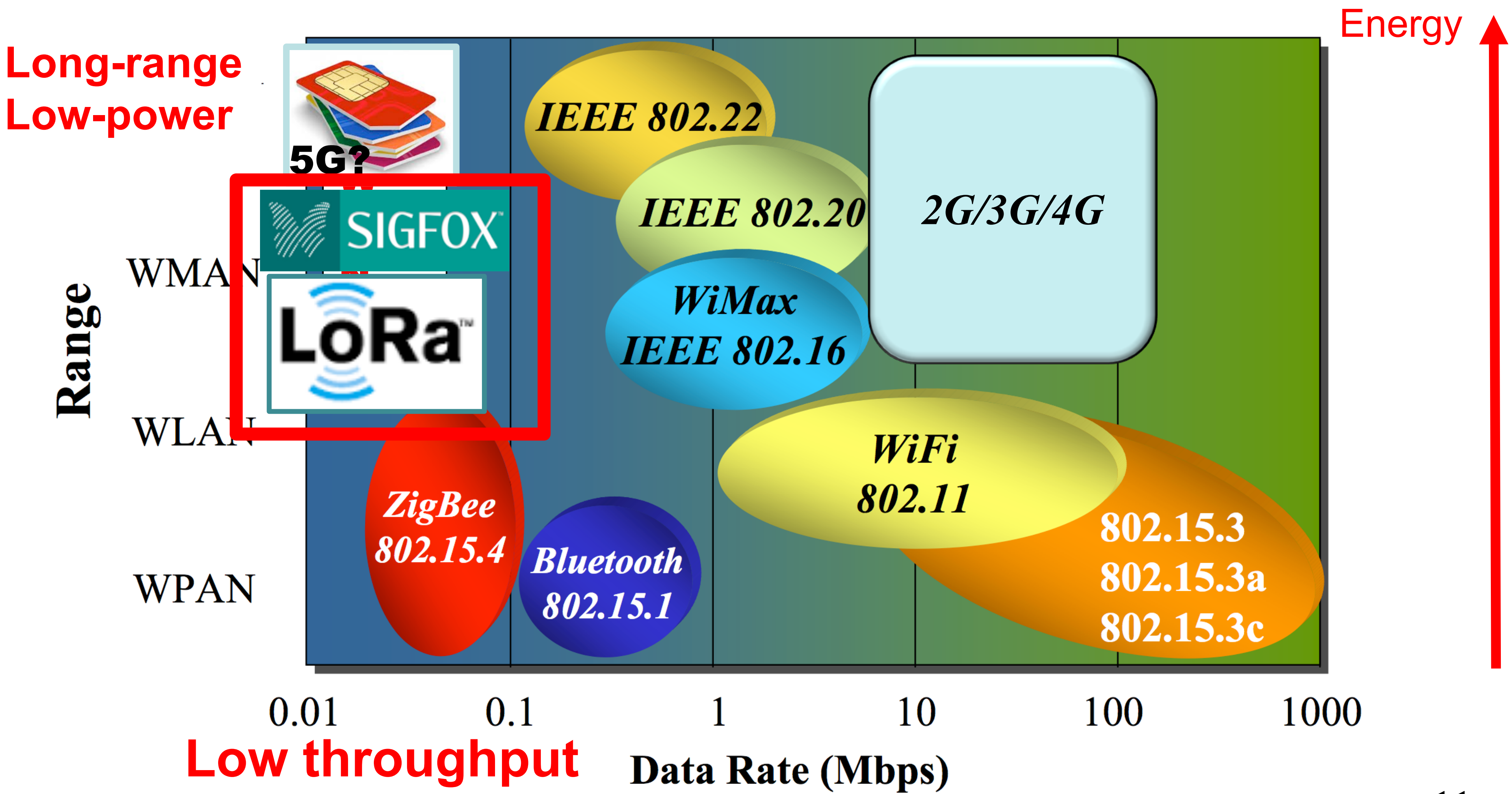
- Placement constraints
- Lifetime constraints

From Peng Zeng & Qin Wang



Low-power & Long-range Radio Technologies

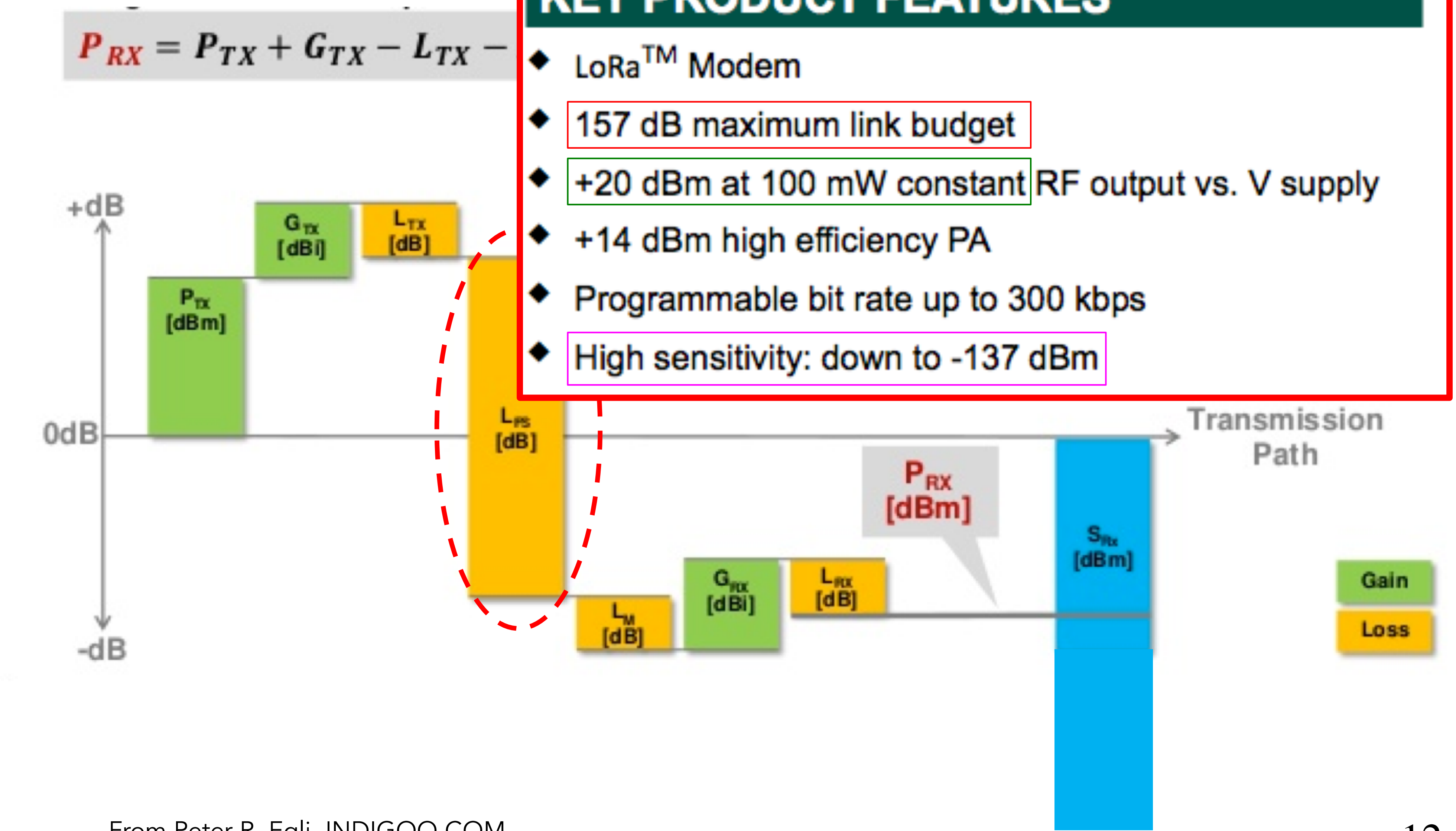
Energy-Range dilemma



Link budget of LPWAN

KEY PRODUCT FEATURES

- LoRa™ Modem
- 157 dB maximum link budget
- +20 dBm at 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -137 dBm



From Peter R. Egli, INDIGOO.COM

Simple loss in signal strength model

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

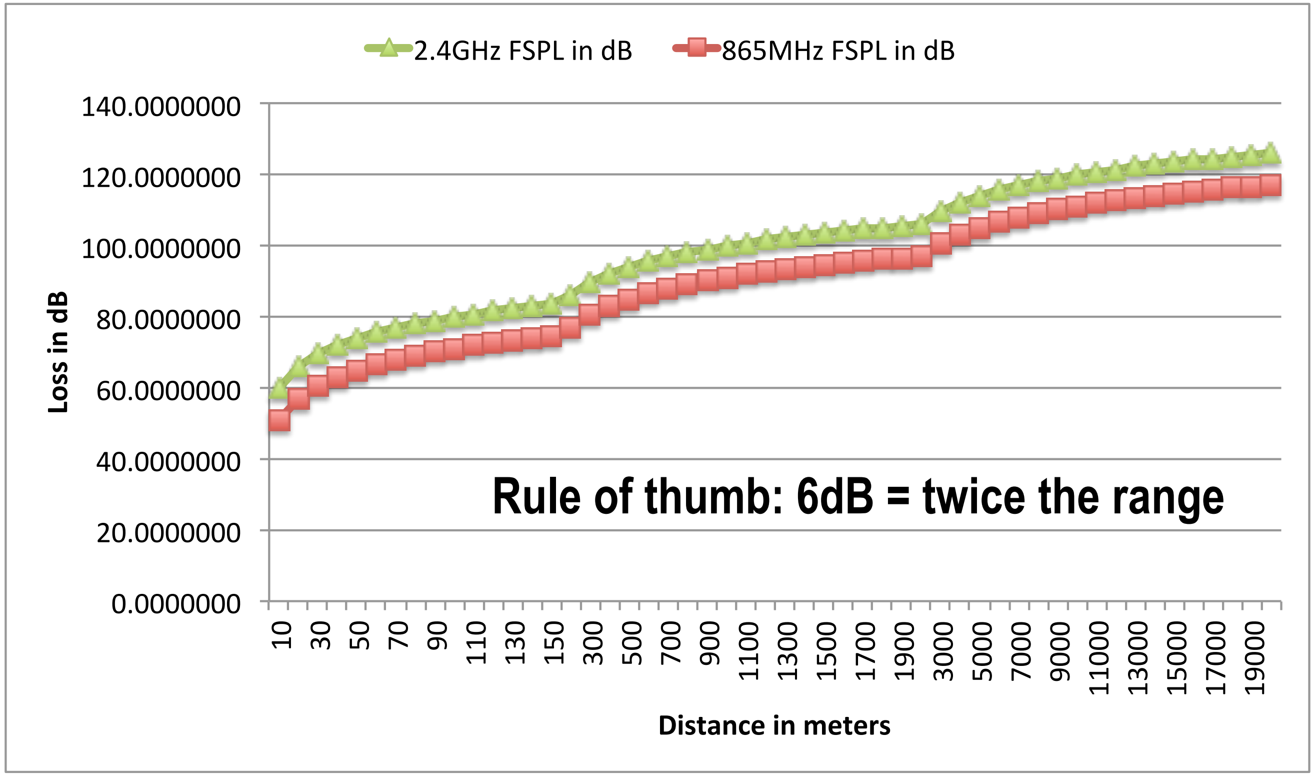
$$FSPL = \frac{P_t}{P_r} G_t G_r$$

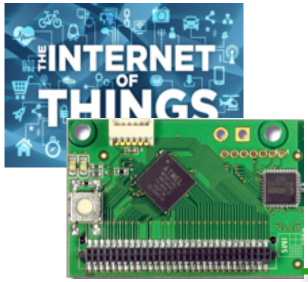
- Free Space Path Loss model

FSPL assume Gt=Gr=1

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

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





Link budget example

- Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) – Losses (dB) [mainly FSL]
- Example
  - Transmitted power is +14dBm (25mw)
  - Losses is 120dB
  - Then Receiver Power (dBm) is -106dBm
- If you have a receiver sensitivity of -137dBm you can handle FSPL up to 151dB!
- Rewriting the equation
  - Losses (dB) = Transmitted Power (dBm) - Received Power (dBm)
  - Losses = link budget & Received Power = max receiver sensitivity
  - Link budget = Transmitted Power - max receiver sensitivity
  - **151dB=14dBm - (-137dBm)**

dBm – **power referred to 1 mW,**

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

Link budget example

- Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) − Losses (dB) [mainly FSL]
- Example
  - Transmitted power is +14dBm (25mw)
  - Losses (FSPL) is 1
  - Then Receiver P
- If you have a rece handle FSPL up to
- Rewriting the equ
  - Losses (dB) = Trans
  - Losses = link budg
  - Link budget = Tran
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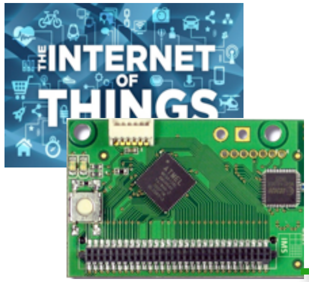
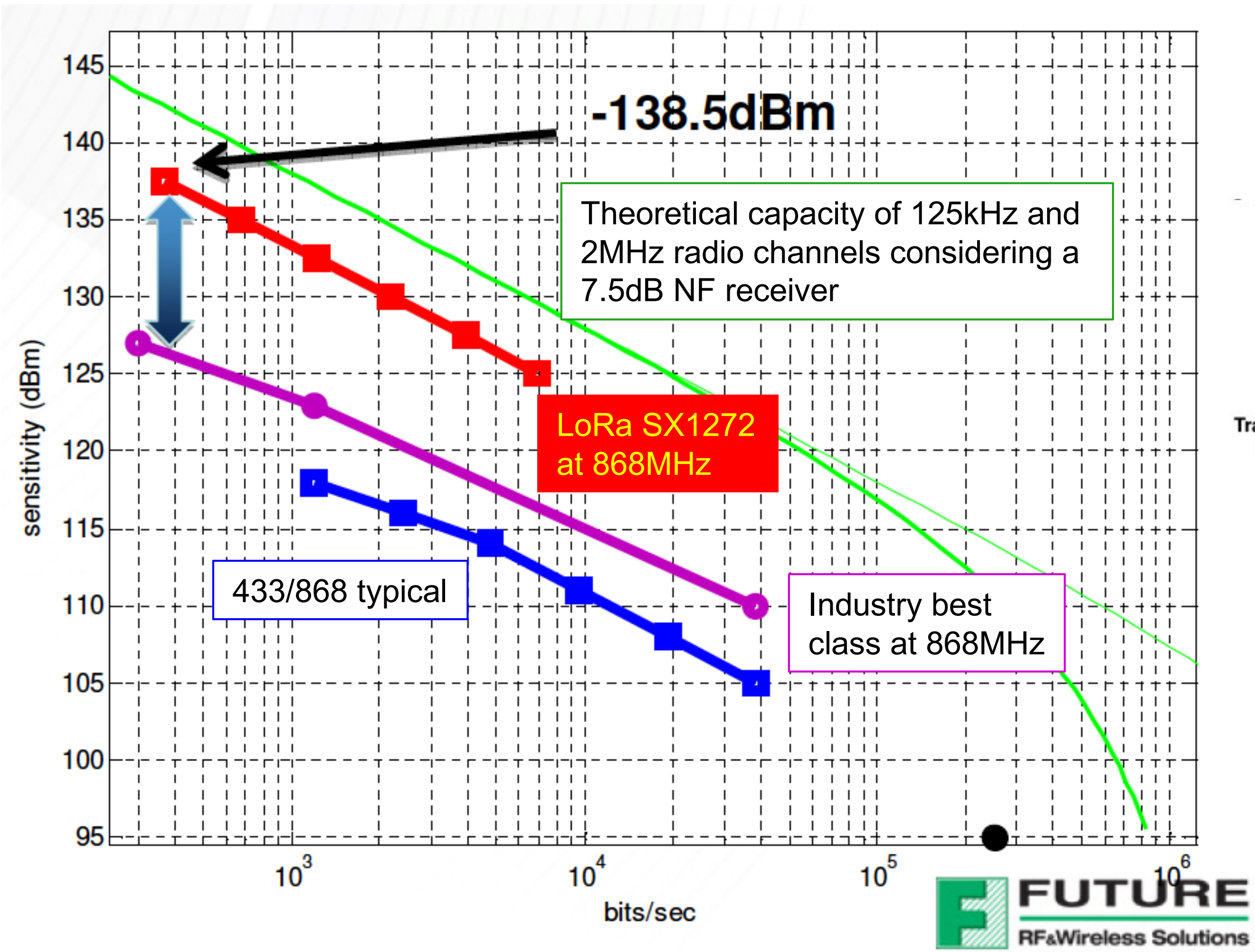
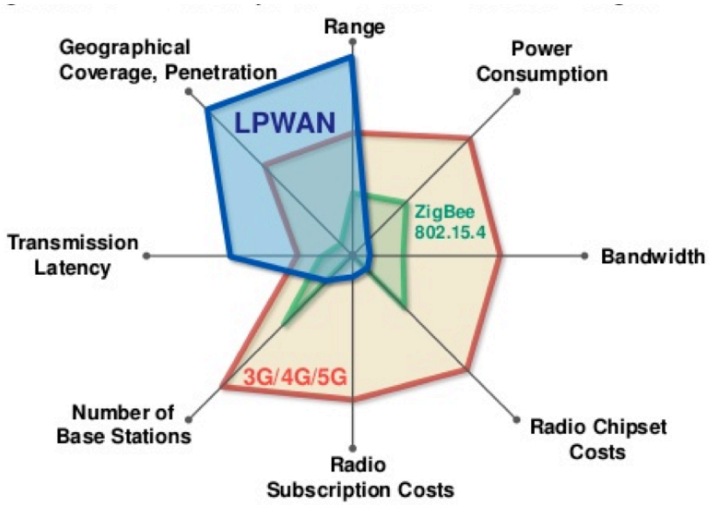


The long-range revolution



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

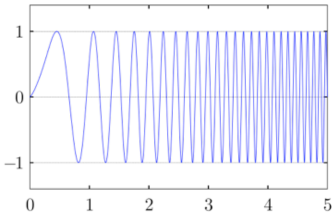


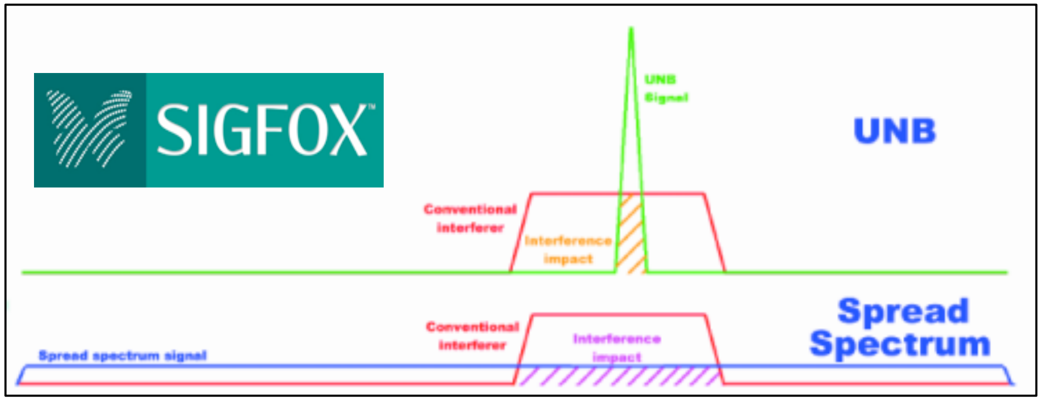
From Peter R. Egli, INDIGOO.COM

The lower the receiver sensitivity, the longer is the range!

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]. Max throughput=~100bps
- LoRa also increases time-on-air when maximum range is needed. But LoRa uses spread spectrum instead of UNB.
  300bps-37.5kbps





LoRa vs Sigfox

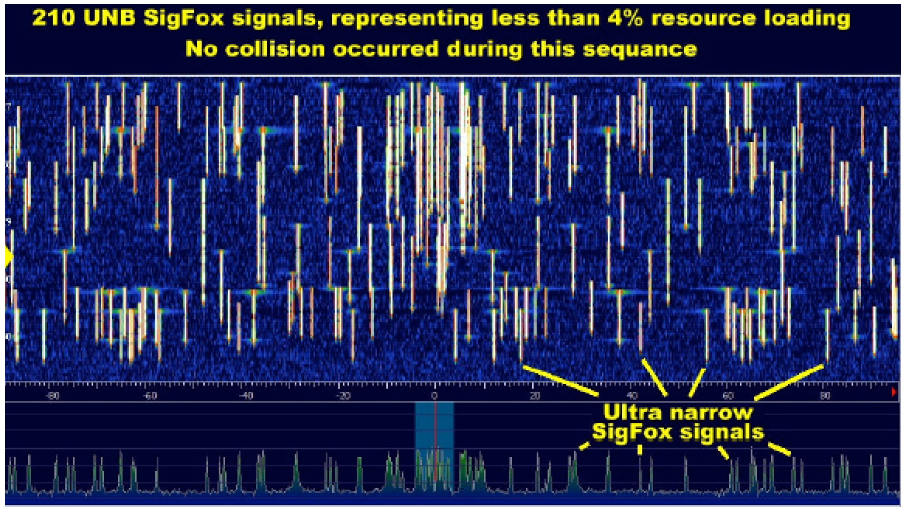


Figure from SigFox

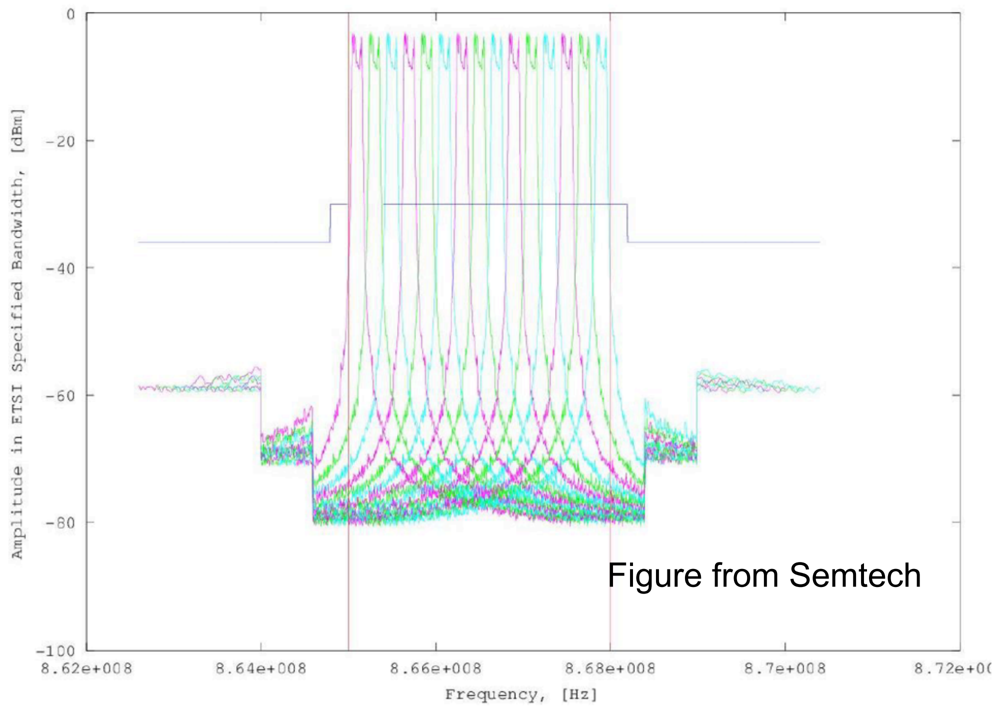


Figure from Semtech

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

Versatile LPWAN!

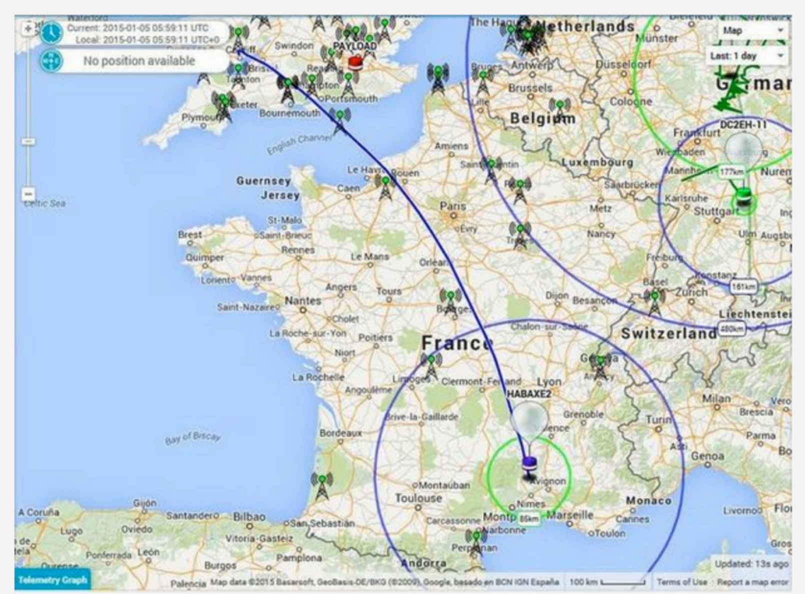
Dense urban areas

Rural areas

Indoor

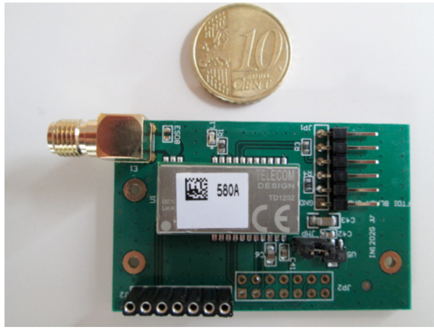
Underground

The higher the better!



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

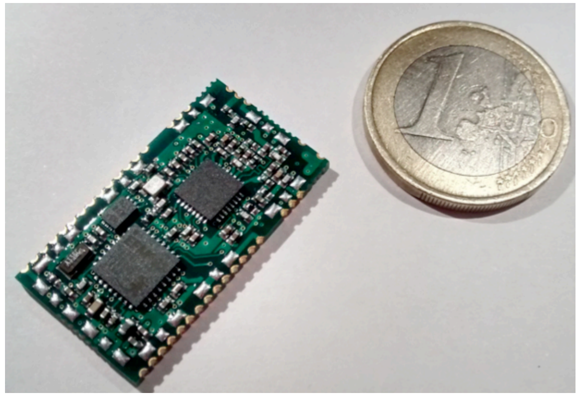
Some SigFox radio modules



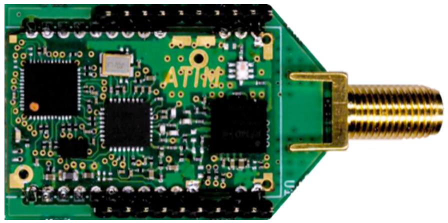
TD120x serie from Telecom Design

SigFox module from CookingHack (Libelium)

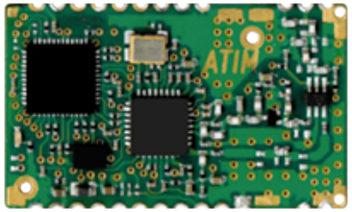
Adeunis SI868



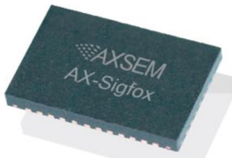
SIGT002 from CG-Wireless



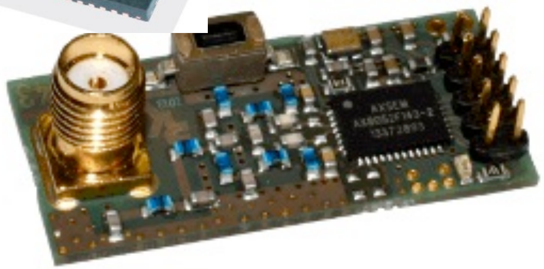
SigBee module from ATIM



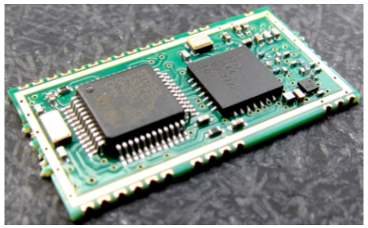
ARM-Nano N8 SigFox module from ATIM



AXSEM SigFox module



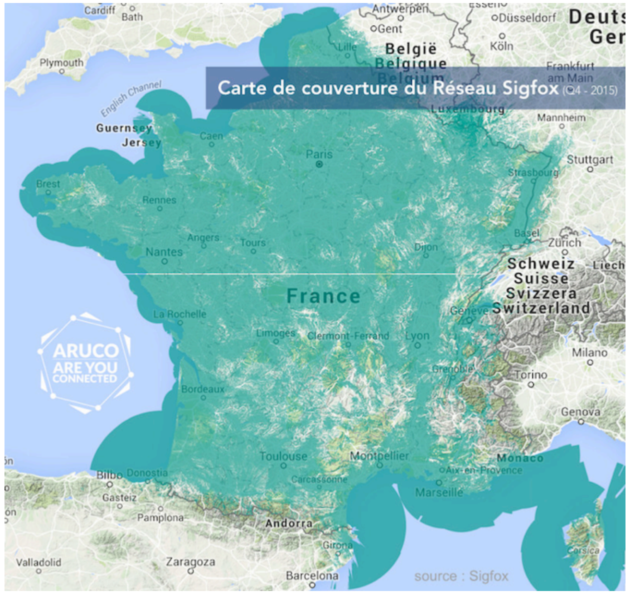
SigFox module from Snoc



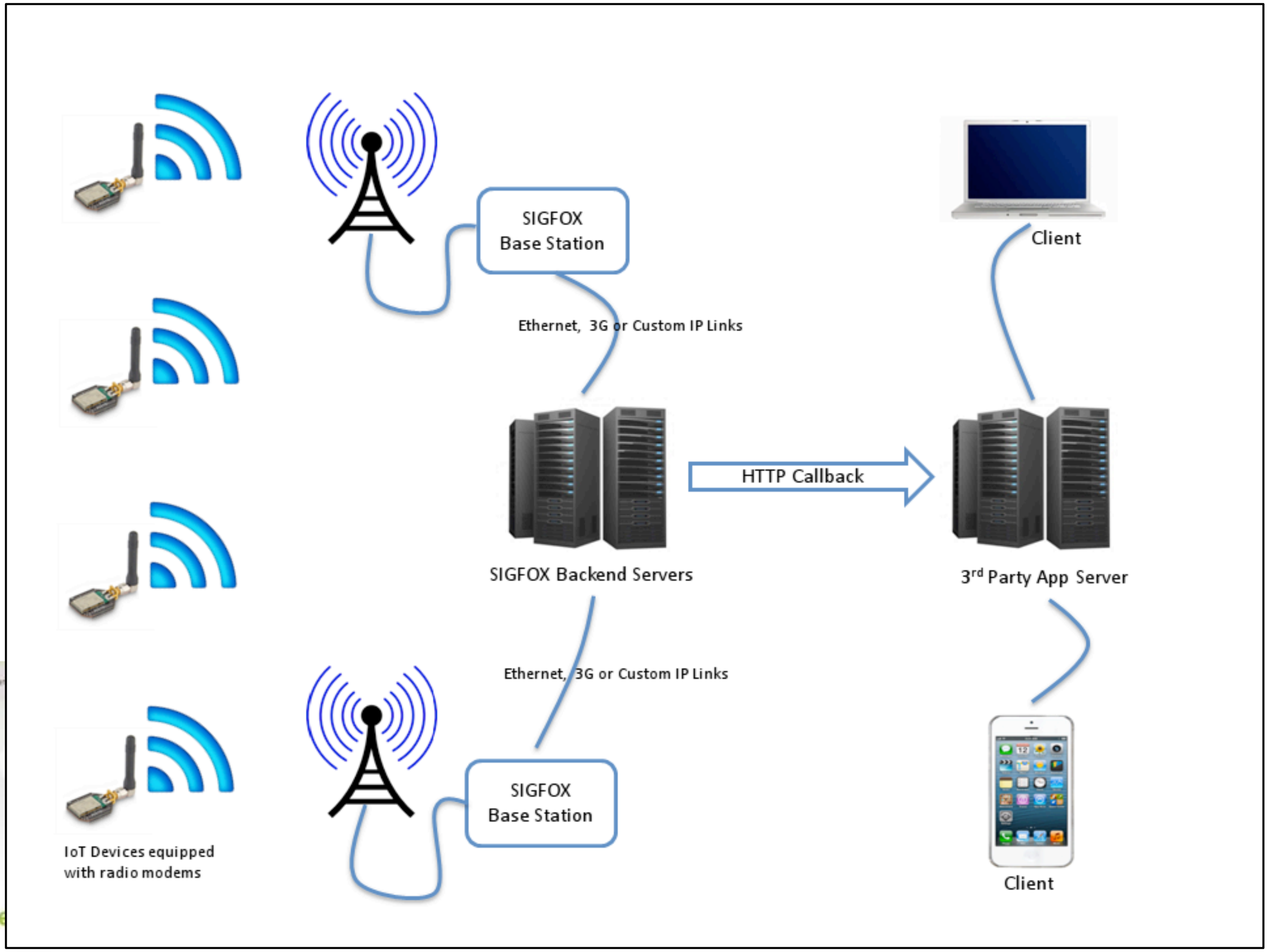
Nemeus MM002-LS-EU LoRa/SigFox

RC1682-SIG from RadioCraft

SIGFOX'S MODEL FOR M2M: THE « OPERATOR » (ALL-IN-ONE) APPROACH

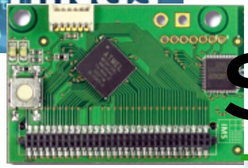


Figures from SigFox

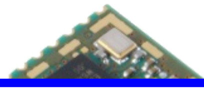


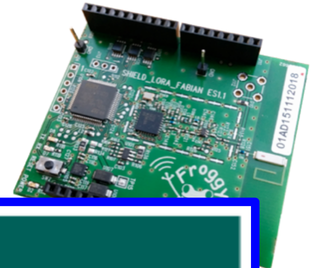
http://www.scoop.it/t/toulouse-networks/?tag=SigFox

LoRa modules from Semtech's SX127x chips



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





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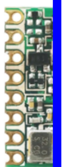

Ho
RF
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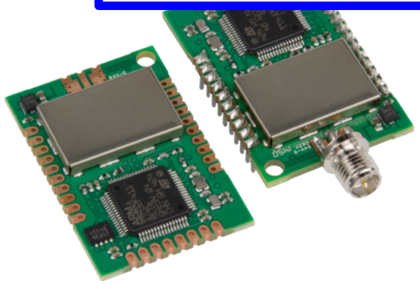
Module

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

Adeunis ARF8030AA- Lo868

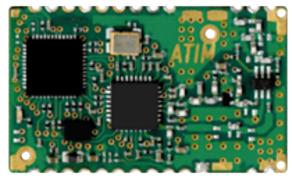
Microship RN2483



Multi-Tech
MultiConnect mDot

habSupplies

AMIHO AM093



ARM-Nano N8 LoRa
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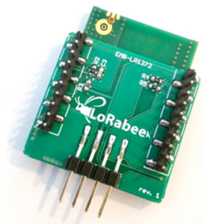
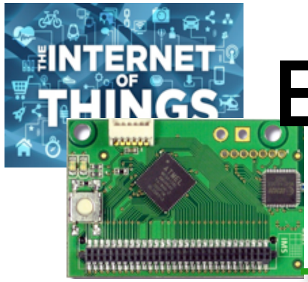


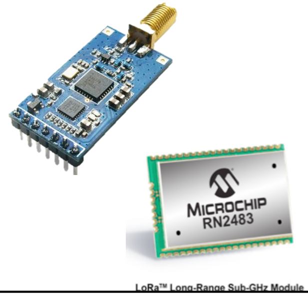
SODAQ LoRaBee
Embit

SODAQ LoRaBee
RN2483

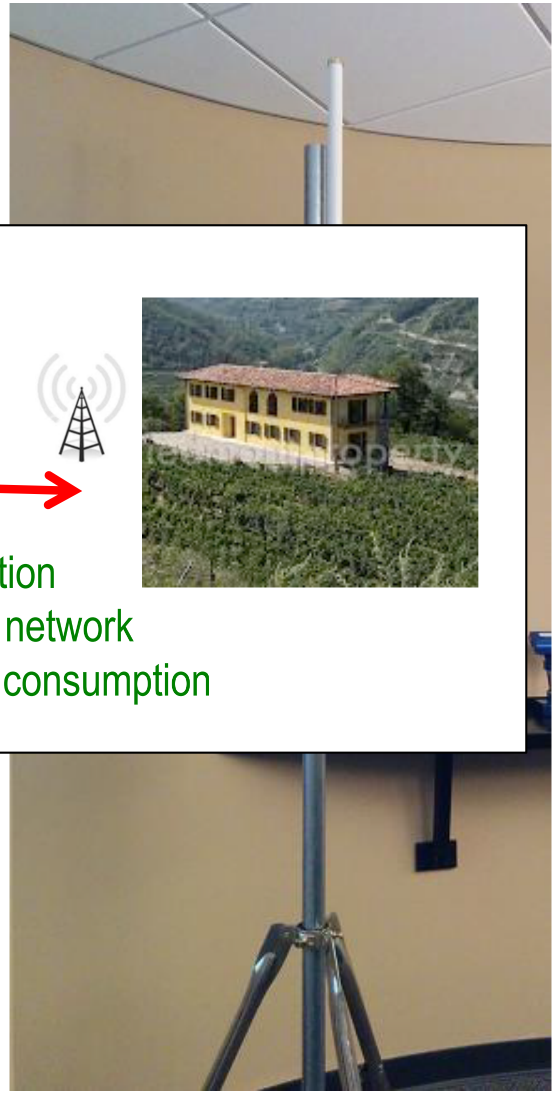


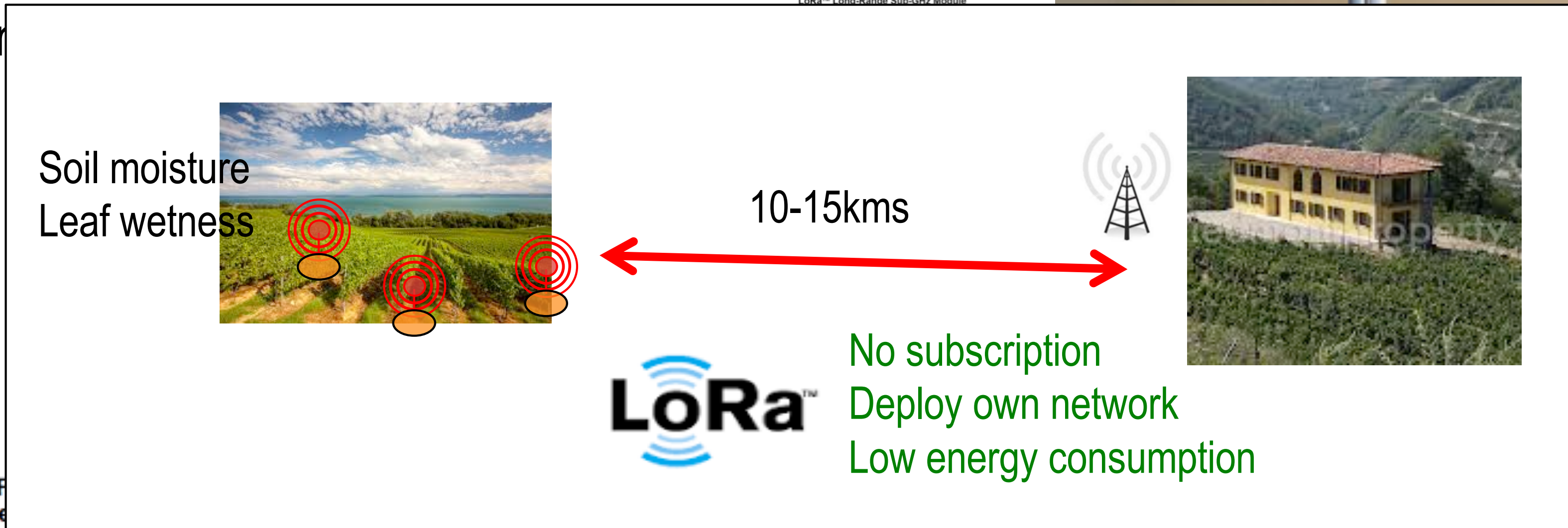
Build your own private LoRa LPWAN

Add LoRa radio module to your preferred dev platform



Install a LoRa gateway and start collectin





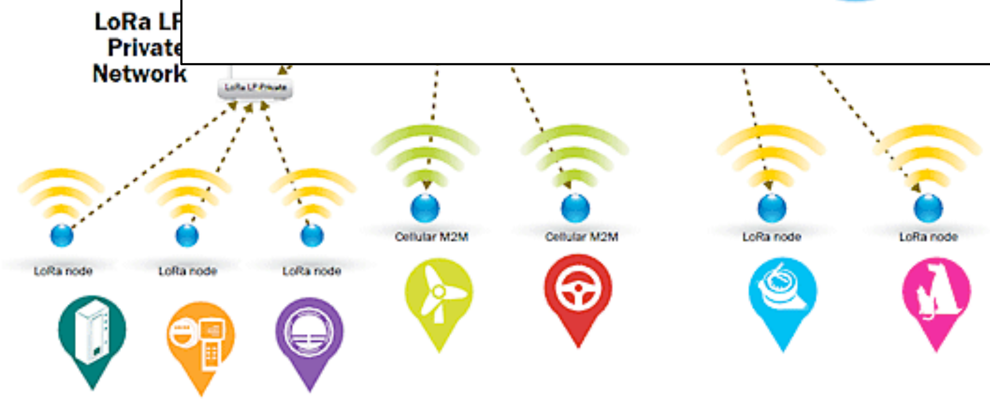
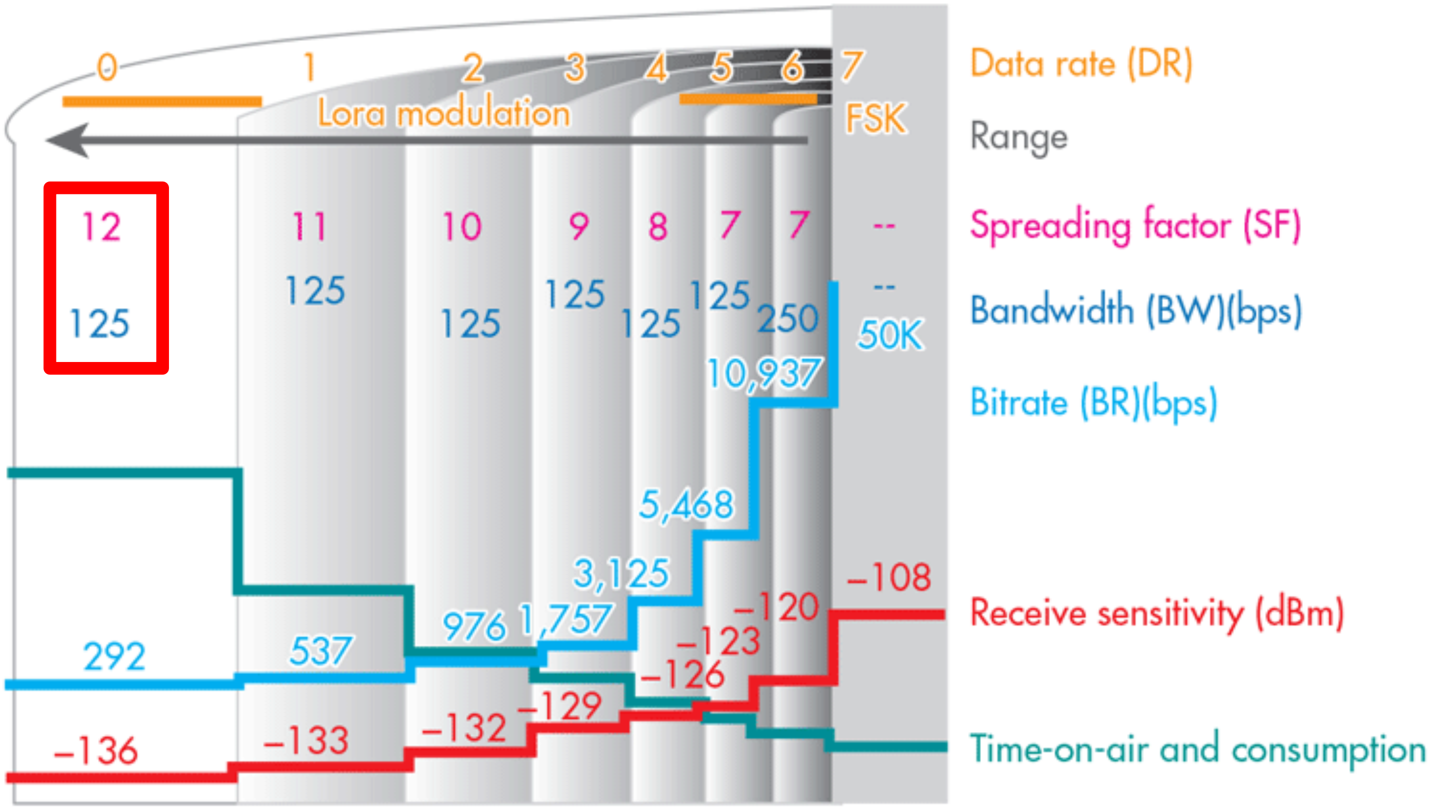


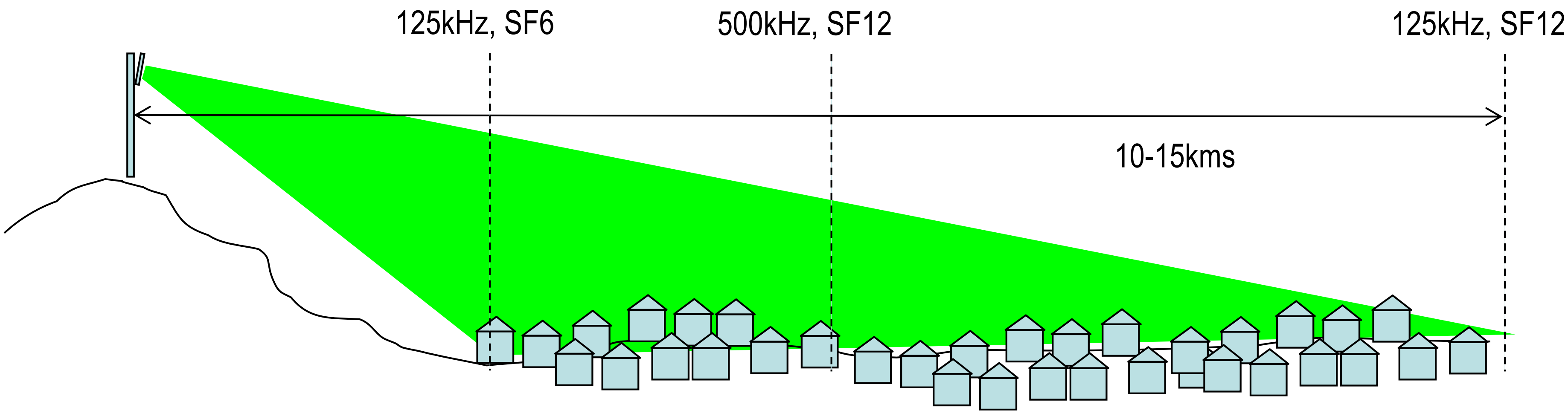
Figure from Semtech

Main LoRa parameters

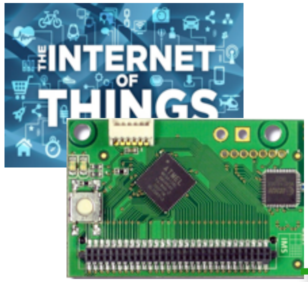
- Main parameters
  - Bandwidth: 62.5kHz, 125kHz, 250kHz, 500kHz
  - Spreading factor: 6 to 12



Relation to range



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



The price to pay!

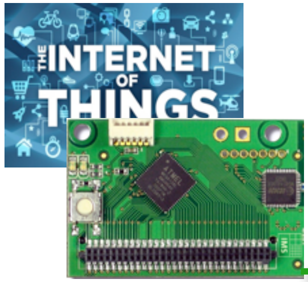
Very low throughput

Transmission time can be several seconds

Range

Throughput

LoRa mode	BW	CR	SF	time on air in second for payload size of 5 bytes	55 bytes	105 bytes	155 Bytes	205 Bytes	255 Bytes	max thr. for 255B in bps
1	125	4/5	12	0.95846	2.59686	4.23526	5.87366	7.51206	9.15046	223
2	250	4/5	12	0.47923	1.21651	1.87187	2.52723	3.26451	3.91987	520
3	125	4/5	10	0.28058	0.69018	1.09978	1.50938	1.91898	2.32858	876
4	500	4/5	12	0.23962	0.60826	0.93594	1.26362	1.63226	1.95994	1041
5	250	4/5	10	0.14029	0.34509	0.54989	0.75469	0.95949	1.16429	1752
6	500	4/5	11	0.11981	0.30413	0.50893	0.69325	0.87757	1.06189	1921
7	250	4/5	9	0.07014	0.18278	0.29542	0.40806	0.5207	0.63334	3221
8	500	4/5	9	0.03507	0.09139	0.14771	0.20403	0.26035	0.31667	6442
9	500	4/5	8	0.01754	0.05082	0.08154	0.11482	0.14554	0.17882	11408
10	500	4/5	7	0.00877	0.02797	0.04589	0.06381	0.08301	0.10093	20212



Energy consumption comparaison

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-40mA
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)

TX power: 30mA. Mean consumption: (8x30+3592x0.2)/3600=0.266mA

2500/0.266=9398h = 391 days = 13 months

Typical scenarios

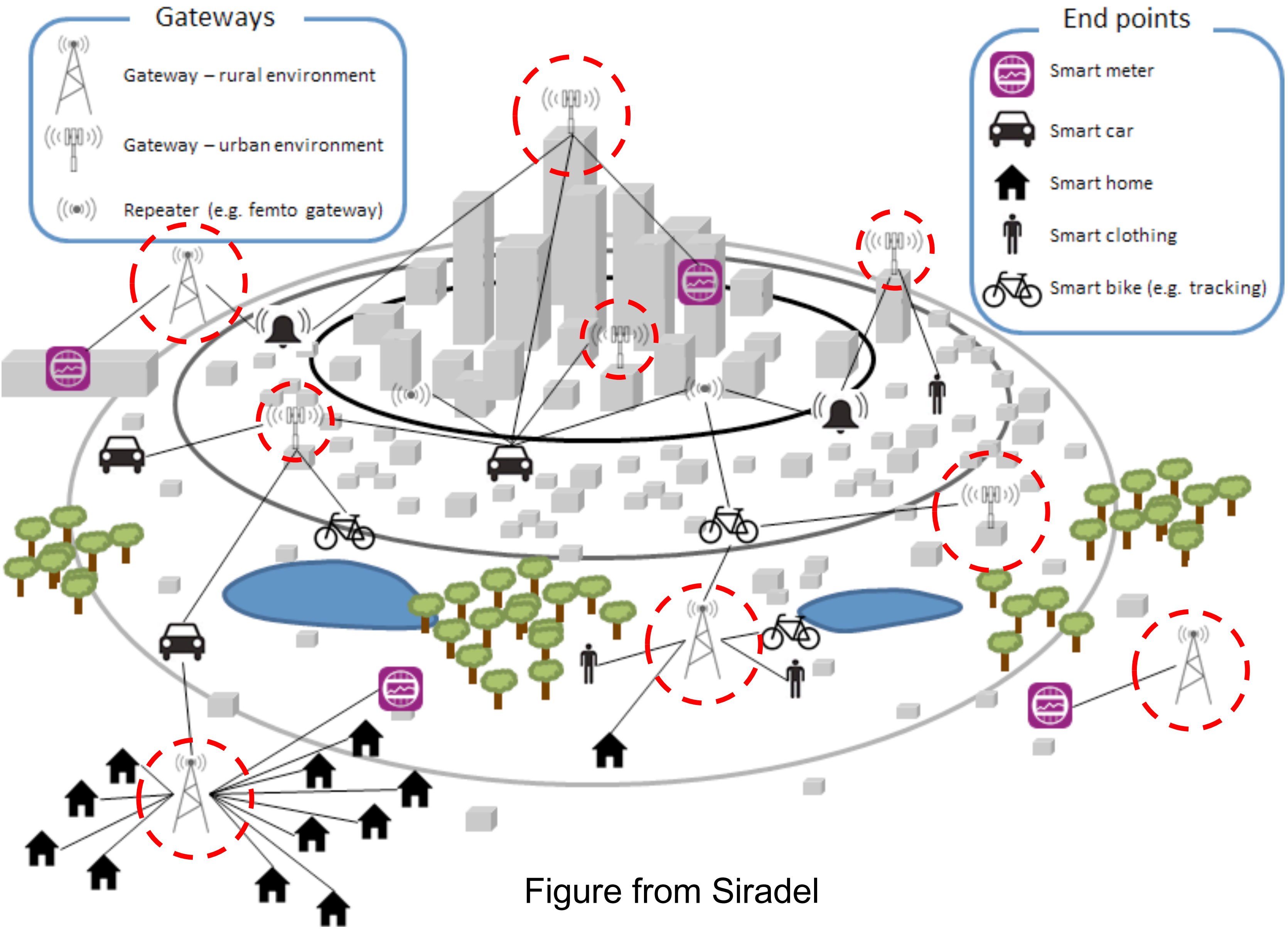
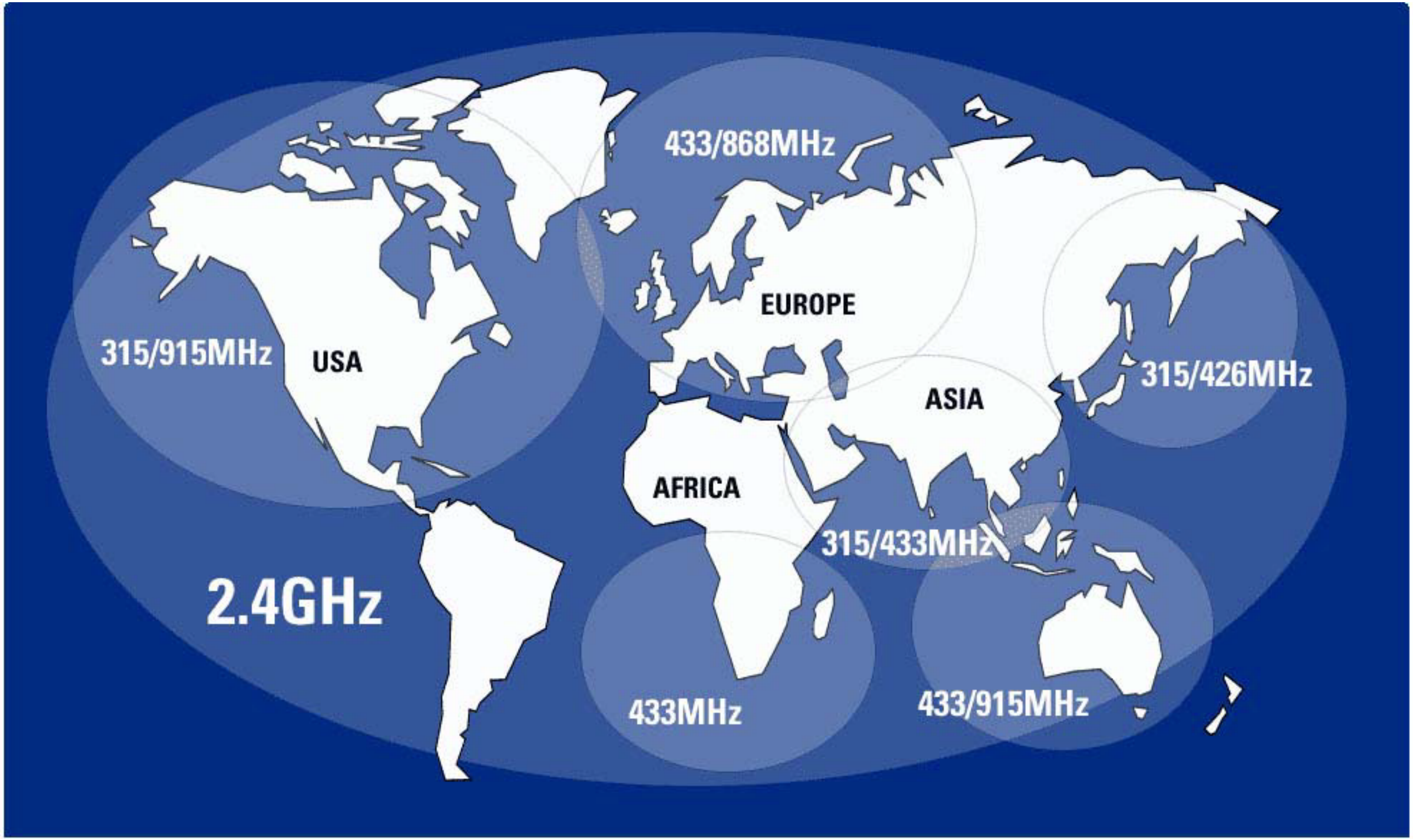
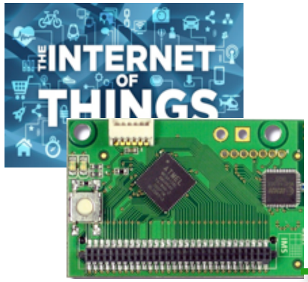


Figure from Siradel

The ISM/SRD License-Free Frequency Bands



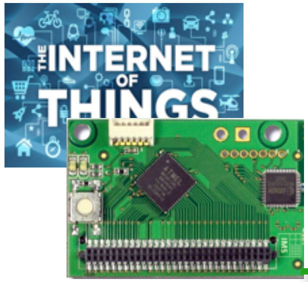


License-free Sub-GHz constraints

- 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



LoRa Alliance

Wide Area Networks for IoT

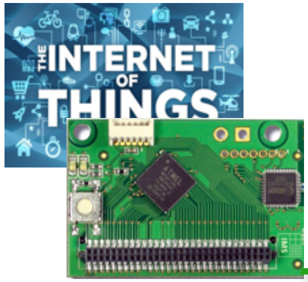
Sponsor members

actility, AUGTEK, bouygues, CISCO, ENDETEC HOMERIDER SYSTEMS, IBM, kerlink, kpn, M2M SPECTRUM NETWORKS, proximus, QOWISIO, SAGEMCOM, SEMTECH

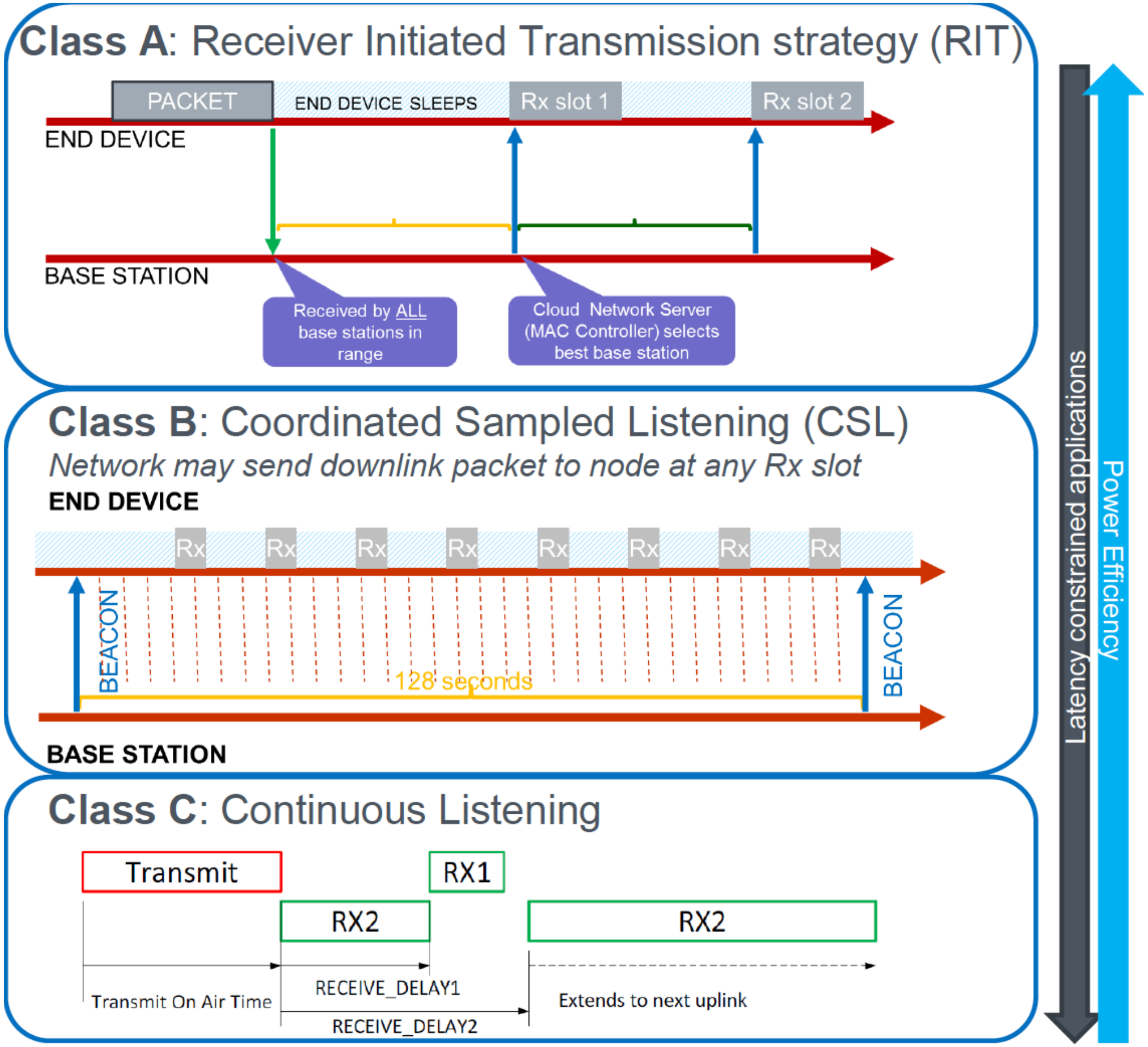
Contributor members

Adeunis RF, ESPOTEL, FastNet, FLASHNET, gemalto, IMST, Inmarsat, irdeto, LA POSTE, LACE, LinkLabs, M2B Communications Planning, MICROCHIP, MULTITECH, myDevices, OrbiWise, senet, SK telecom, stream, swisscom, Vision valley

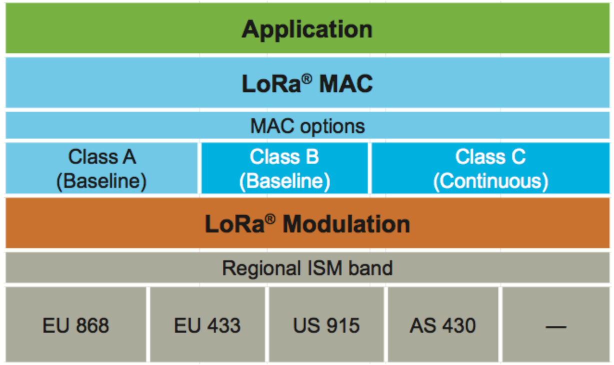
Adopter members

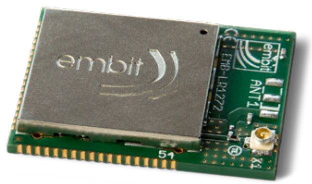


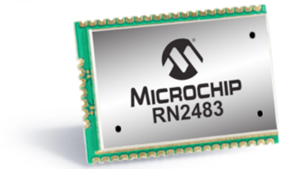
What is LoRaWAN?



LoRa Alliance
Wide Area Networks for IoT

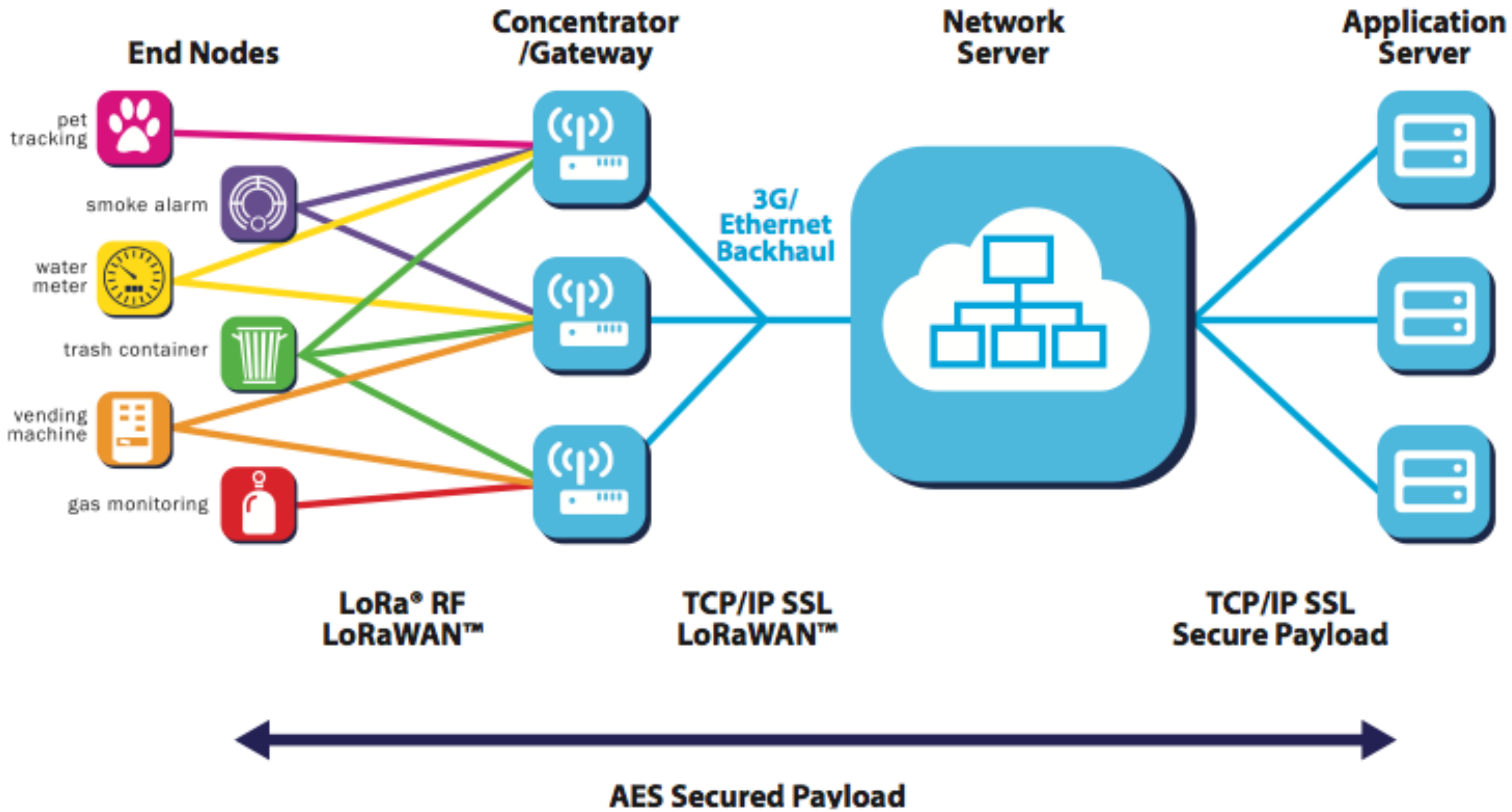






LoRa™ Long-Range Sub-GHz Module (Part # RN2483)

LoRaWAN architecture



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

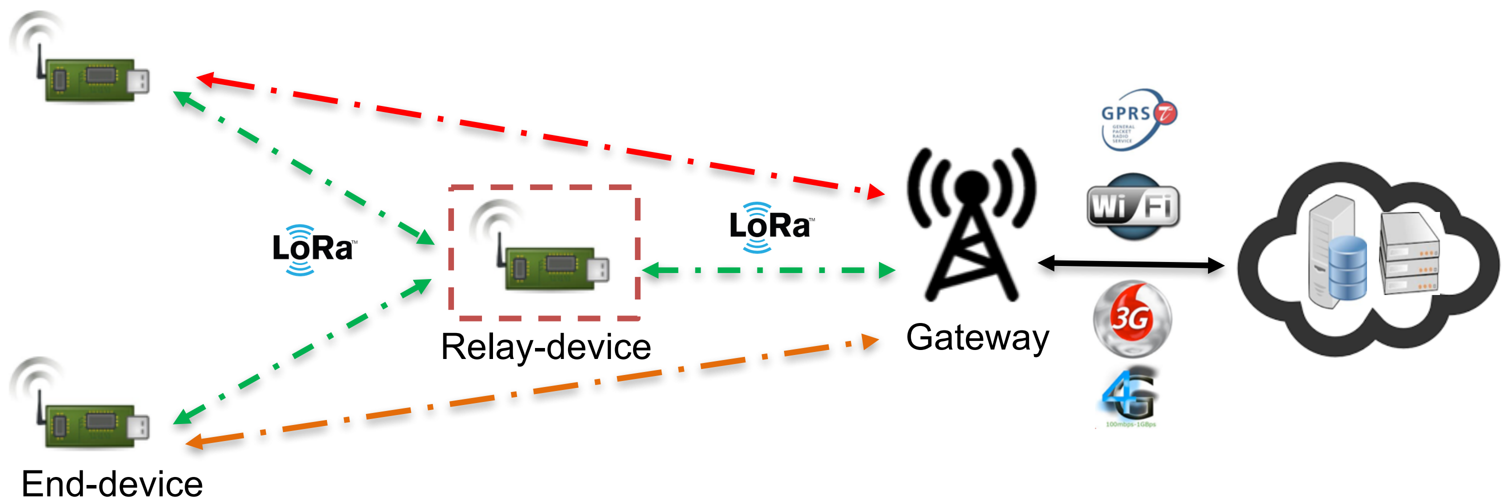
OTHER "LONG-RANGE" TECHNOLOGIES

Real-world deployment

- Provides 2-hop LoRa to solve some connectivity issues in real-world deployment scenario

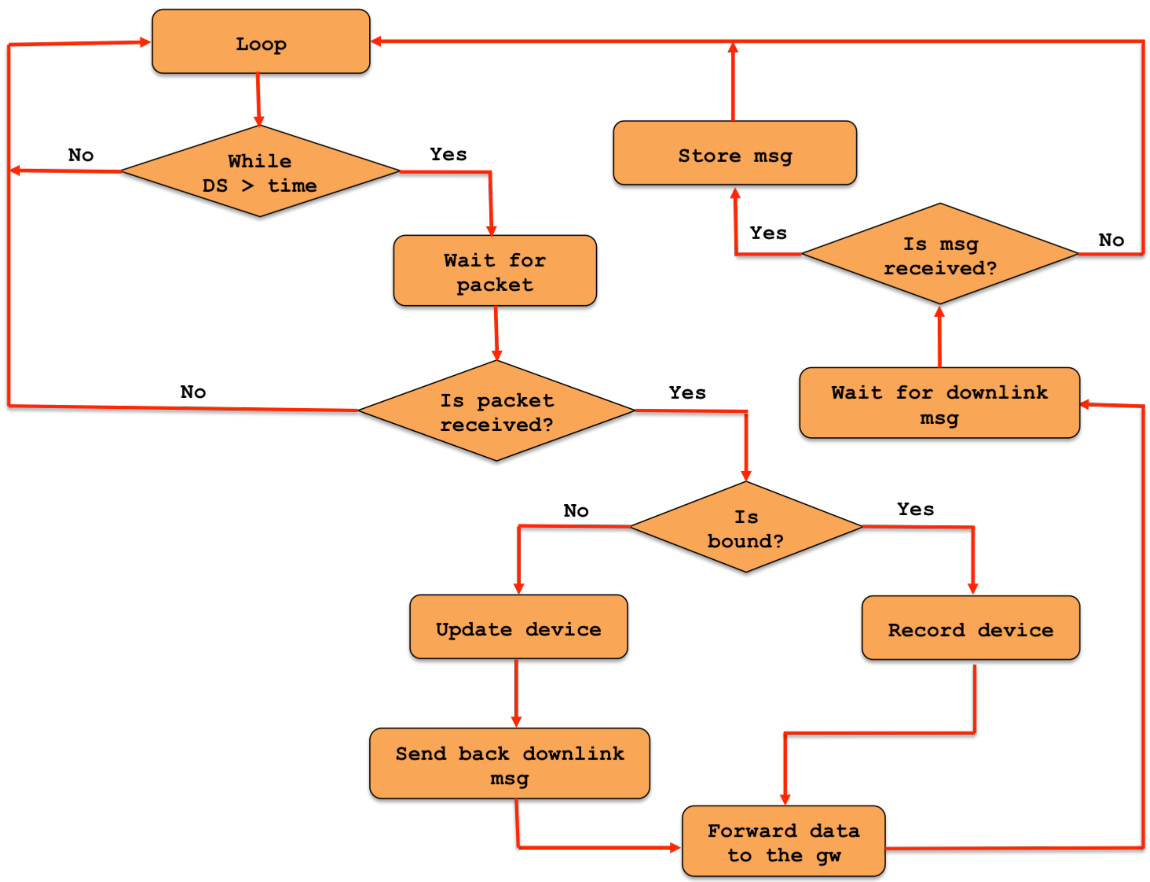
2-hop LoRa approach

- Objective is to have a **smart, transparent** relay node that can be inserted at anytime between end-devices and gateway



Smart relay device learning on-the-fly

- On-the-fly learning of incoming traffic from end-devices: the observation phase



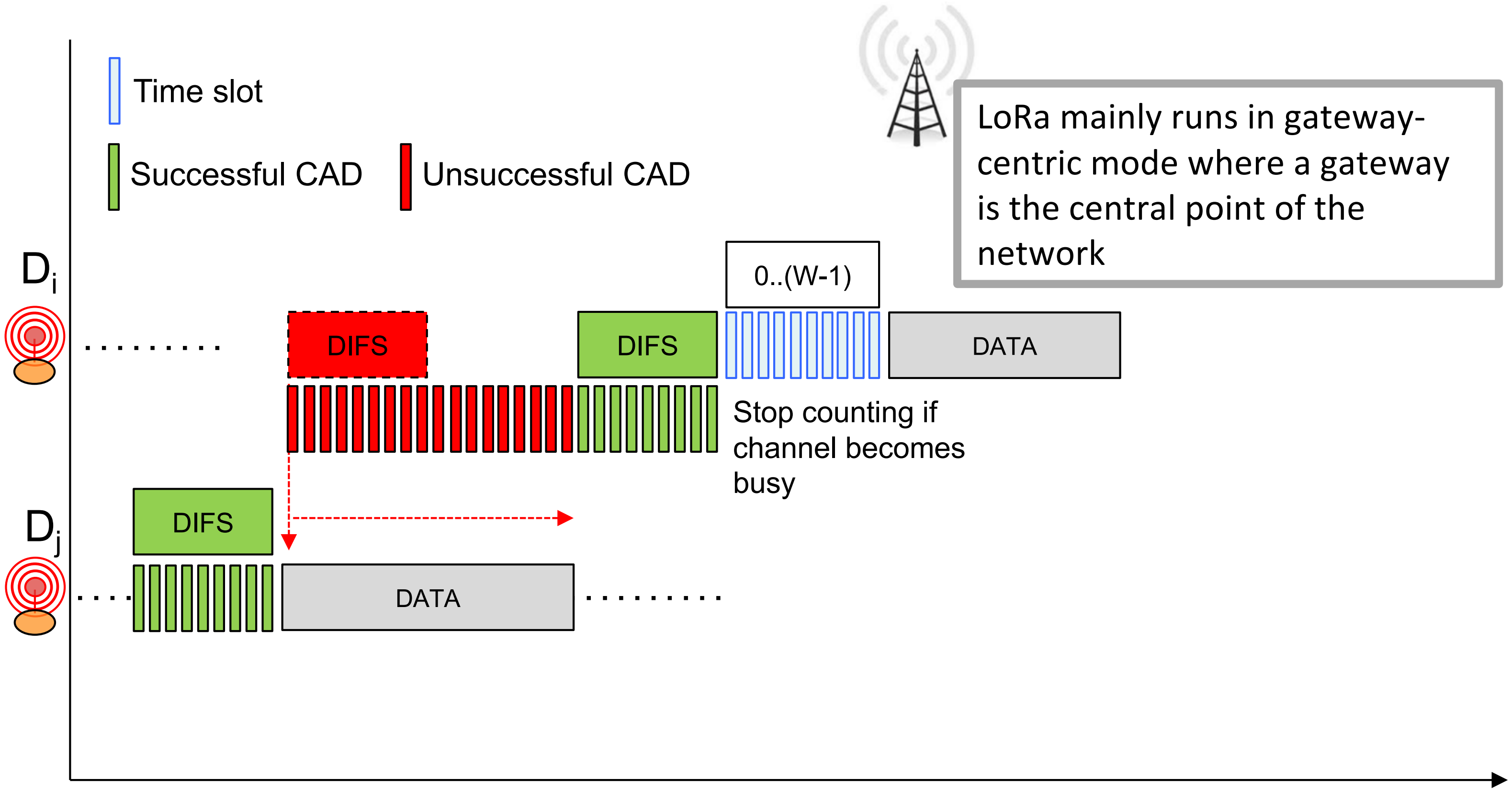
Robust channel access mechanisms

- With densier LoRa networks and more heterogeneous traffic (traditional+image sensors) it is necessary to provide a more robust channel access mechanism
- Objectives are to reduce packet collisions, thus reducing delivery latency, and reduce power consumption due to unsuccessfull transmissions

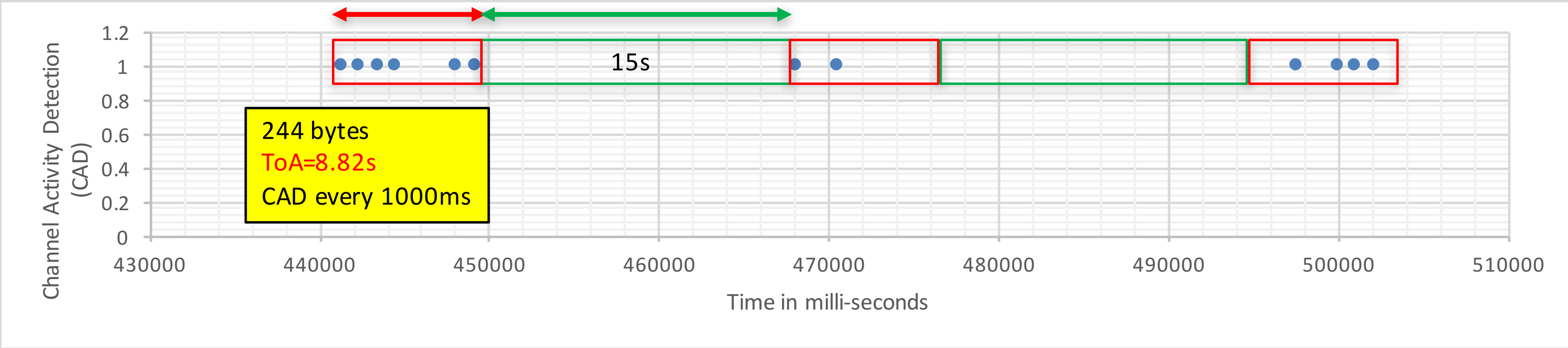
C. Pham, "Investigating and Experimenting CSMA Channel Access Mechanisms for LoRa IoT Networks", IEEE WCNC'2018.

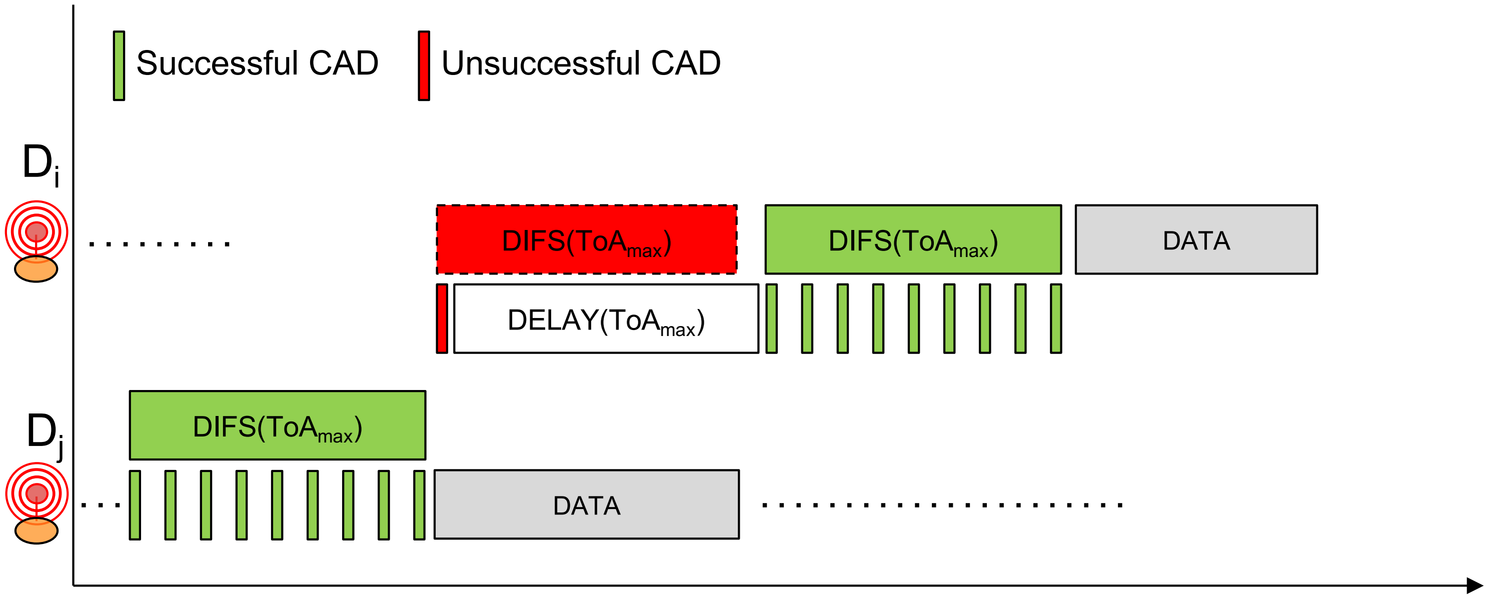
C. Pham, "Robust CSMA for Long-Range LoRa Transmissions with Image Sensing Devices", IEEE WD'2018.

CSMA-based derived from 802.11

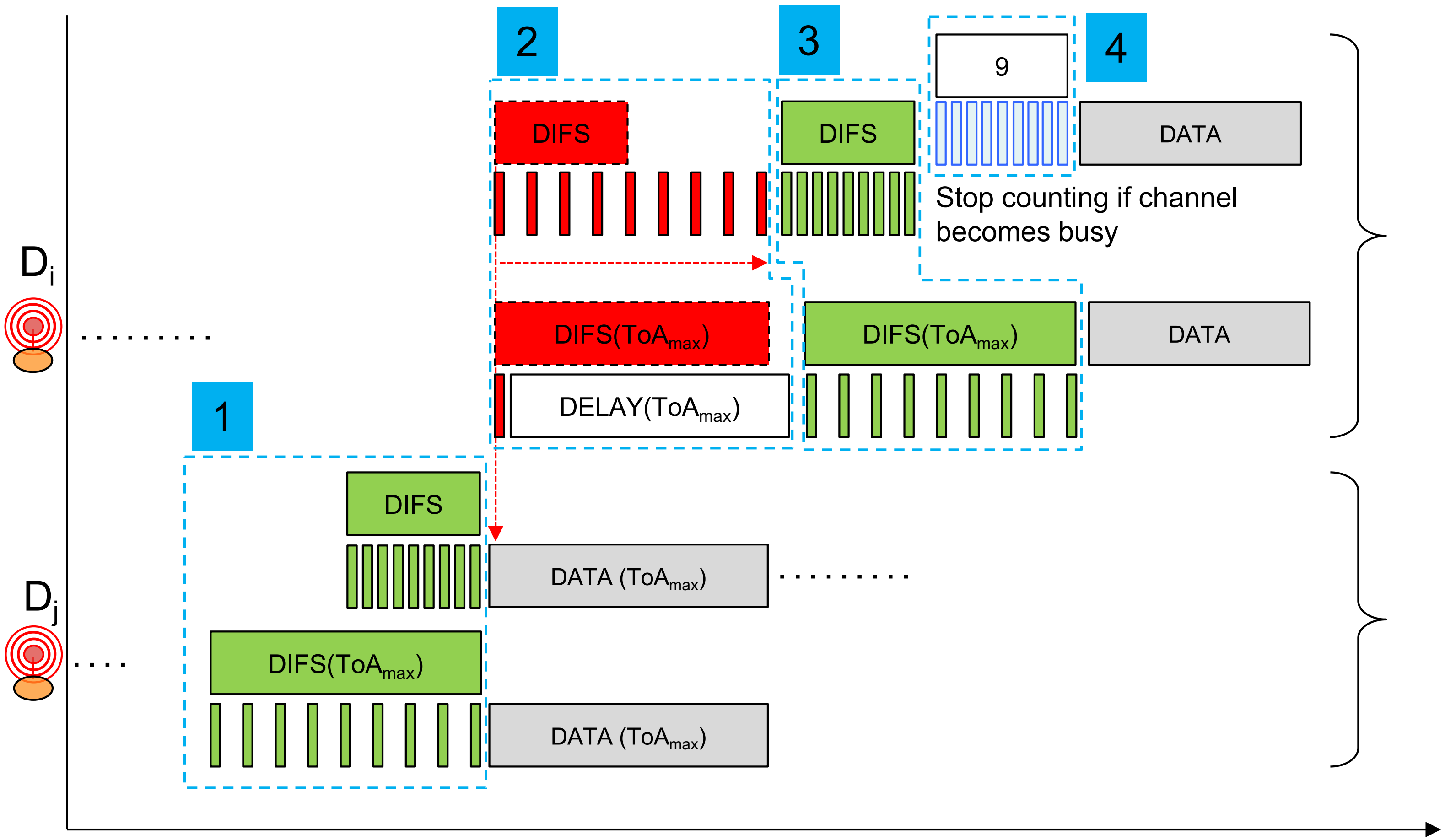


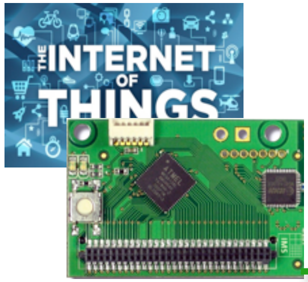
CSMA-based adapted to longer msg





CSMA alternatives & comparison





Quality of Service

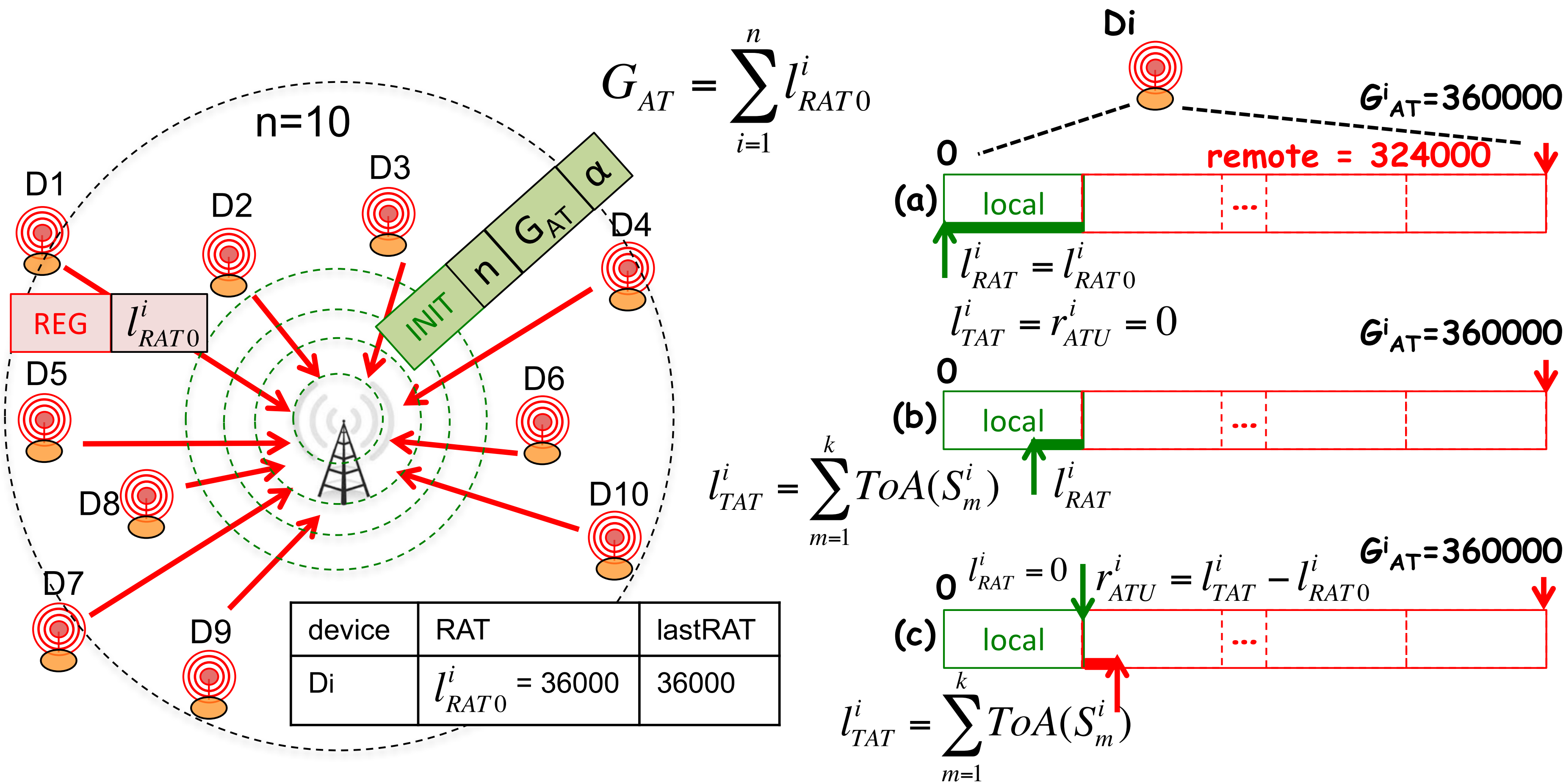
- Regulations stipulate that radio activity duty-cycle should be enforced at devices.
- LoRaWAN specification from LoRa Alliance is a first attempt to standardize LoRa networks but no issues on quality of service.
- Proposition of a Long-range Activity Sharing (LAS) mechanism when running under duty-cycle regulations
- Allow a device to be able to send critical data without having to wait for the next cycle

C. Pham, "Deploying a Pool of Long-Range Wireless Image Sensor with Shared Activity Time". Proceedings of the 11th IEEE WiMob'2015, October 19-21, 2015, Abu Dhabi, UAE.

C. Pham, "Towards Quality of Service for Long-range IoT in Unlicensed Radio Spectrum". IEEE Wireless Days (WD'2016), Toulouse, France, March 2016.

C. Pham, "QoS for Long-Range Wireless Sensors under Duty-Cycle Regulations with Shared Activity Time Usage". ACM Transactions on Sensor Networks, Vol. 12(4), 2016.

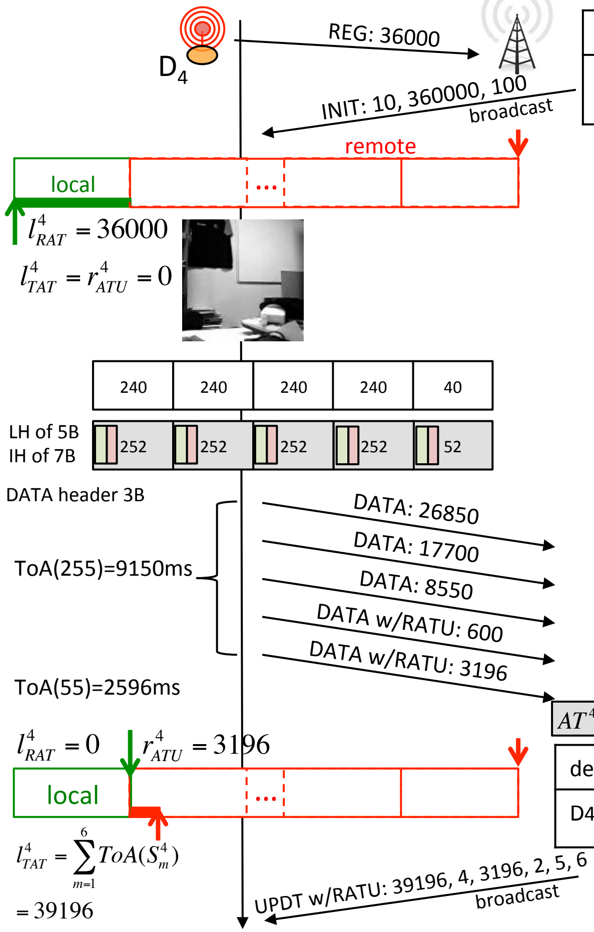
Long-range Activity Sharing (LAS)



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

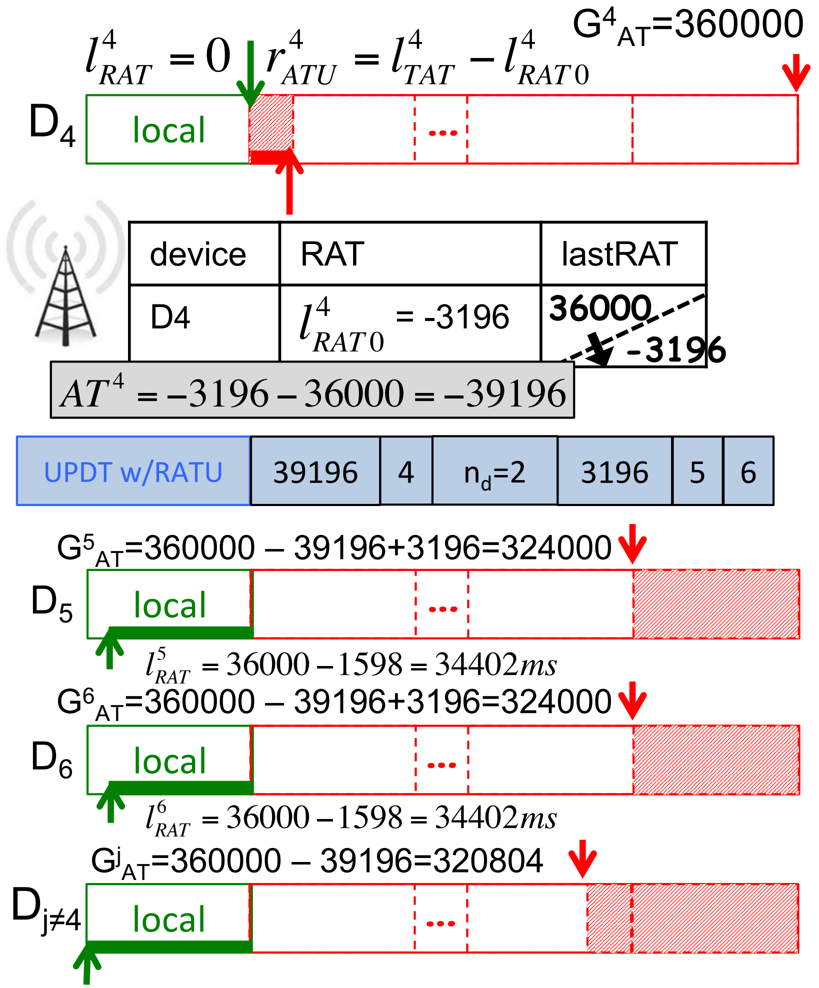
A device can transmit more if needed, provided that other devices will decrease their radio activity time accordingly.

Distributing Remote Activity Time Usage



device	RAT	lastRAT
D4	36000	36000
...		

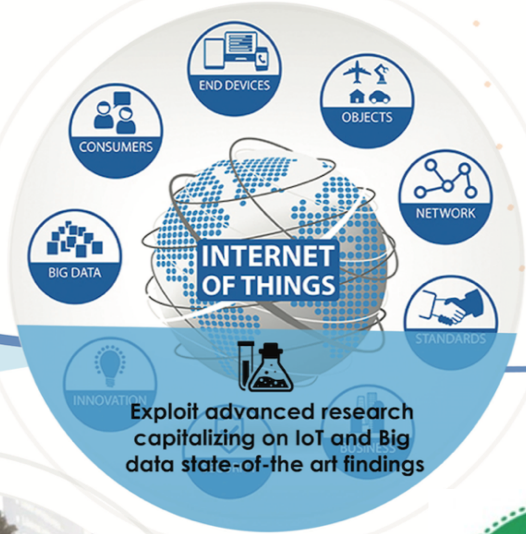
device	RAT	lastRAT
D4	-3196	~~36000~~ -3196



device	RAT	lastRAT
D4	l^4_{RAT0} = -3196	~~36000~~ -3196

WAZIUP Open IoT and Big data platform for Africans, by Africans

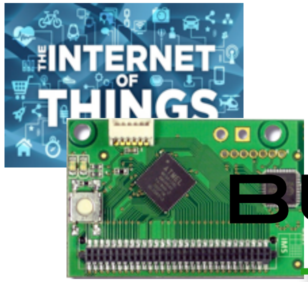
HORIZON 2020



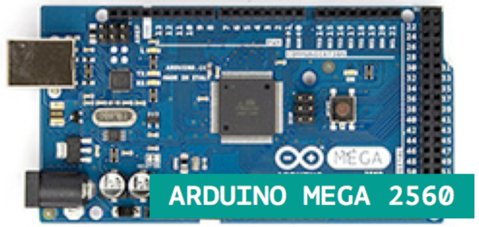
DO MORE with LESS

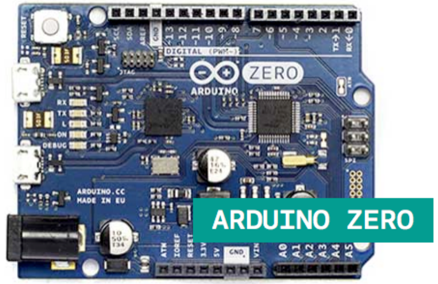
www.waziup.eu
Waziup IoT
Waziup IoT
Waziup
Waziup

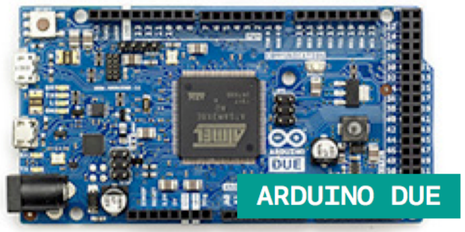
waziup.community@create-net.org

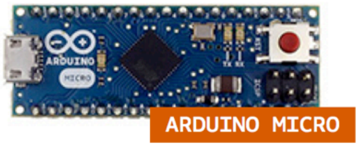


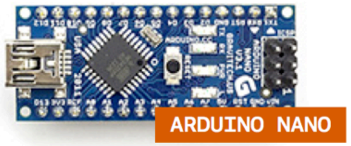
WAZIUP PROVIDES SW/HW BUILDING BLOCKS INTEGRATION

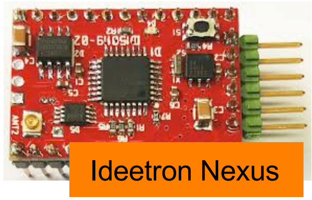


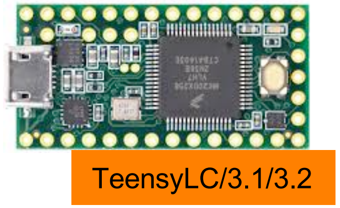


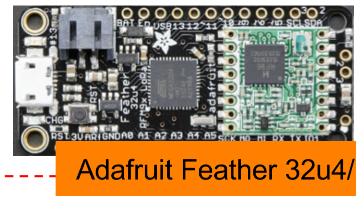








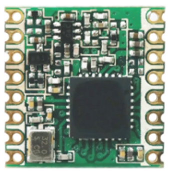




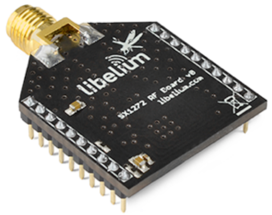
More to come…

LoRa™

LoRa radios that our library already supports



HopeRF RFM92W/95W



Libelium LoRa

Modtronix inAir9/9B

NiceRF LoRa1276

Long-Range communication library

Ready-to-use templates

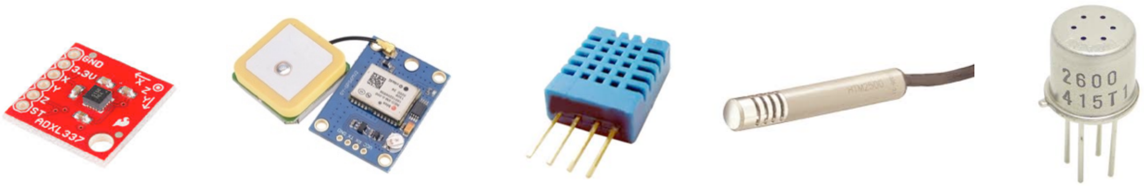
Moisture/
Temperature of
storage areas

10-15kms

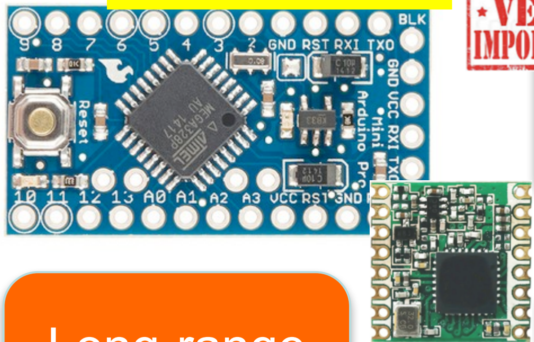
Physical sensor

Physical sensor

Physical sensor



Arduino Pro Mini @3.3V



Physical sensor mgmt

VERY IMPORTANT

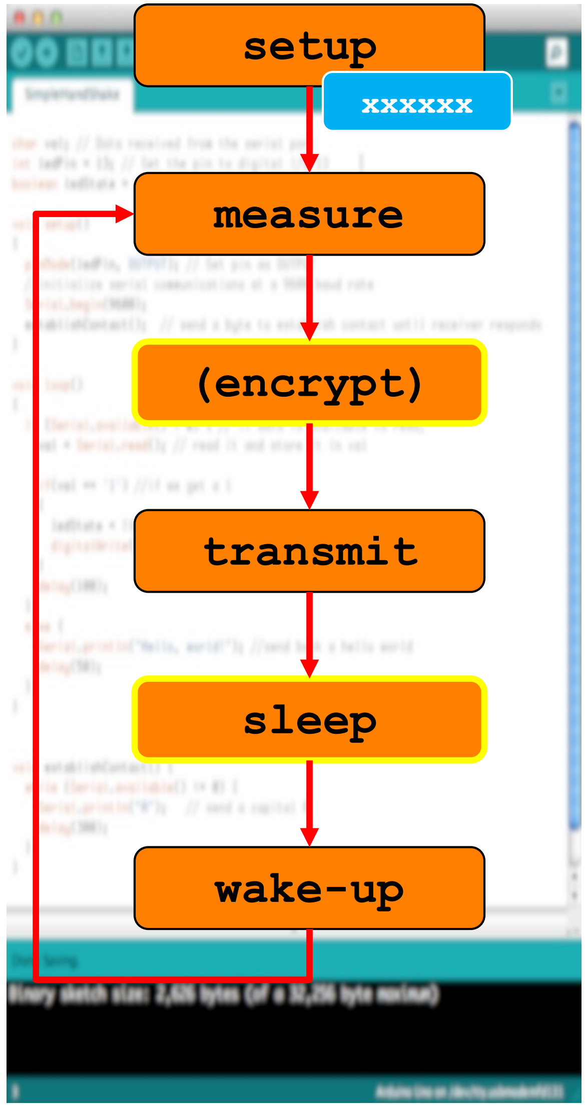
Activity duty-cycle, low power

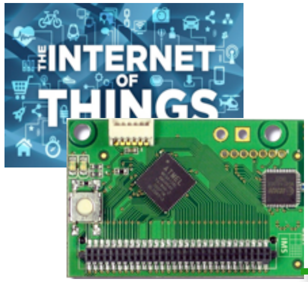
VERY IMPORTANT

AES encryption

Long-range transmission

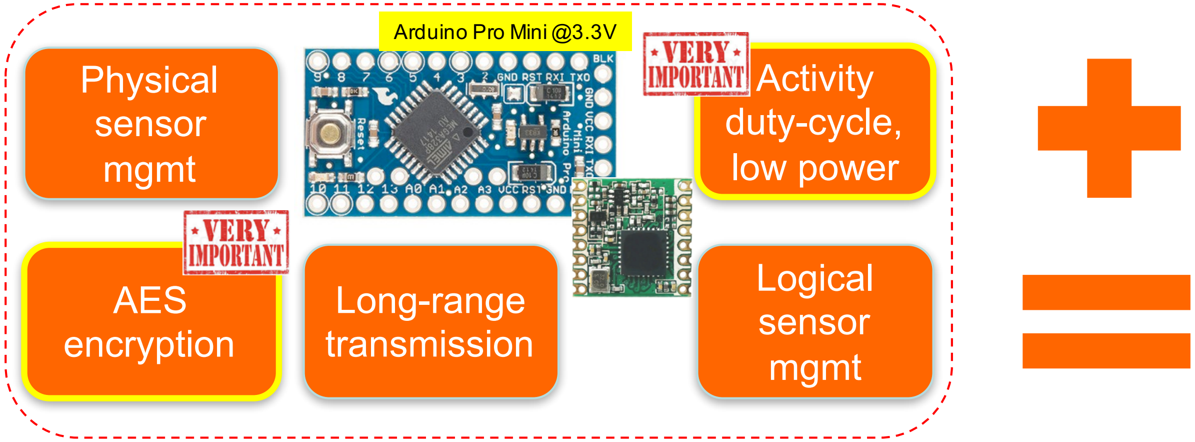
Logical sensor mgmt

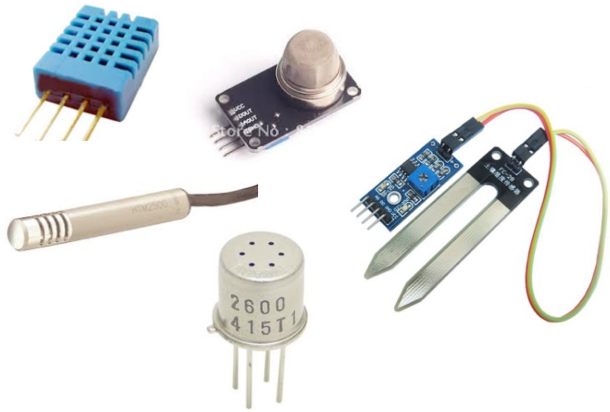


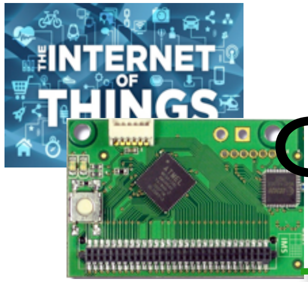


Generic sensing IoT device vs Highly specialized

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

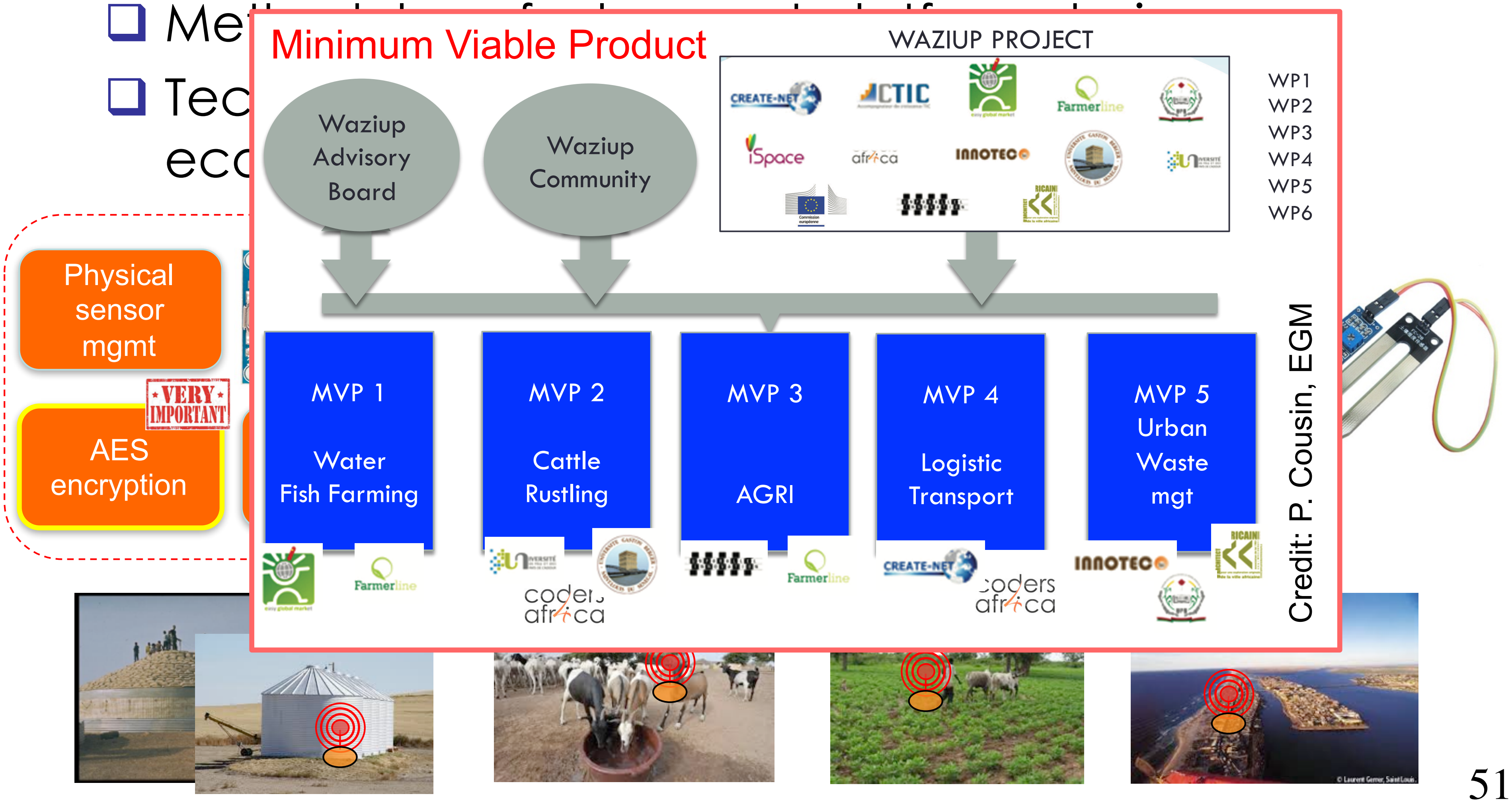






Generic sensing IoT device

- Build low-cost, low-power, Long-range enabled generic platform
- Me
- Tec eco



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.