Understand challenges and stakes of Internet of Things

Monday 14th, December
UGB, Saint-Louis, Senegal

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Comprendre les défis et les enjeux de l'Internet des Objets

Lundi 14 décembre
UGB, Saint-Louis, Senegal

Prof. Congduc Pham
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Université de Pau, France

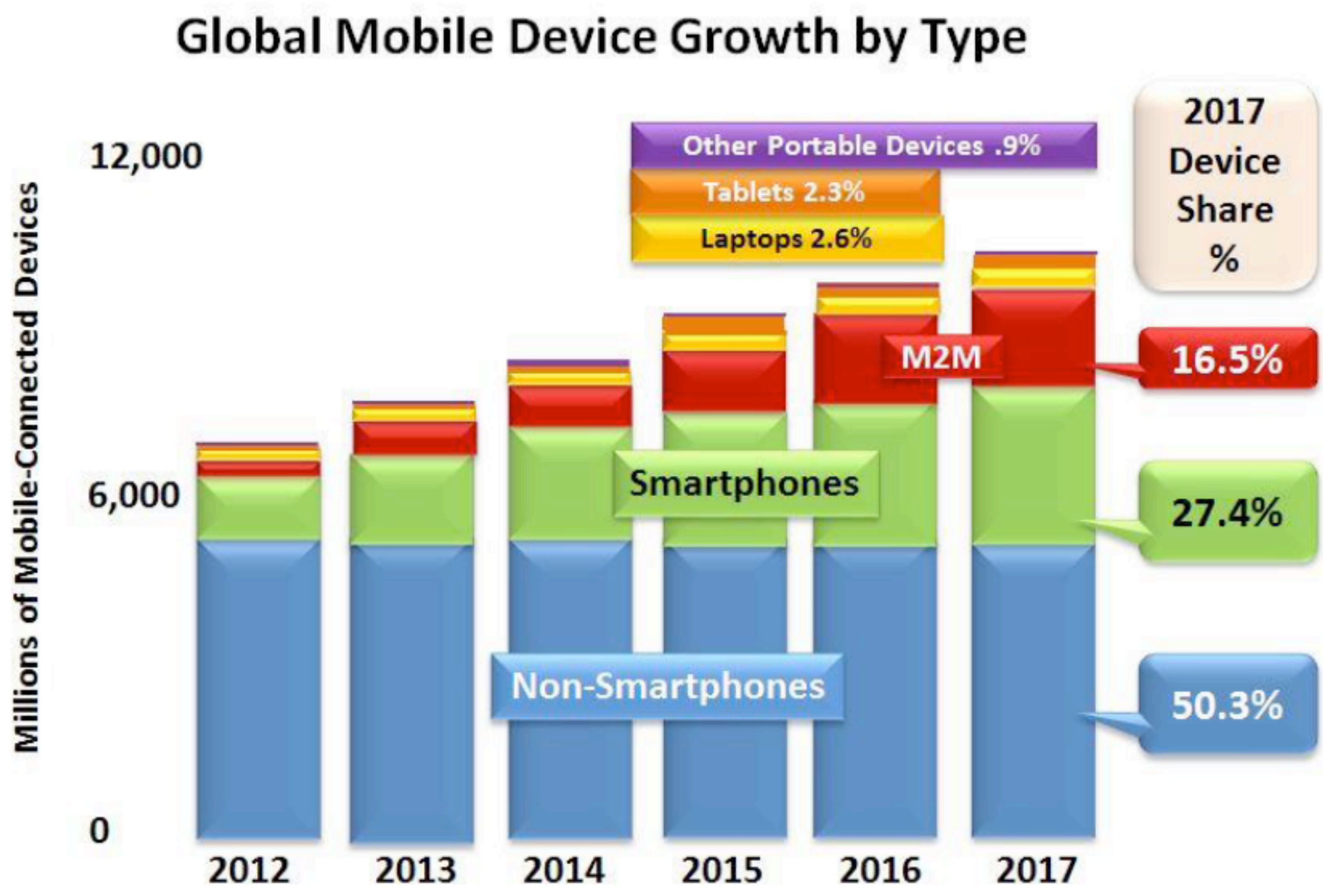
DIGITAL DEVICE DIVERSITY

Smartphones...

...Are not really part of IoT !!!

IoT, M2M, D2D,...

4G Americas / **4G Mobile Broadband Evolution: 3GPP Release 11 & Release 12 and Beyond** / February 2014

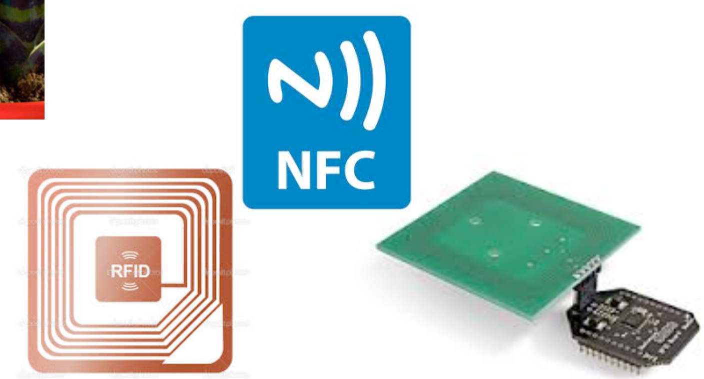


ADDING (WIRELESS) COMMUNICATION FEATURES TO OBJECTS!

- Native communication:

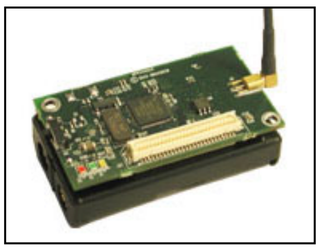
- Added communication
  - Active communication

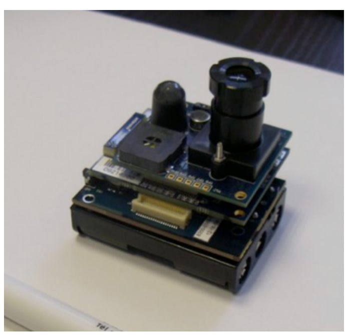
  - Passive communication

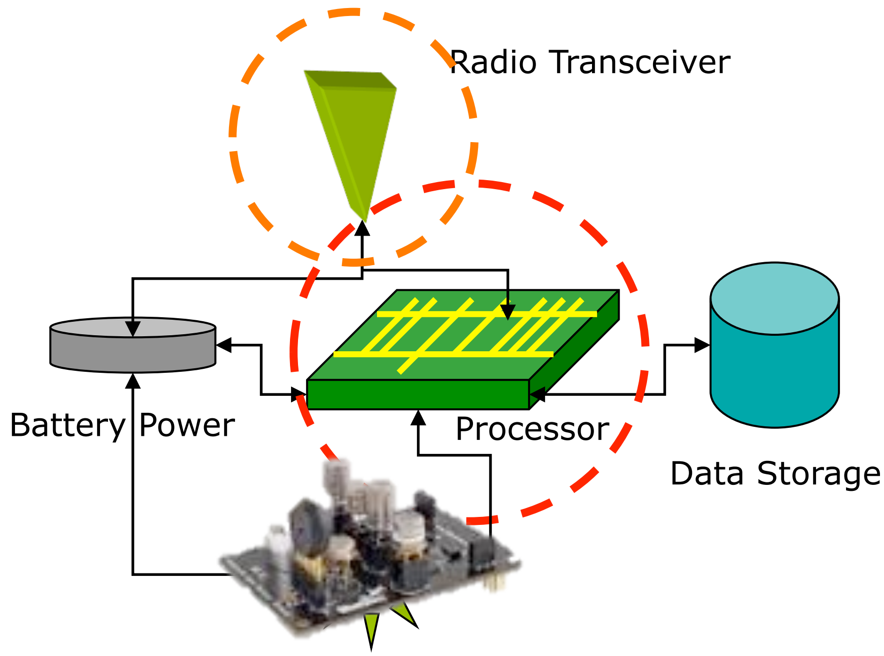


What's before IoT?

- Wireless Sensor Nodes/Networks
- Physical sensor + on-board processing

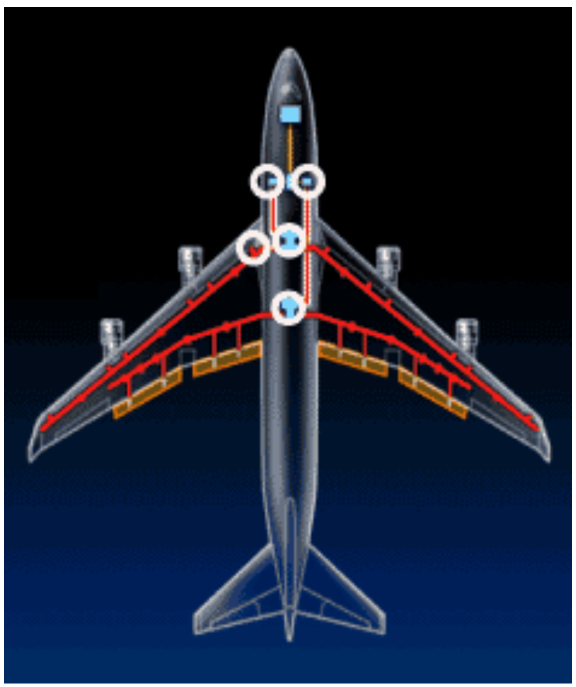


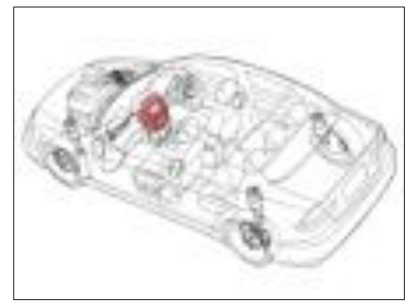




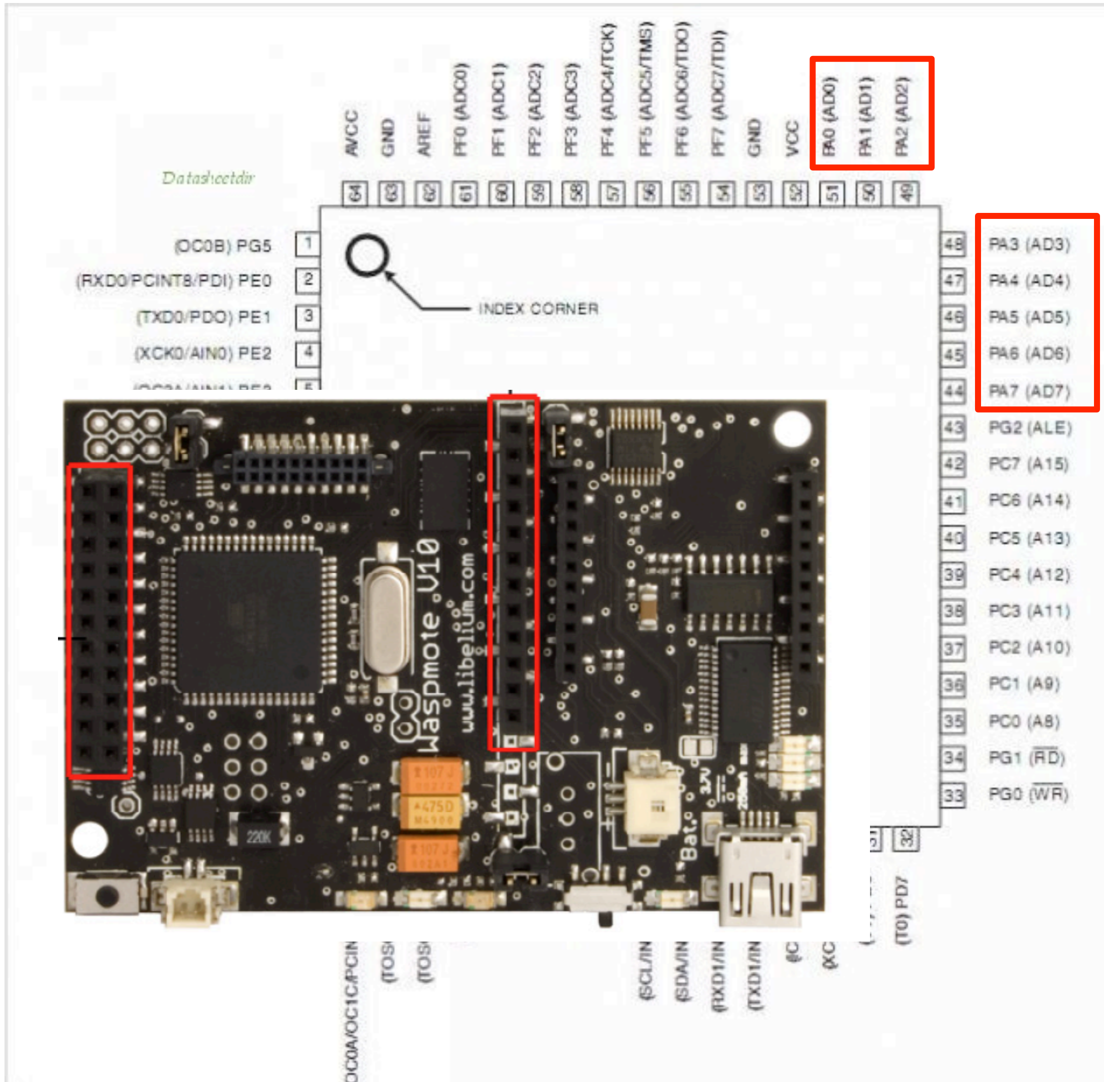
What's before WSN?

- Wire sensors
- Telemetry systems





Powerfull micro-controller boards...

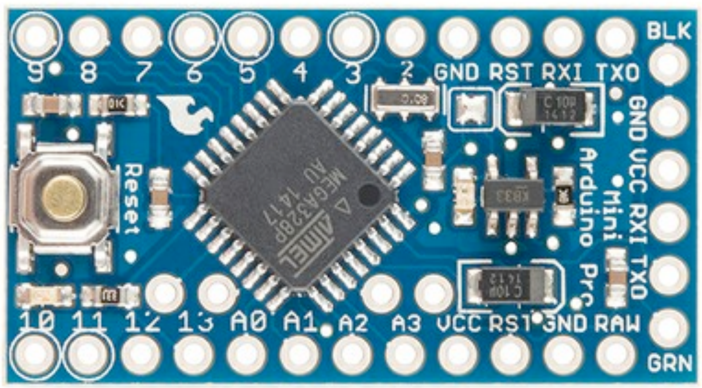


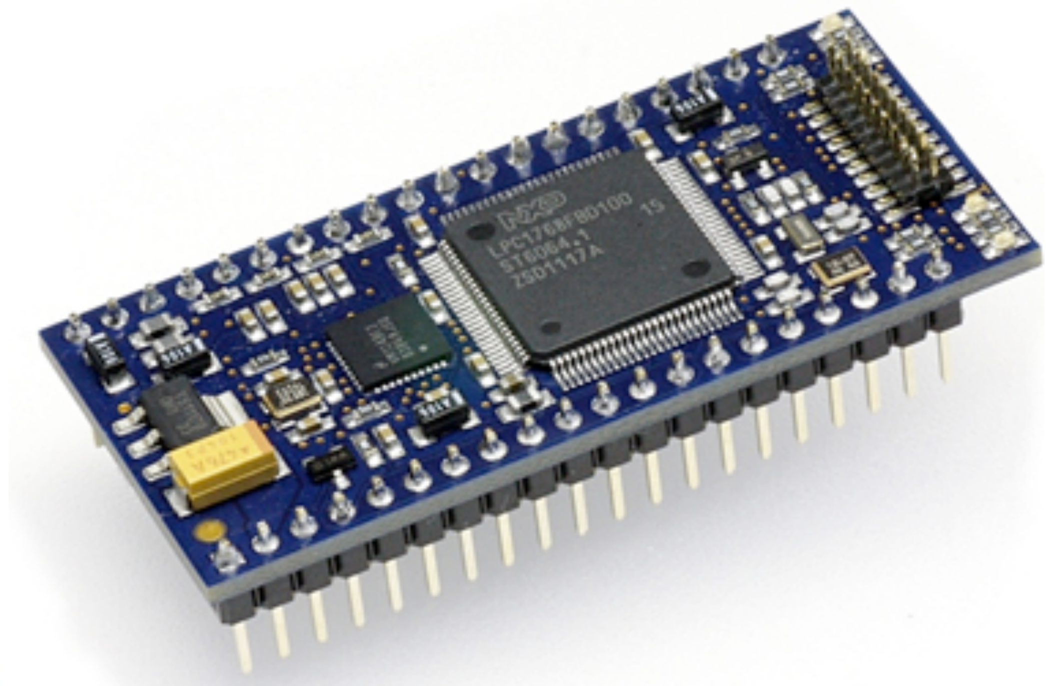
Input voltage between 0 and Vref (e.g. 3.3V). ADC usually have 10-bit resolution:

0 is for 0V
1014 is for 3.3V

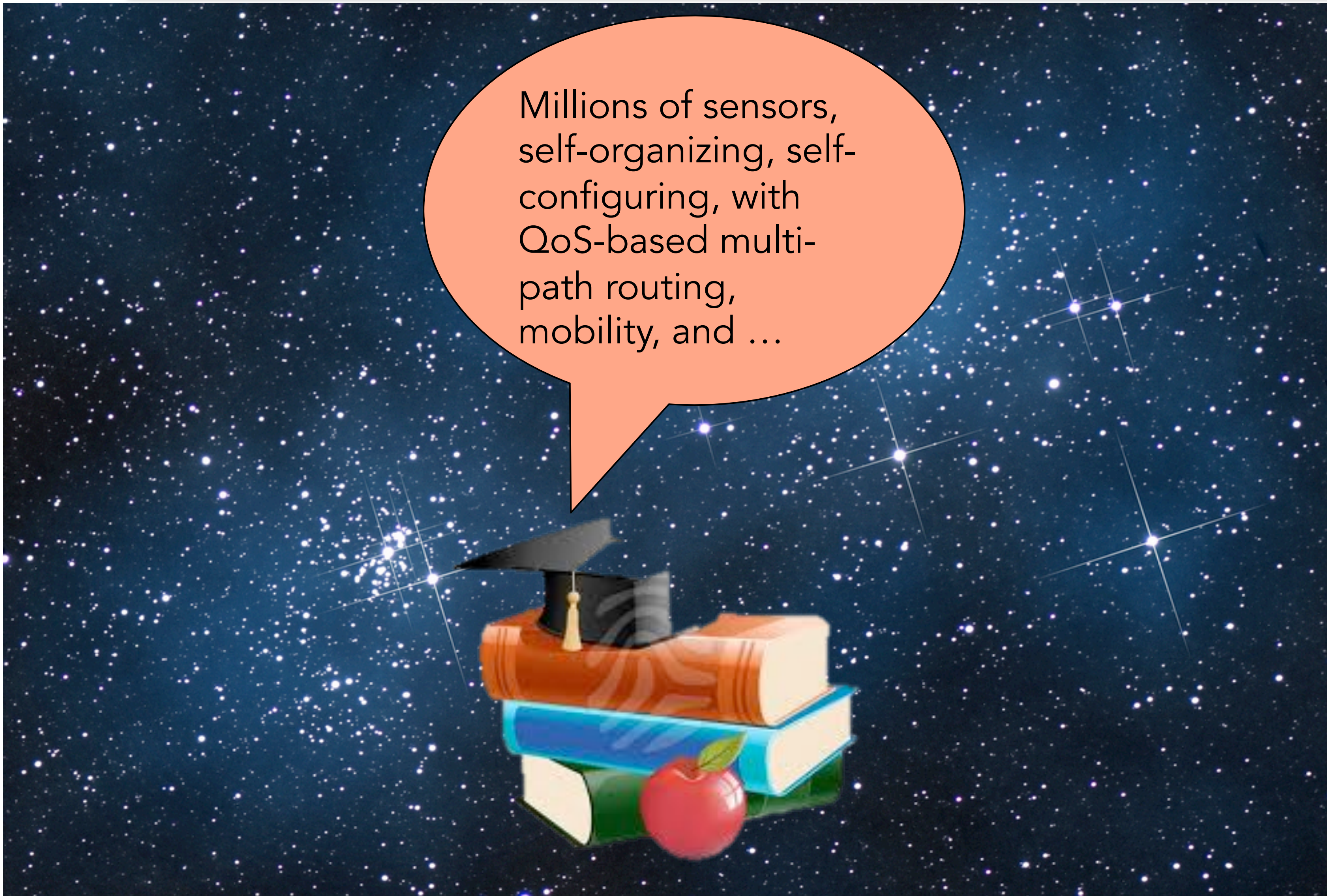
WaspMote figure from Libelium

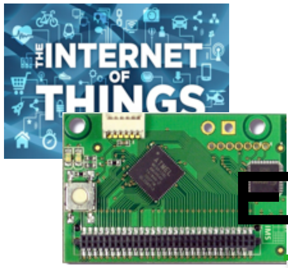
...GETTING SMALLER AND SMALLER !!



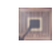


The early age, full of dreams!

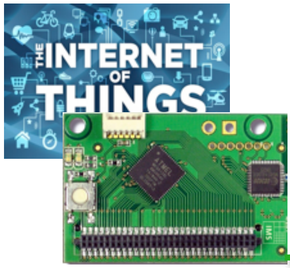




The idea of a digital ecosystem has emerged



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



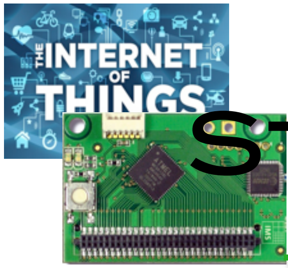
Step 1: measuring the physical world

Sensing

Step 2: store, process

Pervasive Systems

Sensing



Step 3: Connect, Interact

Pervasive Systems

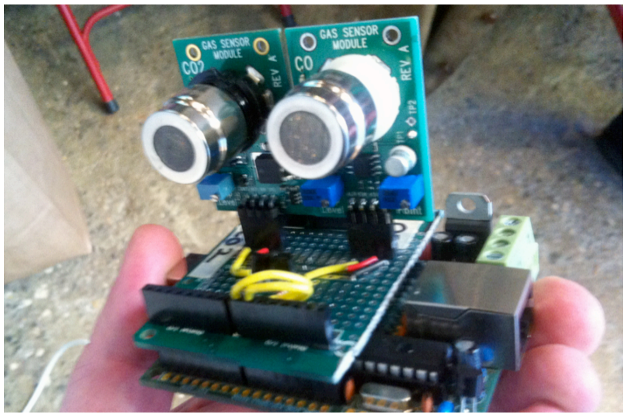
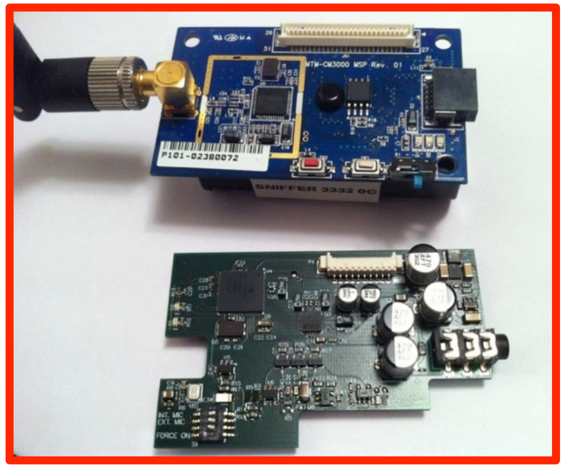
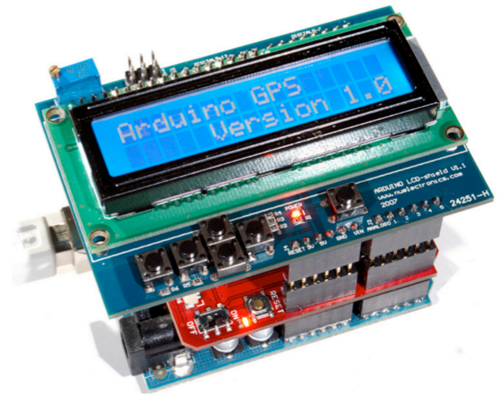
↓

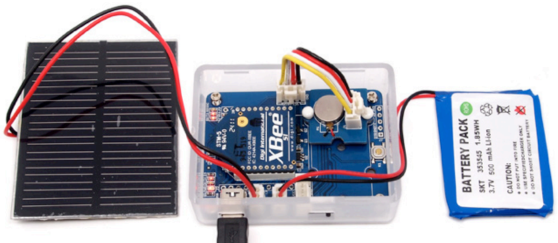
Sensing

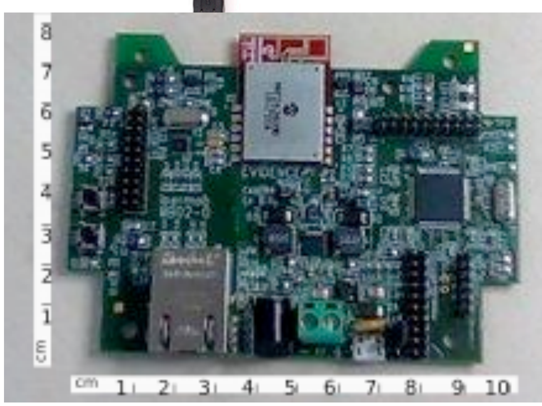
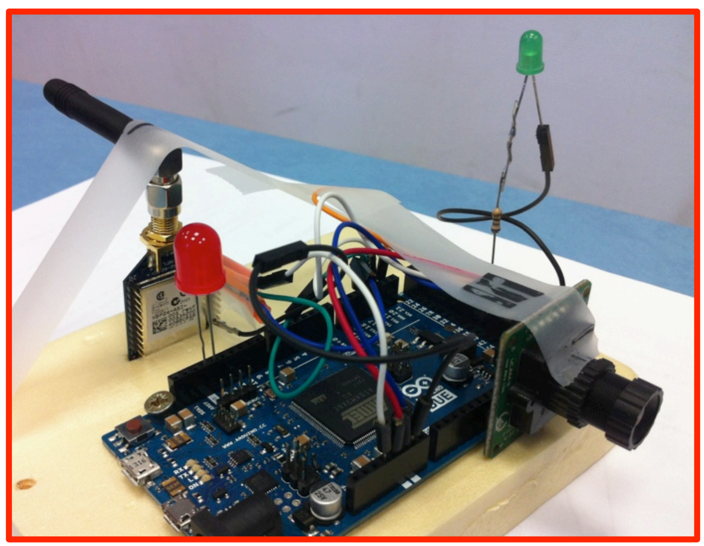
↓

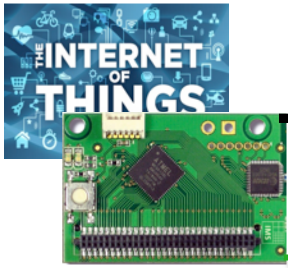
Peoples, Infrastructures, Buildings, Vehicules,...

From custom developments...

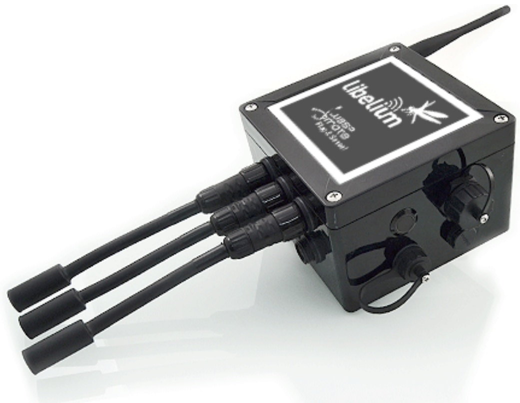






…To maturation of the IoT market



Step 4: Control, Optimize & Instrument !

DATA ANALYSIS, OPTIMIZATION & CONTROL

↓

PERVASIVE SYSTEMS

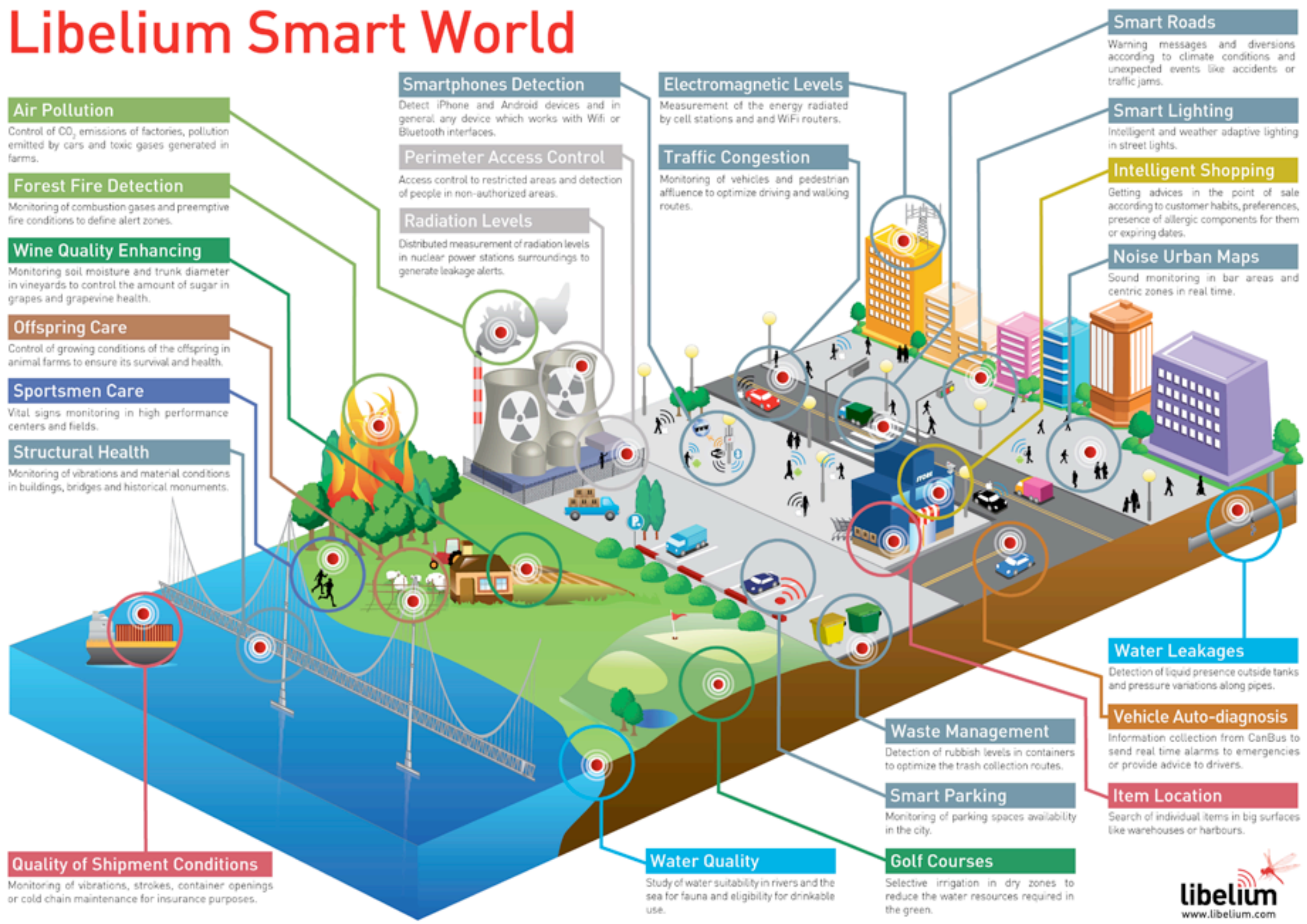
↓

SENSING

↓

PEOPLES, INFRASTRUCTURES, BUILDINGS, VEHICULES

Smart Cities



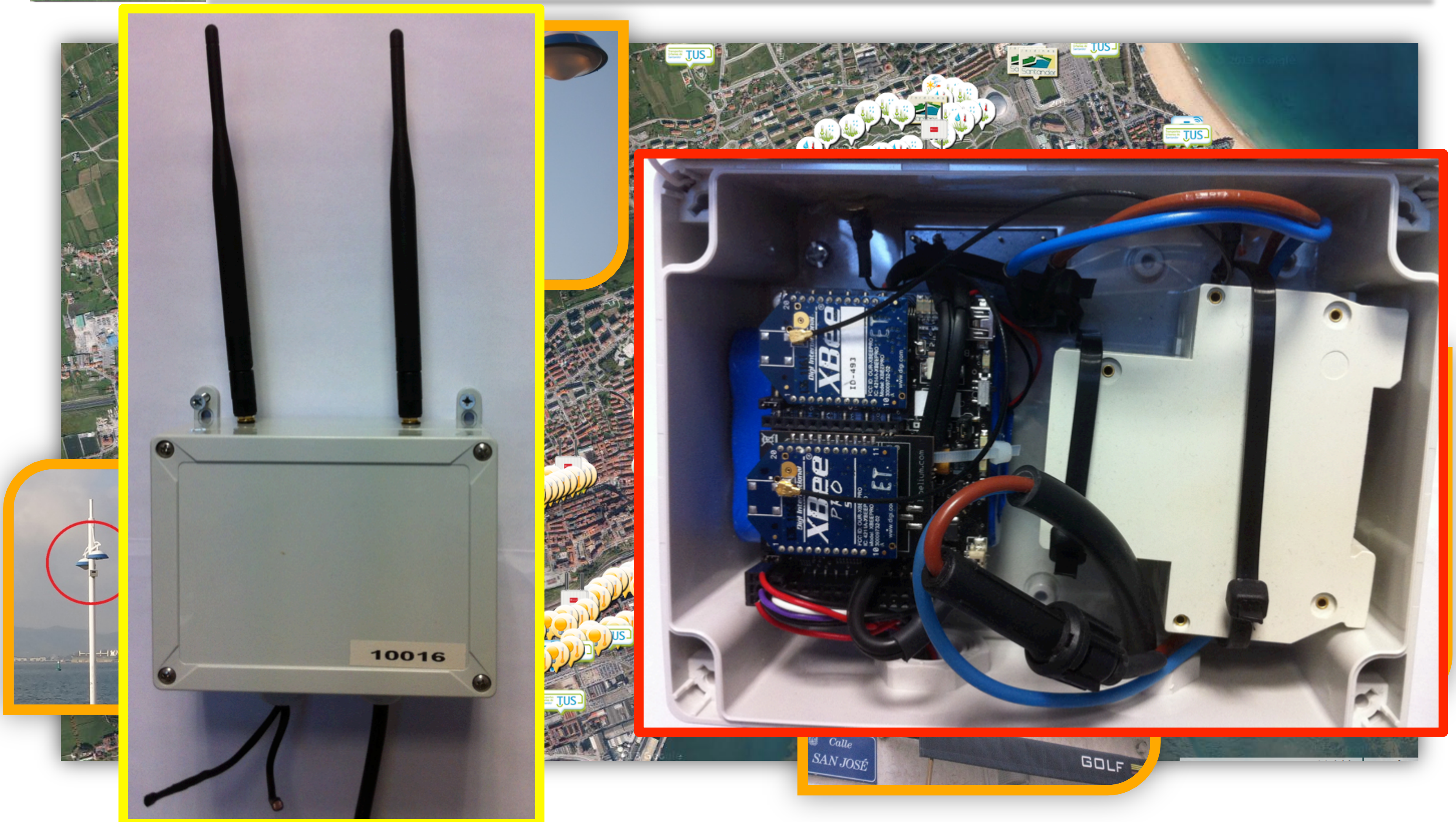
HTTP://WWW.LIBELIUM.COM/TOP_50_IOT_SENSOR_APPLICATIONS_RANKING/#SHOW_INFOGRAPHIC

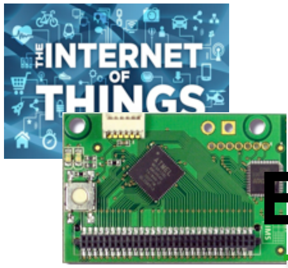
SmartSantander

www.smartsantander.eu

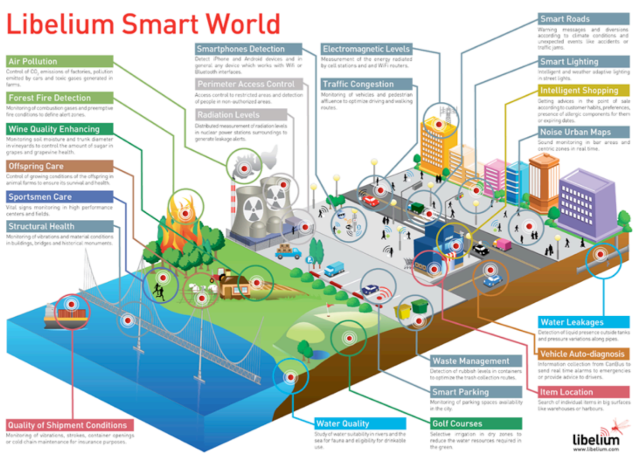
SmartSantander test-bed

Sensor network deployment



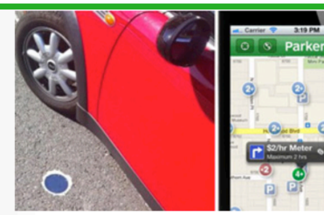


Smart Cities with real business model behind!



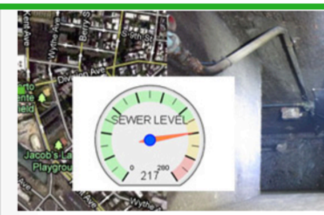
KEEP STREETS CLEAN

Products like the cellular communication enabled Smart Belly trash use real-time data collection and alerts to let municipal services know when a bin needs to be emptied. This information can drastically reduce the number of pick-ups required, and translates into fuel and financial savings for communities service departments. // Visit



STOP DRIVING IN CIRCLES

With the use of installed sensors, mobile apps, and real-time web applications like those provided in Streetline's ParkSight service, cities can optimize revenue, parking space availability and enable citizens to reduce their environmental impact by helping them quickly find an open spot for their cars. // Visit

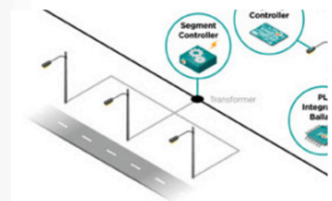


RECEIVE POLLUTION WARNINGS

The DontFlushMe project by Leif Percifield is an example that combines sensors installed in Combined Sewer Overflows (CSOs) with alerts to local residents so they can avoid polluting local waterways with raw sewage by not flushing their toilets during overflow events. // Visit

USE ELECTRICITY MORE EFFICIENTLY

The SenseNET system uses battery-powered clamp sensors to quickly measure current on a line, calculate consumption levels, and send that data to a hosted application for analysis. Significant financial and energy resources are saved as the clamps can easily identify meter tampering issues, general malfunctions, and any installation issues in the system. // Visit



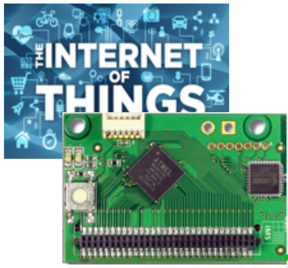
LIGHT STREETS MORE EFFECTIVELY

This smart lighting system from Echelon allows a city to intelligently provide the right level of lighting needed by time of day, season, and weather conditions. Cities have shown a reduction in street lighting energy use by up to 30% using solutions like this. // Visit

SHARE YOUR FINDINGS

AirCasting is a platform for recording, mapping, and sharing health and environmental data using your smartphone. Each AirCasting session lets you capture real-world measurements (Sound levels recorded by their phone microphone; Temperature, humidity, carbon monoxide (CO) and nitrogen dioxide (NO2) gas concentrations), and share it via the CrowdMap with your community. // Visit

http://www.postscapes.com/internet-of-things-examples/

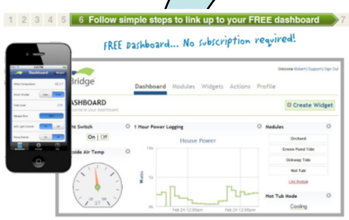


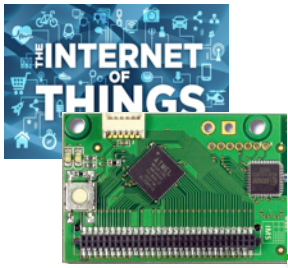
Link with Big Data!

Pervasive Systems

Sensing

Peoples, Infrastructures, Buildings, Vehicules





IoT cloud?

Dropbox

Firebase

FIWARE

Axeda®

ioBridge®
Connect things.

ThingSpeak

GroveStreams

SensorCloud™

freeboard

dweet.io

OpenRemote

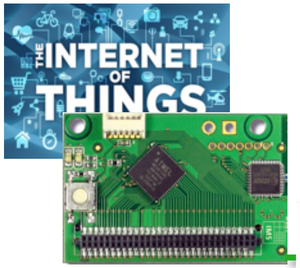
TempoIQ

Who is concerned?

Societal needs

- In support of rural activities
  - Agriculture, precise irrigation
  - Storage premises, silos
  - Cattle rustling
- Health
  - Water quality
  - Pollution detection
- Logistics
  - Goods transportation
  - Tracking & Monitoring of travel conditions
- …and a lot more, depending on your imagination



EU H2020 WAZIUP

HORIZON 2020 · UNIVERSITÉ DE PAU ET DES PAYS DE L'ADOUR · UNIVERSITÉ GASTON BERGER SAINT-LOUIS DU SÉNÉGAL · WAZIUP *Open up for innovation*

- The WAZIUP project is a collaborative research project using cutting edge technology applying IoT and Big Data to improve the working conditions in the rural ecosystem of Sub-Saharan Africa
- WAZIUP has support from multiple African stakeholders with the aim of defining new innovation space to advance the African Rural Economy
- WAZIUP will deliver a communication and big data application platform and generate locally the know how by training by use case and examples

1ST ISSUE: COLLECT DATA

DATA ANALYSIS, OPTIMIZATION & CONTROL

PERVASIVE SYSTEMS

SENSING

PEOPLES, INFRASTRUCTURES, BUILDINGS, VEHICULES

Wireless Communication made easy

Wi Fi
wimax
ZigBee® Member
4G
100mbps-1GBps
3G
Lte™
WiMedia ALLIANCE

But connectivity is still a challenge

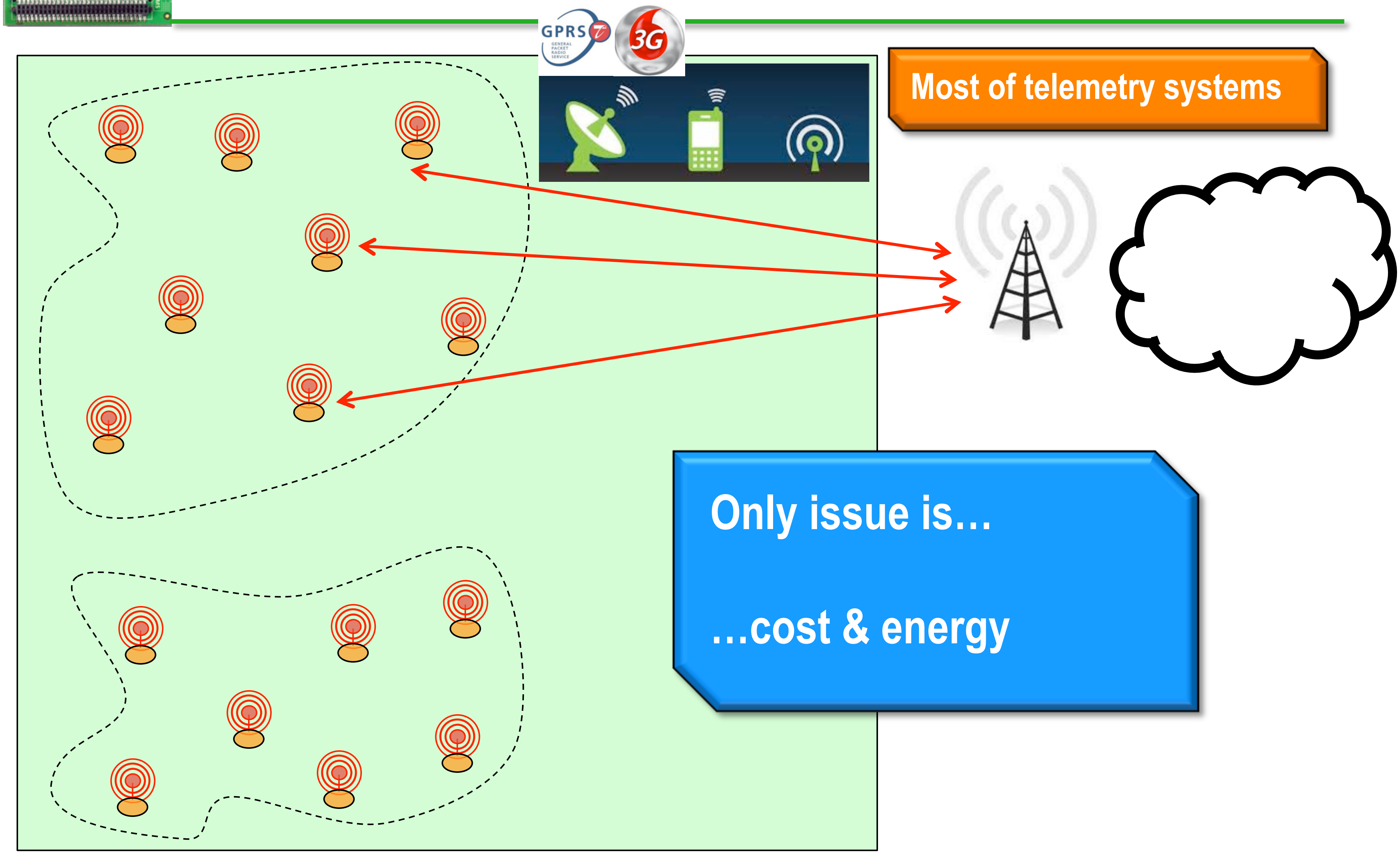
Internet of Objects
80% of volume

Requirements:

- How to connect Low Cost Assets or having no Energy source, non rechargeable?
- Low Cost communication
- Low Cost Infrastructure
- Low Power Technology
- Robust Communication
- Allowing Mobility
- Scalability

Slide from Semtech

1-HOP COMMUNICATION

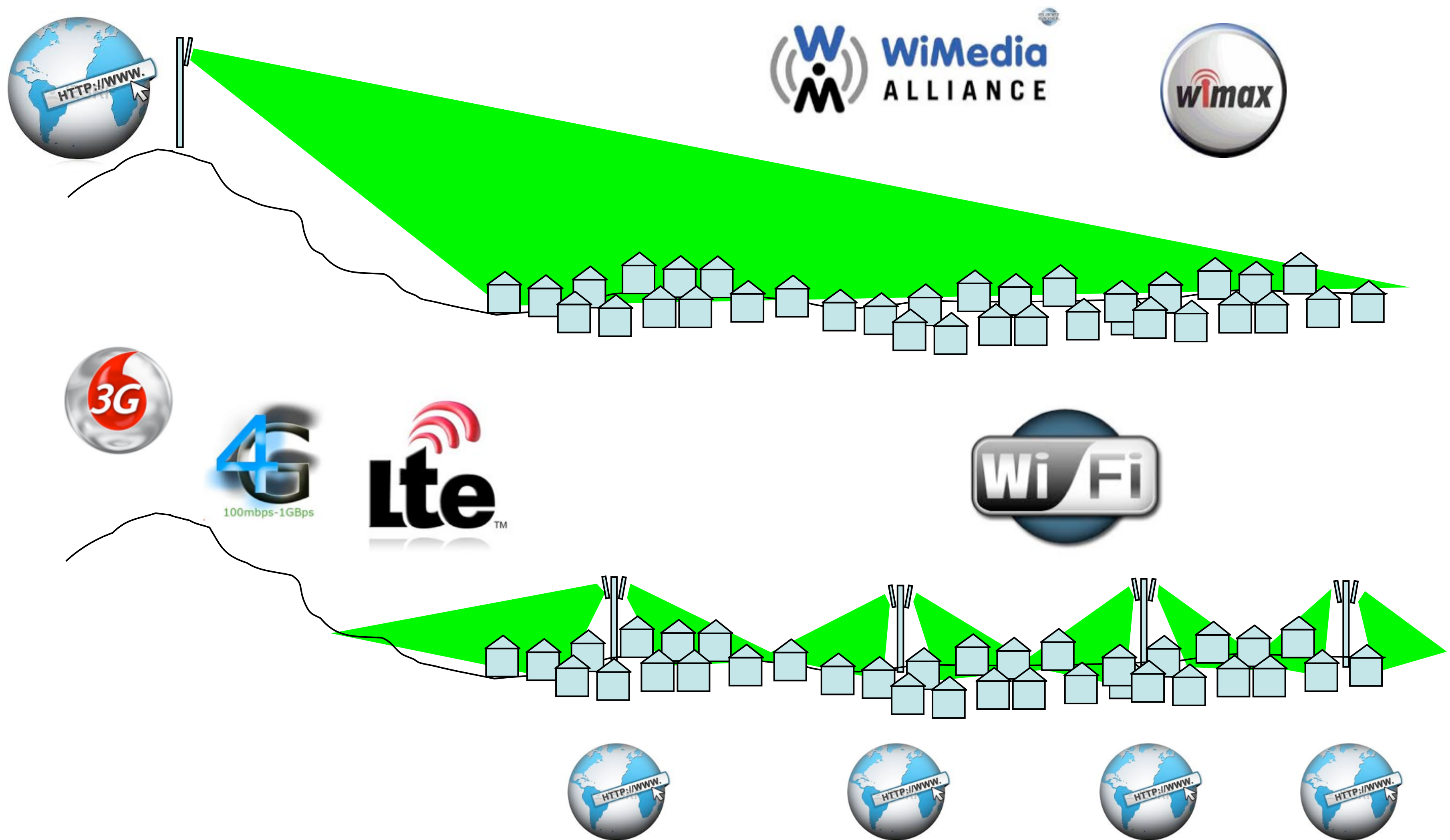


Most of telemetry systems

Only issue is…

…cost & energy

Cellular model



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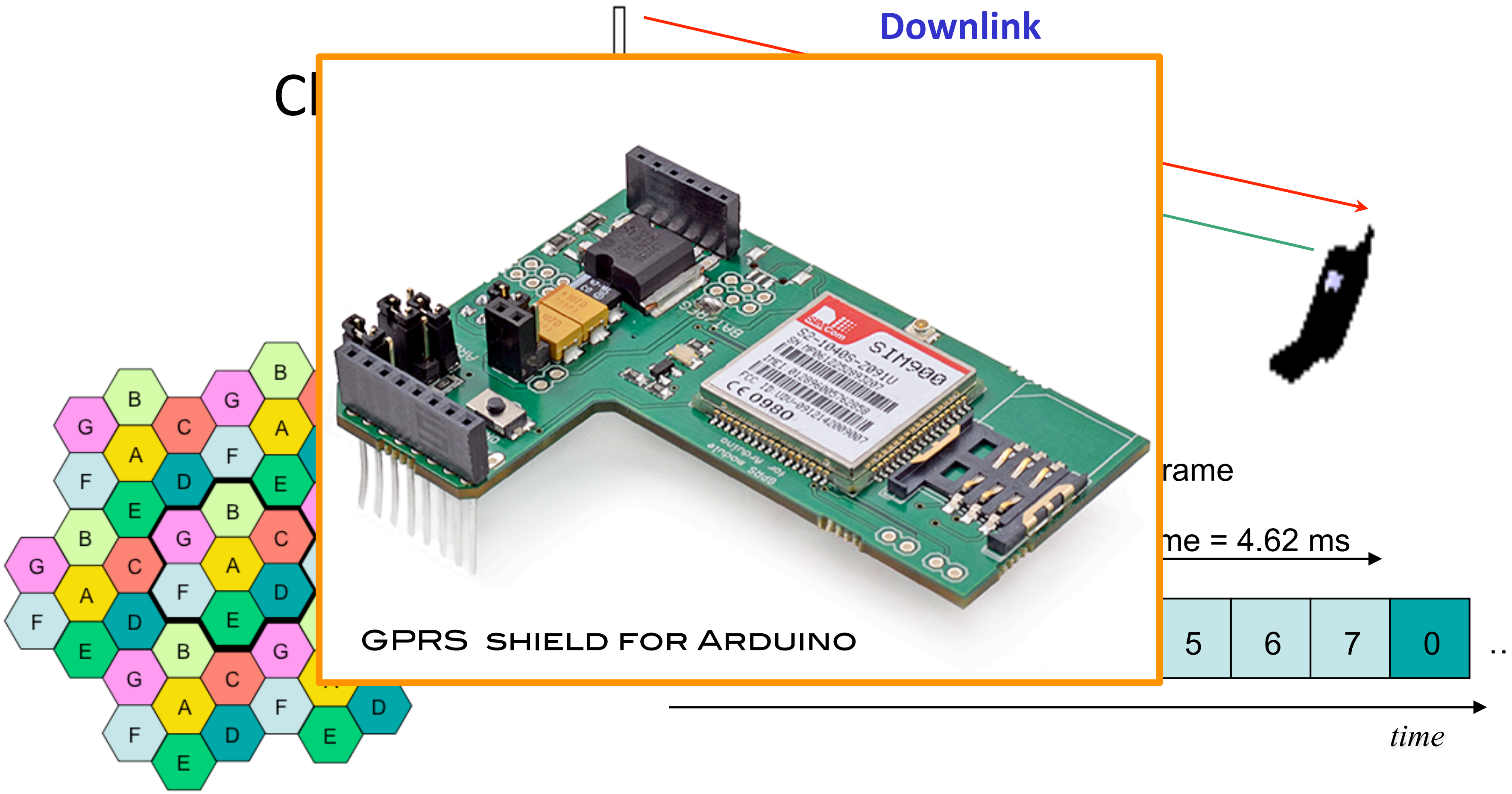
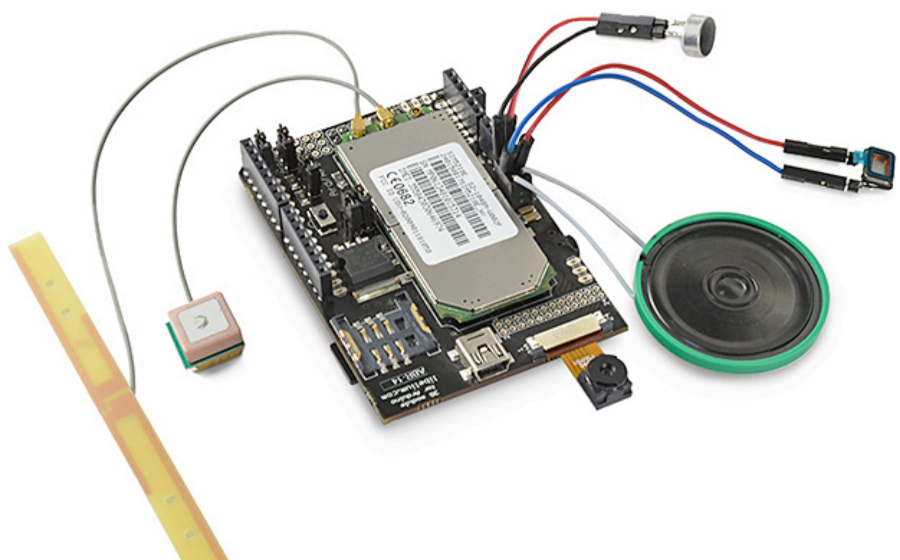
GSM (2G)/GPRS


Downlink
Cl
rame
me = 4.62 ms
5
6
7
0
…
time
GPRS shield for Arduino
SIM900

3G AND BEYOND

- ❑ 3G and beyond use CDMA techniques

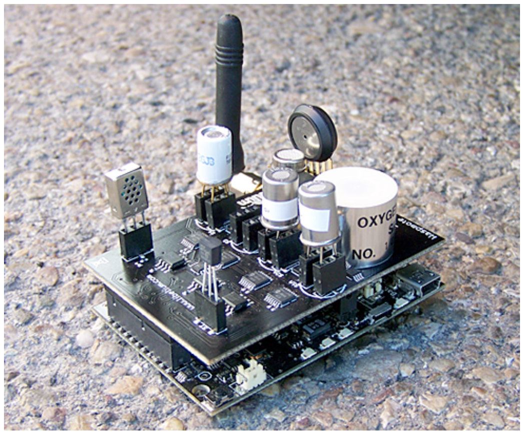


3G shield sold by Libelium

How costly is transmission?

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

Energy consideration



18720 Joules

TX power: 500mA

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

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

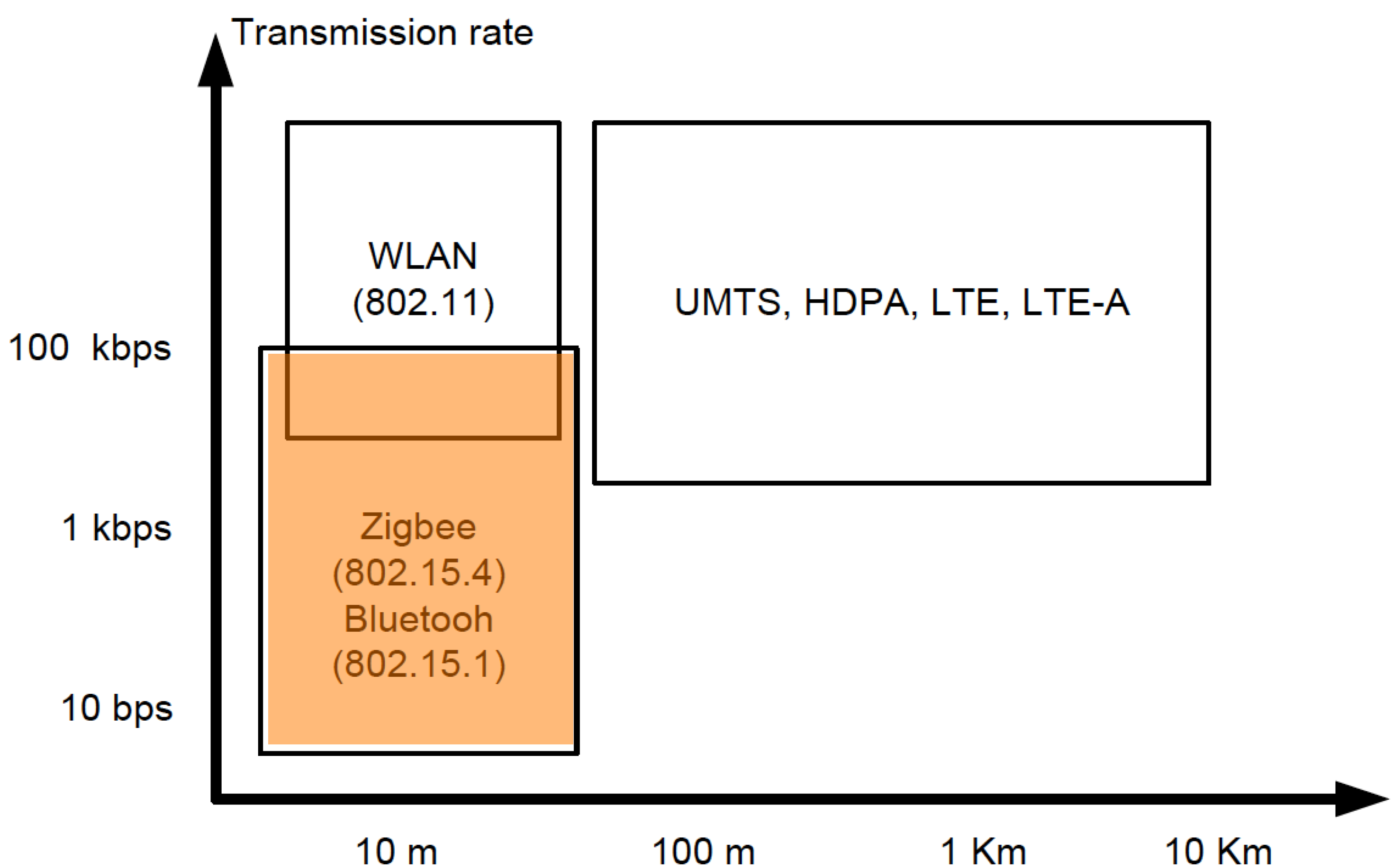
11345s or 3h9mins

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:

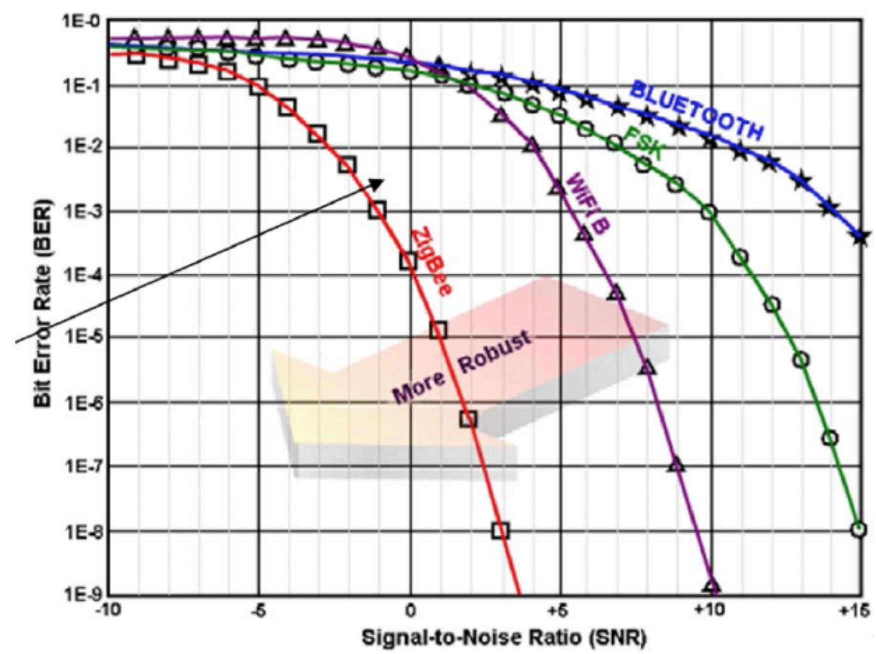
- Baseline power consumption of the sensor board
- RX consumption!
- Event capture consumption
- Event processing consumption

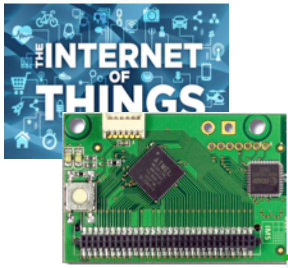
Shorter range communications (for lower energy cost)



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

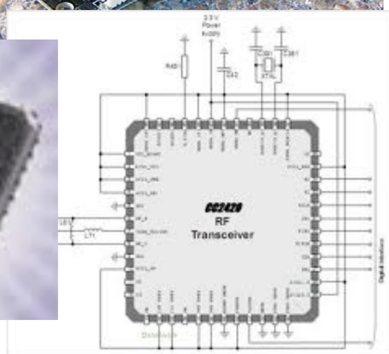
18720 Joules

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



Chipcon Products from Texas Instruments

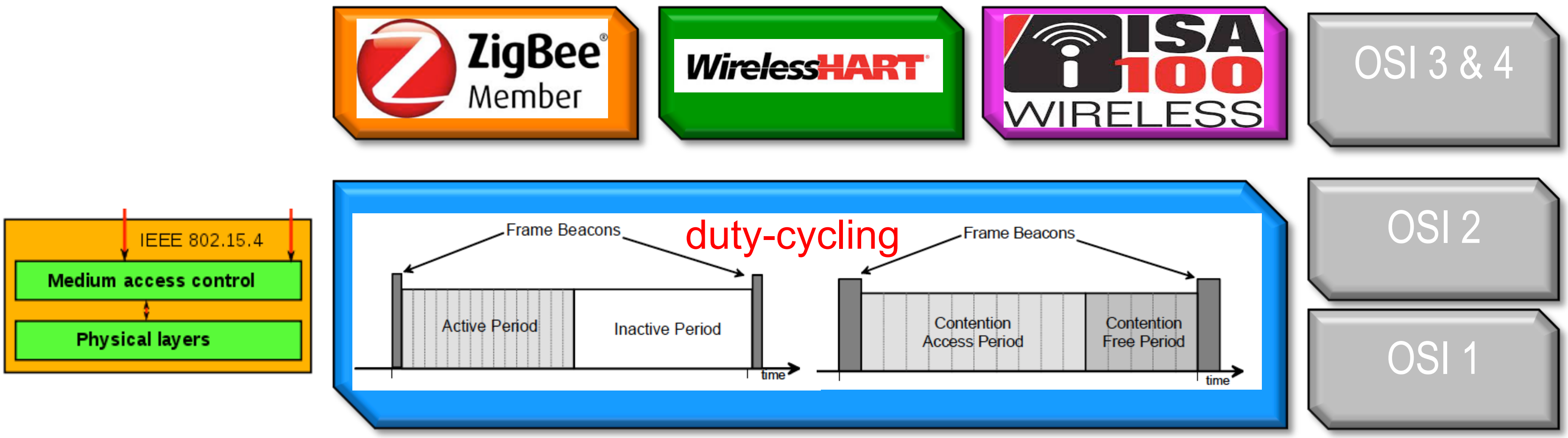
CC2420

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	

Haven't considered:

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

IEEE 802.15.4 in Industry



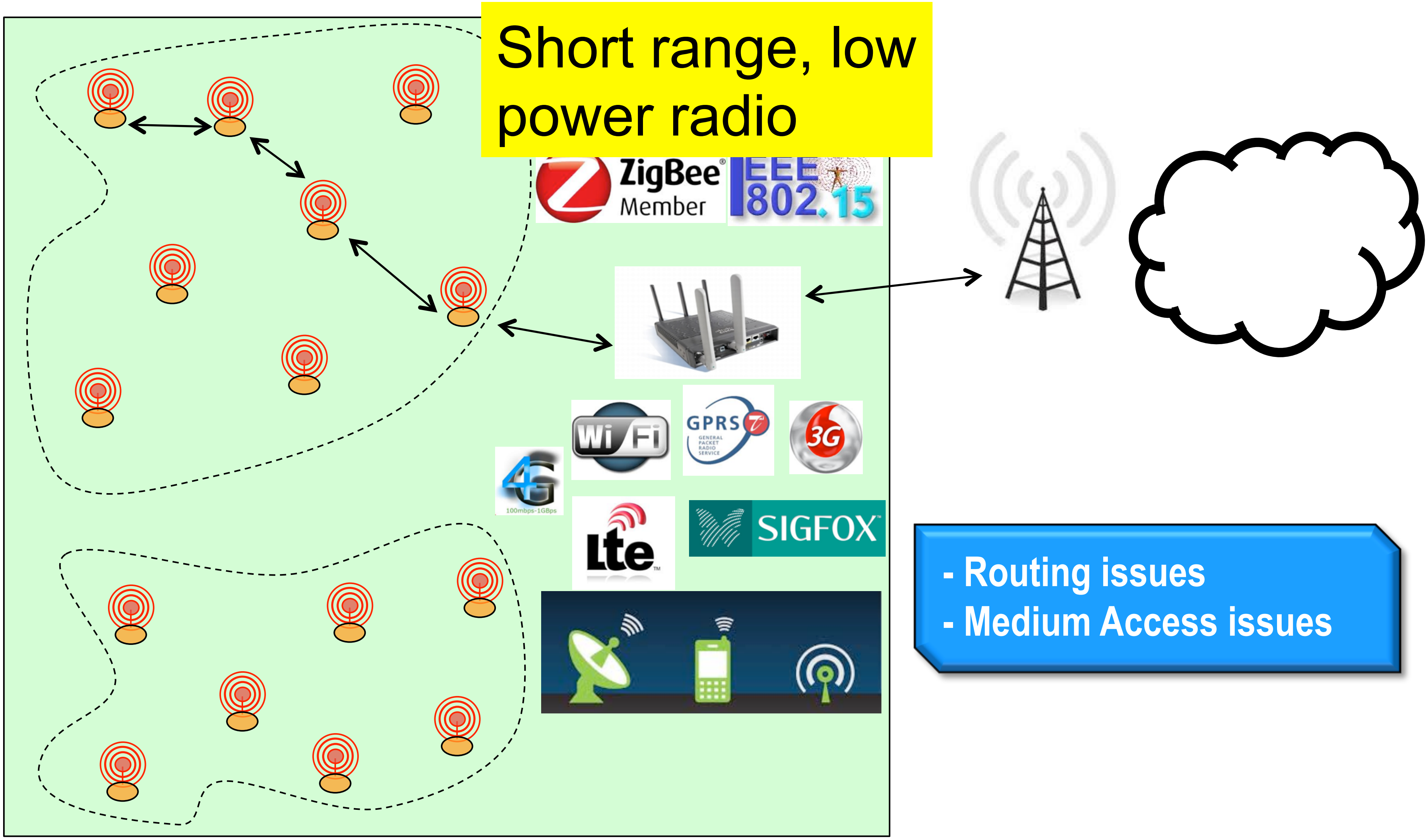
CC2420 (TI)

XBee (Digi)

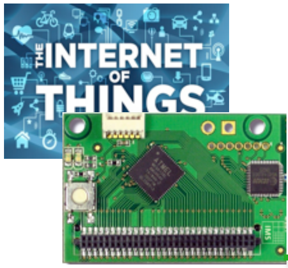
MRF24J40MA (Microchip)

ZigBit AT86RF230 (Atmel)

Multi-hop to gateways



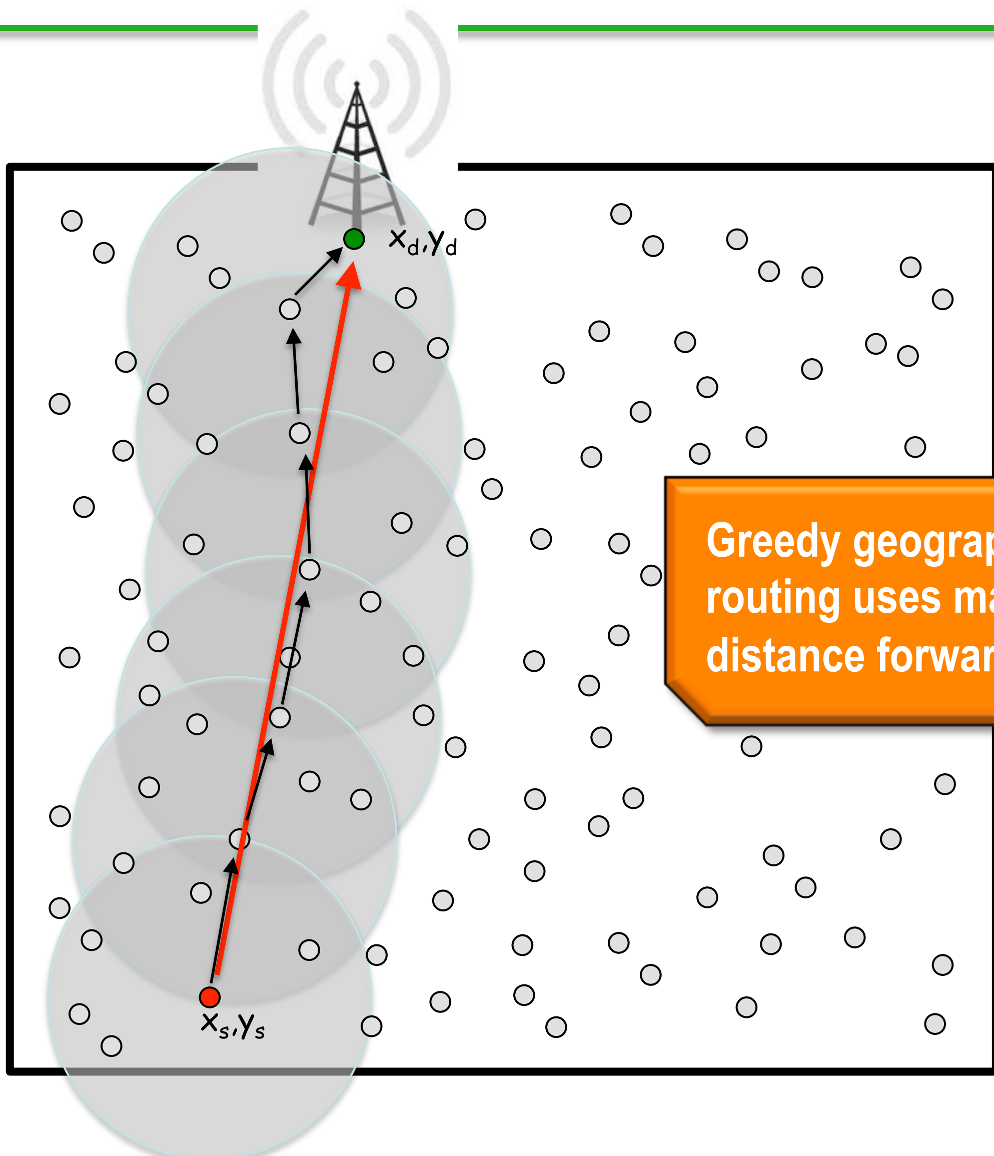
- Routing issues
- Medium Access issues



15 YEARS OF MULTI-HOP ROUTING !

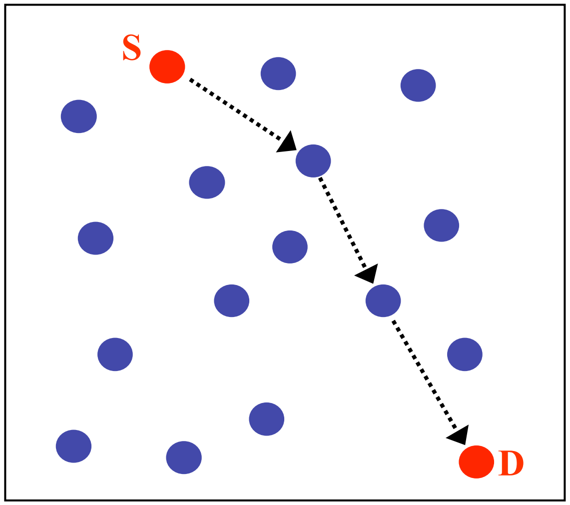
- 1-hop model is not economically tractable in large scale deployment
- 1-hop model is usually not energy-efficient
- 1-hop model is hard to optimize in terms of radio access methods
- Routing in WSN is fundamentally different from routing in other type of networks, even other wireless networks

Multi-hop greedy

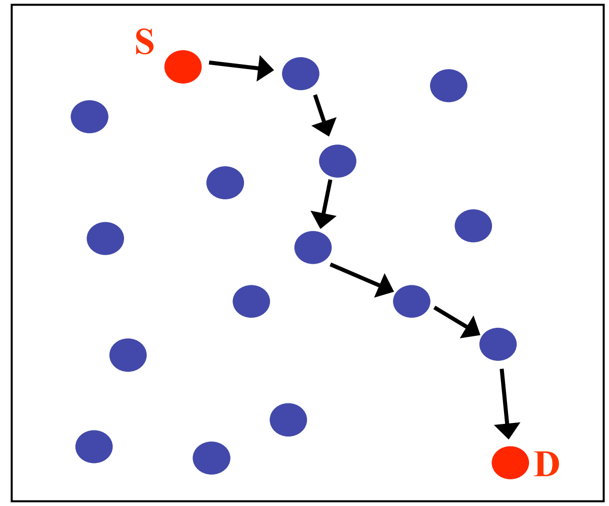


Greedy geographic routing uses maximum distance forwarding

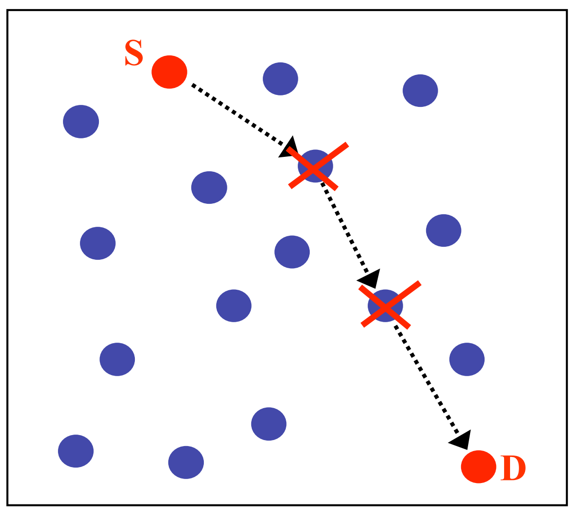
Is maximum distance always good?



Few long links with low quality



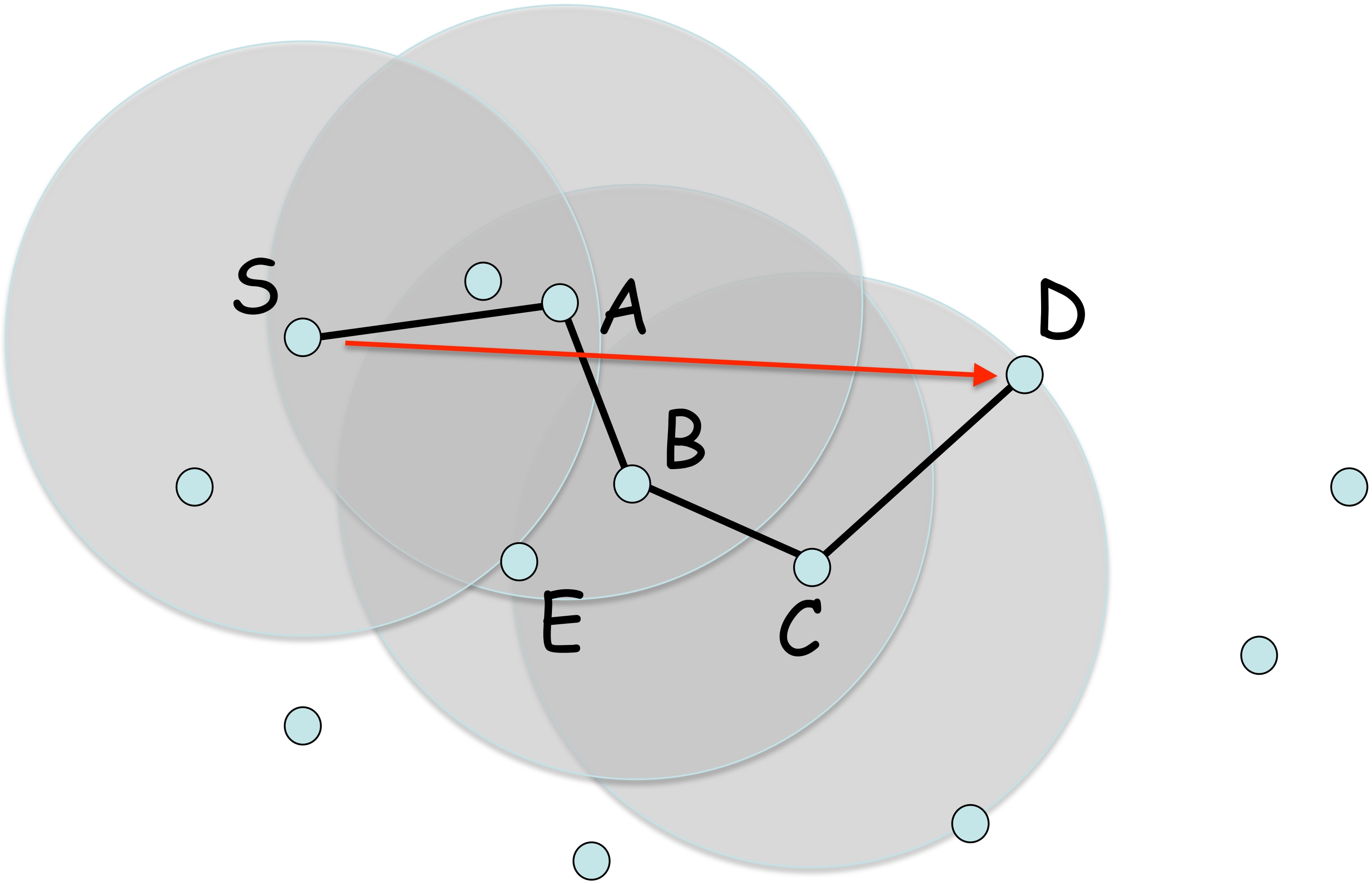
Many short links with high quality



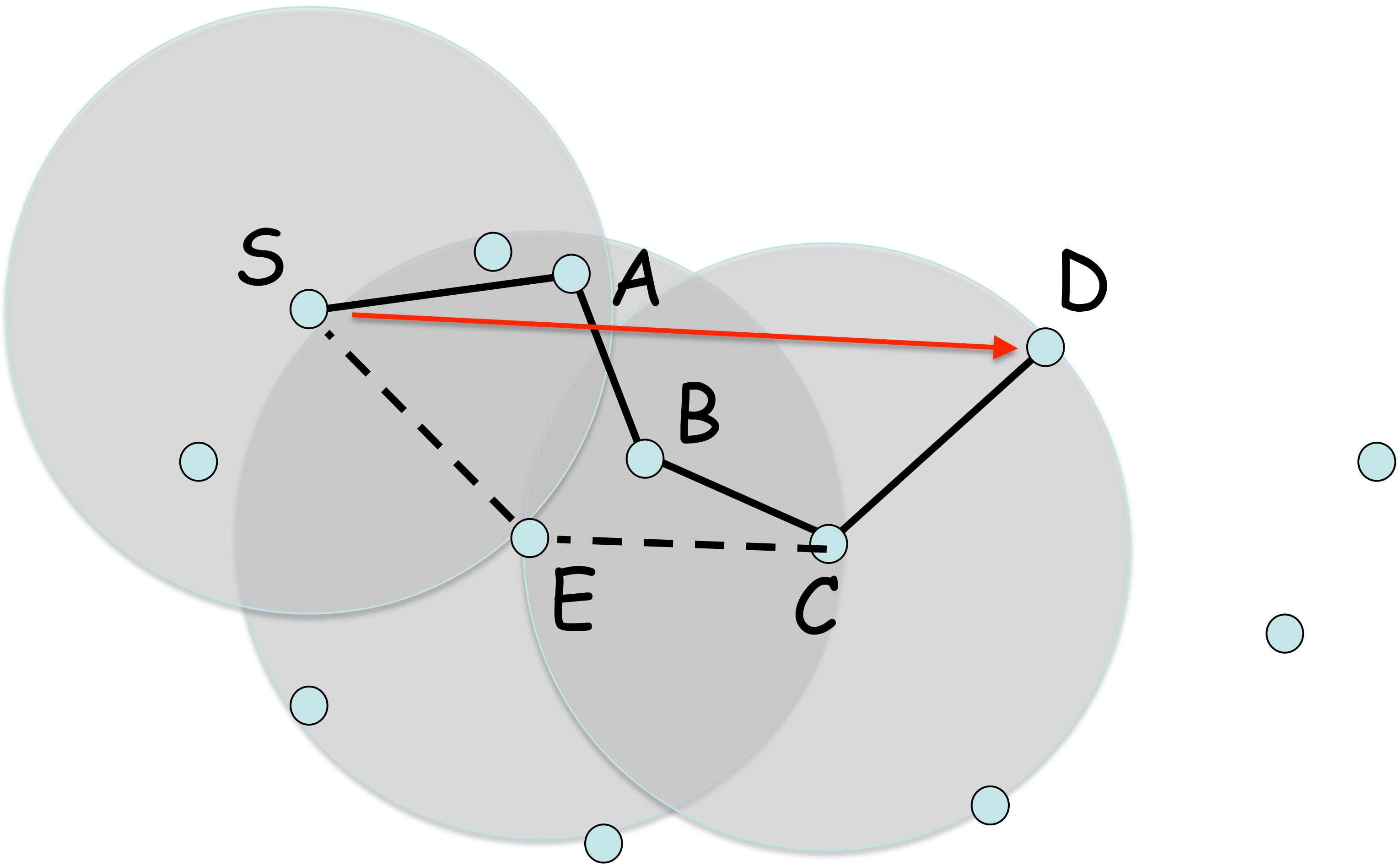
Intermediate nodes that are more sollicited die first

Adapted from Ahmed Helmy, "Robust Geographic Routing and Location-based Services"

Greedy=shortest path?



Greedy=shortest path?

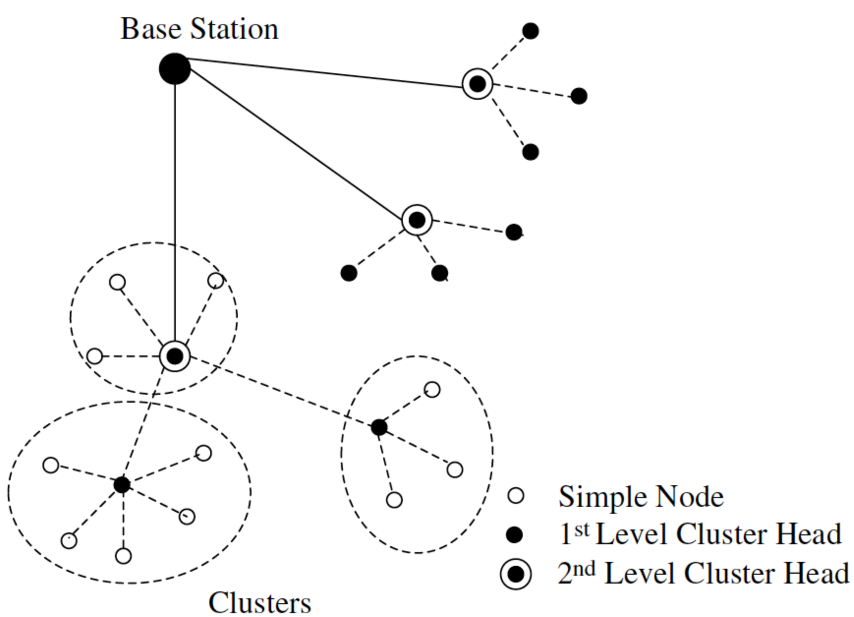


Organizing the Network

- The network is no longer useful when node's battery dies
- Organizing the network allows for spacing out the lifespan of the nodes
- Hierarchical routing protocols often give priority to energy
- Ex: Low-Energy Adaptive Clustering Hierarchy (LEACH)

Clustering

- A cluster-head collect data from their surrounding nodes and pass it on to the base station
- The job of cluster-head rotates



LEACH cluster-head

- Cluster-heads can be chosen *stochastically* (randomly based) on this algorithm:

$$T(n) = \frac{P}{1 - P \times (r \bmod P^{-1})} \qquad \forall n \in G$$

$$T(n) = 0 \qquad \forall n \notin G$$

Where n is a random number between 0 and 1
P is the cluster-head probability and
G is the set of nodes that weren't cluster-heads the previous rounds

- If $n < T(n)$, then that node becomes a cluster-head
- The algorithm is designed so that each node becomes a cluster-head at least once

W.B. Heinzelman, A.P. Chandrakasan, H. Balakrishnan, Application specific protocol architecture for wireless microsensor networks, IEEE Transactions on Wireless Networking (2002).

Example

```
p=0.05, r=0 initially
draw N a random number [0,1[ at each
round

N < 0.0500 = 0.05/(1-0.05*0) ?
N < 0.0526 = 0.05/(1-0.05*1) ?
N < 0.0555 = 0.05/(1-0.05*2) ?
N < 0.0588 = 0.05/(1-0.05*3) ?
N < 0.0625 = 0.05/(1-0.05*4) ?
N < 0.0666 = 0.05/(1-0.05*5) ?
N < 0.0714 = 0.05/(1-0.05*6) ?
N < 0.0769 = 0.05/(1-0.05*7) ?
N < 0.0833 = 0.05/(1-0.05*8) ?
N < 0.0909 = 0.05/(1-0.05*9) ?
N < 0.1000 = 0.05/(1-0.05*10) ?

N < 0.5000 = 0.05/(1-0.05*18) ?
N < 1.0000 = 0.05/(1-0.05*19) ?
```

- Number of clusters may not fixed in any round.

$$T(n) = \begin{cases} \dfrac{P}{1 - P[r \bmod (1/P)]} & \text{if } n \in G, \\ 0 & \text{otherwise,} \end{cases}$$

IoT: « I » for Internet

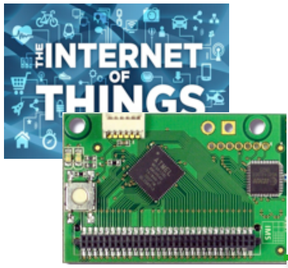
From ad-hoc to standardized protocols

Don't reinvent the wheel!

RFC 768	UDP - User Datagram Protocol	[1980]
RFC 791	IPv4 – Internet Protocol	[1981]
RFC 792	ICMPv4 – Internet Control Message Protocol	[1981]
RFC 793	TCP – Transmission Control Protocol	[1981]
RFC 862	Echo Protocol	[1983]
RFC 1101	DNS Encoding of Network Names and Other Types	[1989]
RFC 1191	IPv4 Path MTU Discovery	[1990]
RFC 1981	IPv6 Path MTU Discovery	[1996]
RFC 2131	DHCPv4 - Dynamic Host Configuration Protocol	[1997]
RFC 2375	IPv6 Multicast Address Assignments	[1998]
RFC 2460	IPv6	[1998]
RFC 2765	Stateless IP/ICMP Translation Algorithm (SIIT)	[2000]
RFC 3068	An Anycast Prefix for 6to4 Relay Routers	[2001]
RFC 3307	Allocation Guidelines for IPv6 Multicast Addresses	[2002]
RFC 3315	DHCPv6 - Dynamic Host Configuration Protocol for IPv6	[2003]
RFC 3484	Default Address Selection for IPv6	[2003]
RFC 3587	IPv6 Global Unicast Address Format	[2003]
RFC 3819	Advice for Internet Subnetwork Designers	[2004]
RFC 4007	IPv6 Scoped Address Architecture	[2005]
RFC 4193	Unique Local IPv6 Unicast Addresses	[2005]
RFC 4291	IPv6 Addressing Architecture	[2006]
RFC 4443	ICMPv6 - Internet Control Message Protocol for IPv6	[2006]
RFC 4861	Neighbor Discovery for IP version 6	[2007]
RFC 4944	Transmission of IPv6 Packets over IEEE 802.15.4 Networks	[2007]

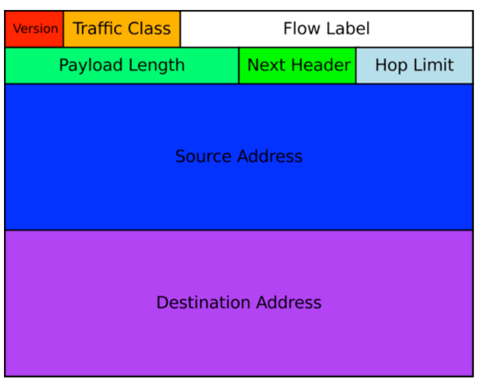
RFC6282 Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks [2011]

From ArchRock "6LowPan tutorial"

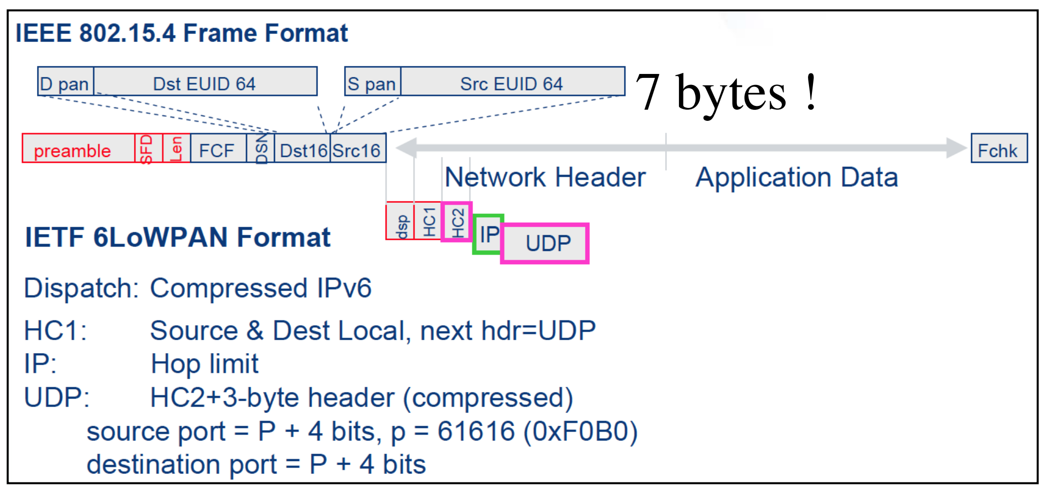


IP NEED IP ADDRESSES!

- IPv4 has no more addresses!
- IPv6 gives plenty of addresses
  - 128bit address=16bytes!
- 6LowPan adapts IPv6 to resource-constrained devices
  - Compressed IPv6 header



40 bytes



From ArchRock "6LowPan tutorial"

IPv4 vs. IPv6 Addressing

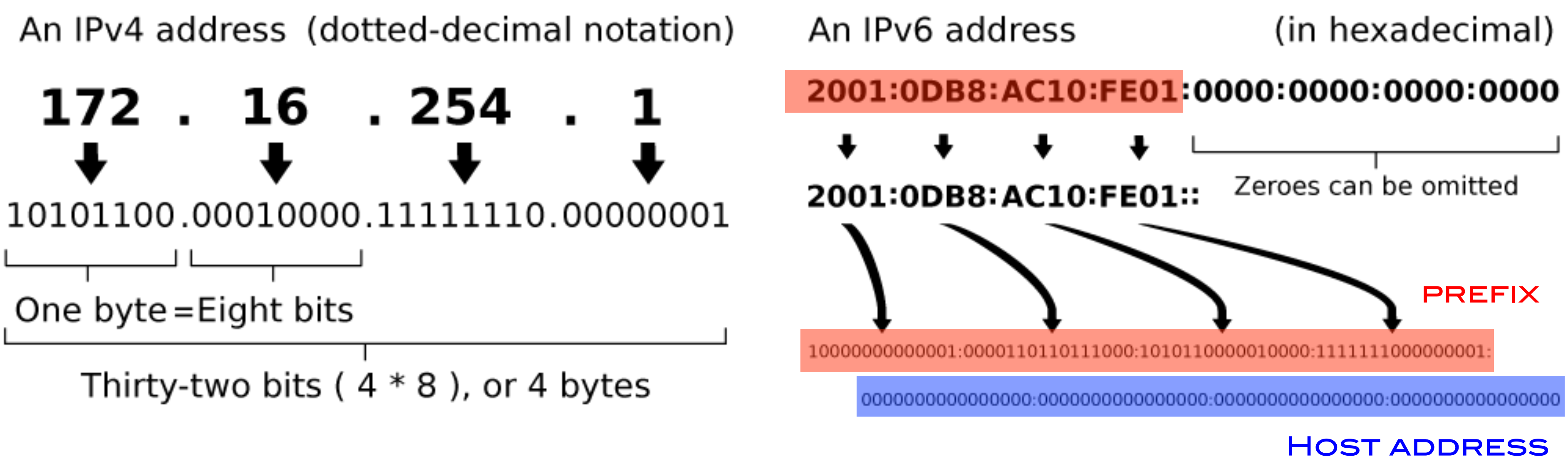


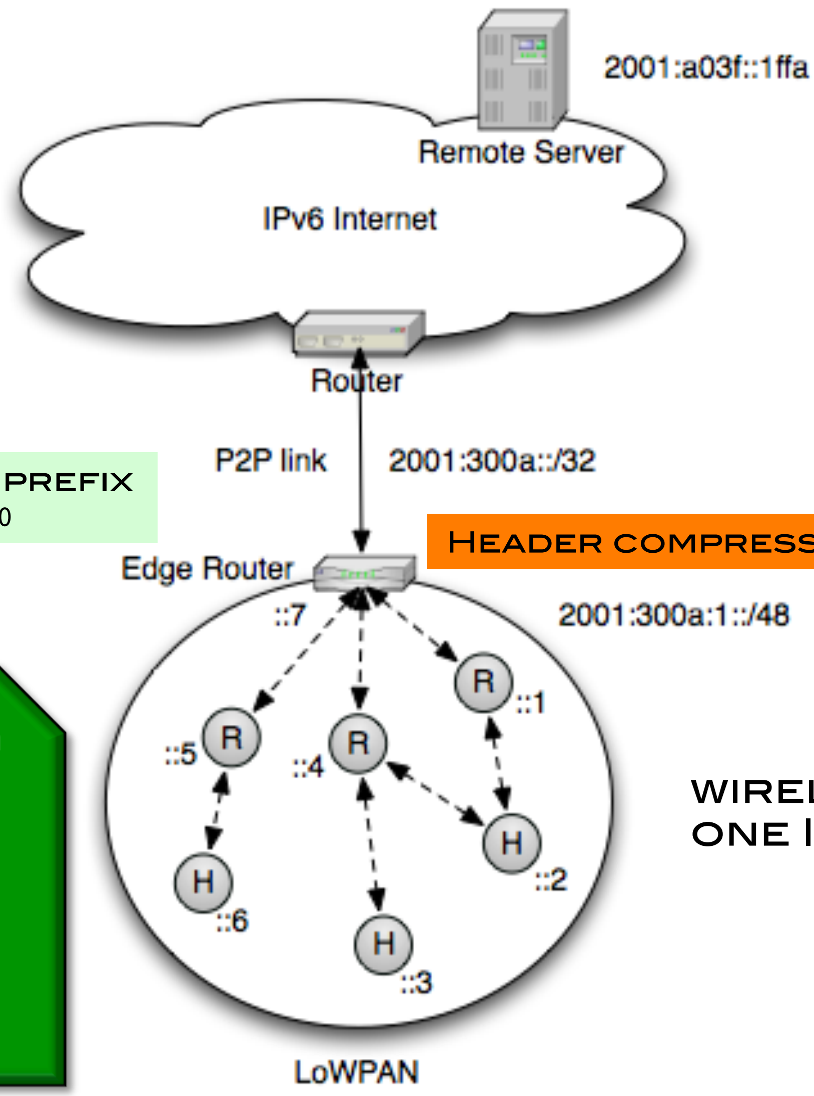
Image source: Indeterminant (Wikipeida) GFDL

6LoWPAN Addressing

- IPv6 addresses are compressed in 6LoWPAN
- A LoWPAN works on the principle of
  - flat address spaces (wireless network is one IPv6 subnet)
  - with unique MAC addresses (e.g. 64-bit or 16-bit: 0x0013A20040568B34 or 0x0220)
- 6LoWPAN compresses IPv6 addresses by
  - Eliding the IPv6 prefix
    - Global prefix known by all nodes in network
    - Link-local prefix indicated by header compression format
  - Compressing the Interface ID
    - Elided for link-local communication
    - Compressed for multihop dst/src addresses
  - Compressing with a well-known "context"
  - Multicast addresses are compressed

From "6LoWPAN: The Wireless Embedded Internet, Shelby & Bormann"

Addressing Example



Advertise prefix
`2001:300a:1:0`

Header compression

Build an IPv6 address with prefix and a combination of 802.15.4:

- PANID
- 16-bit address

or

- 64-bit address

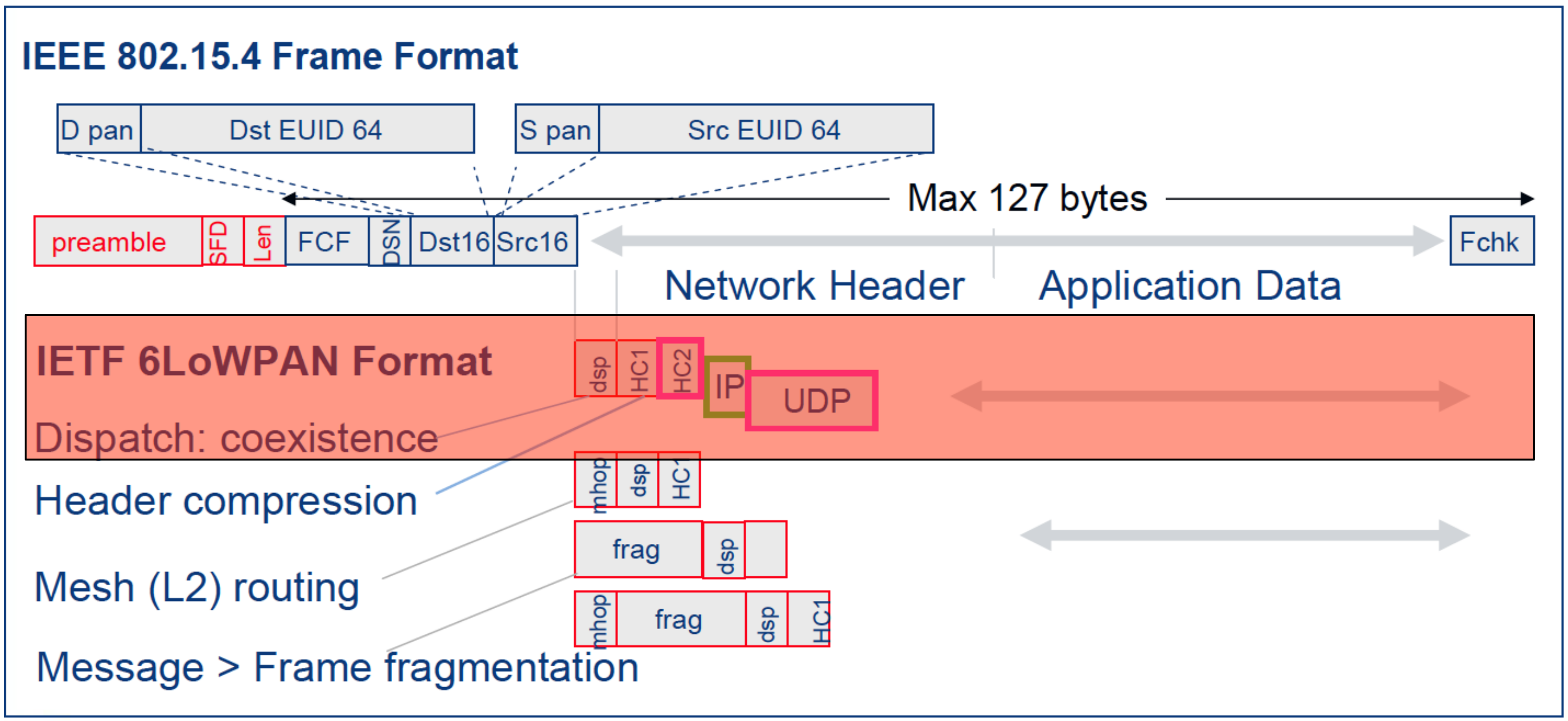
Wireless network is one IPv6 subnet

Based from "6LoWPAN: The Wireless Embedded Internet, Shelby & Bormann"

Use RFC4944 compression scheme for simplicity. New scheme should follow RFC6282

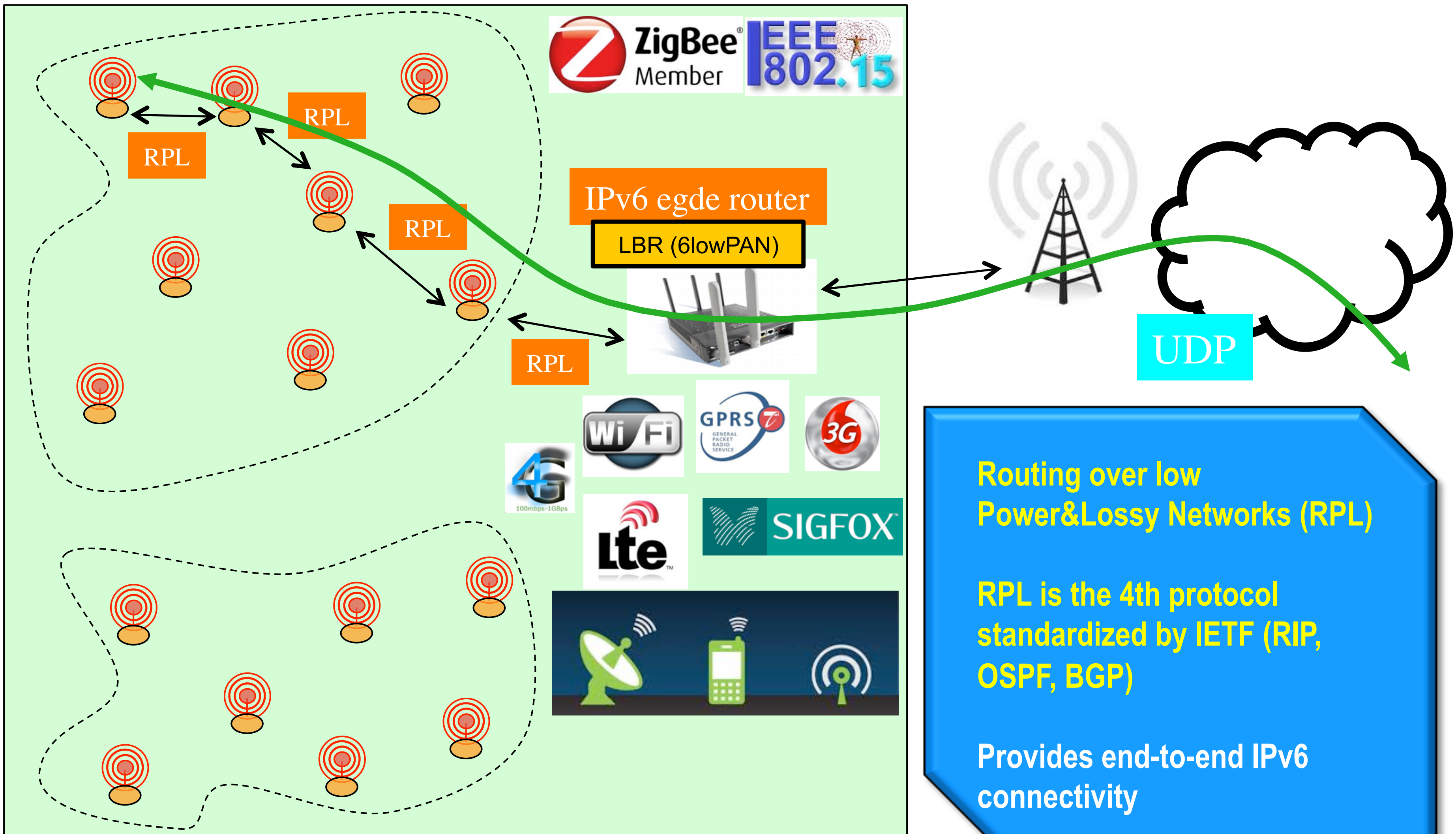
6LoWPAN Format Design

- Orthogonal stackable header format
- Almost no overhead for the ability to interoperate and scale.
- Pay for only what you use



From ArchRock "6LowPan tutorial"

OK, BUT WHAT ABOUT ROUTING?



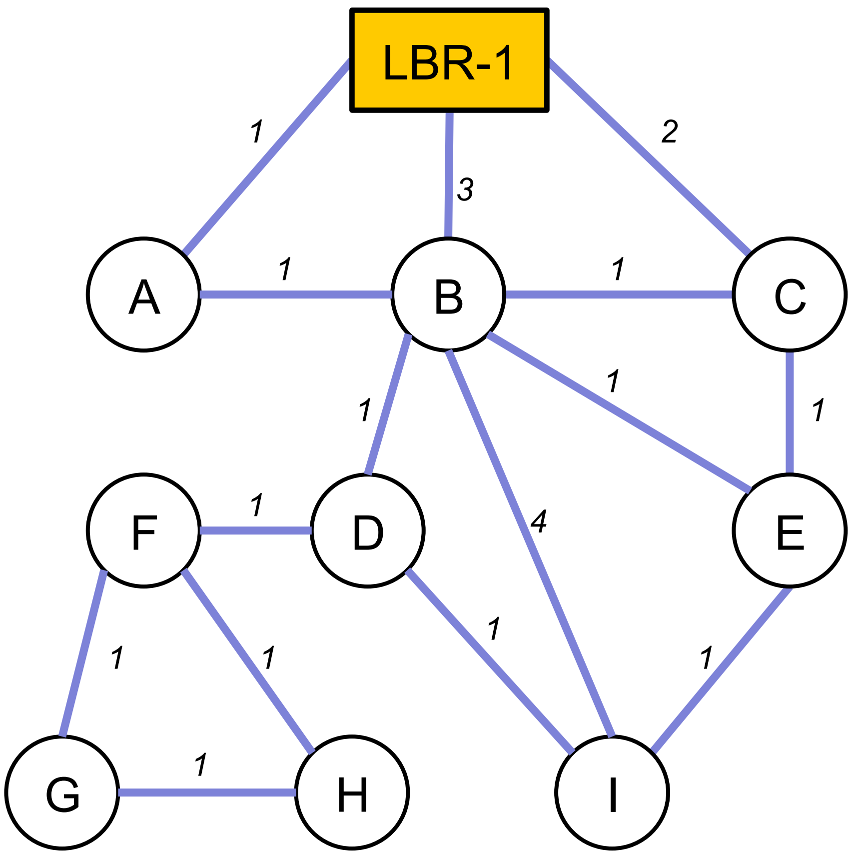
Routing over low Power&Lossy Networks (RPL)

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

Provides end-to-end IPv6 connectivity

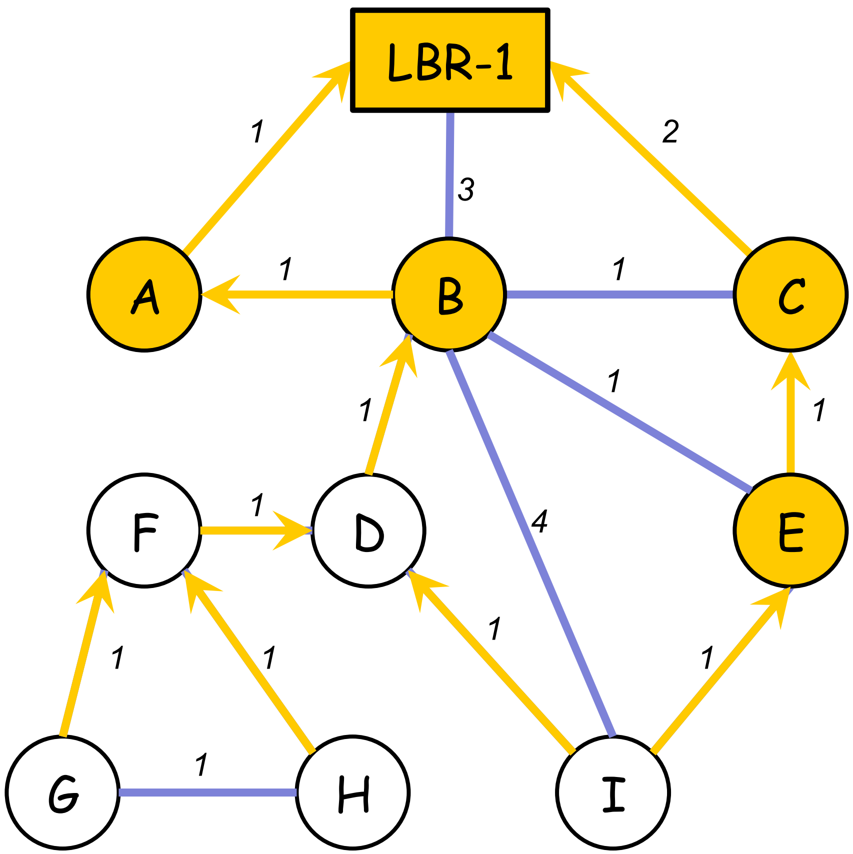
DAG Construction

Low power and lossy network Border Router

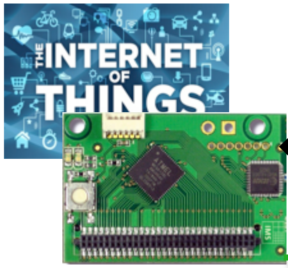


- LLN links are depicted
- LBR form a Destination Object DAG (DODAG)
- Links are annotated w/ ETX (Expected Transmission Count)
- It is expected that ETX variations will be averaged/filtered as per [ROLL-METRICS] to be stable enough for route computation

DAG Construction



- DAG Construction continues…
- And is continuously maintained



« Internet for things »

UDP, TCP?

RPL
Routing Protocol for Low power & Lossy Networks

6LowPan
802.15.4

IPv6 egde router

LBR (6lowPAN)

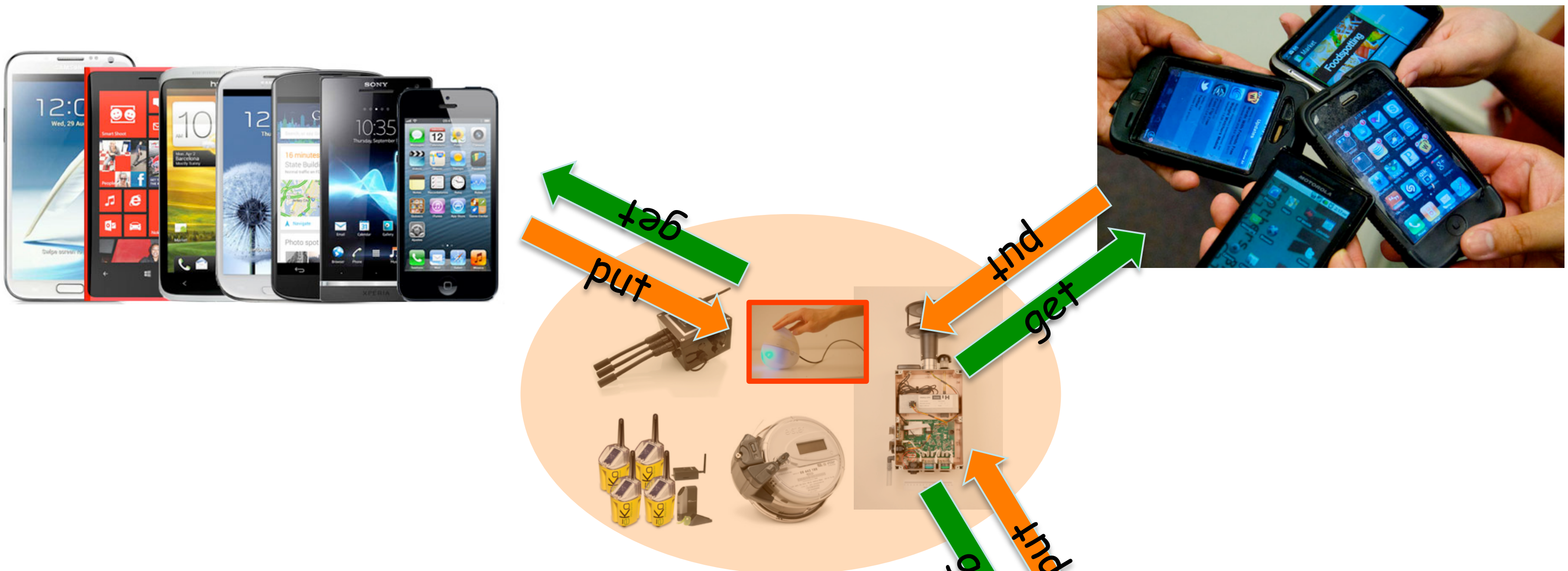
TCP, UDP

Internet Routing Protocols: RIP, OSPF, BGP,…

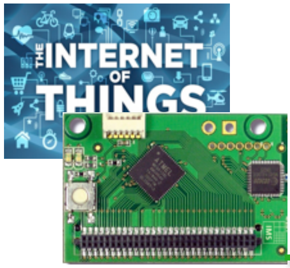
IPv4, IPv6

3G 4G Lte WiFi

IoT FOR HUMAN?



Internet of Things for you & me



IETF « Internet for things »

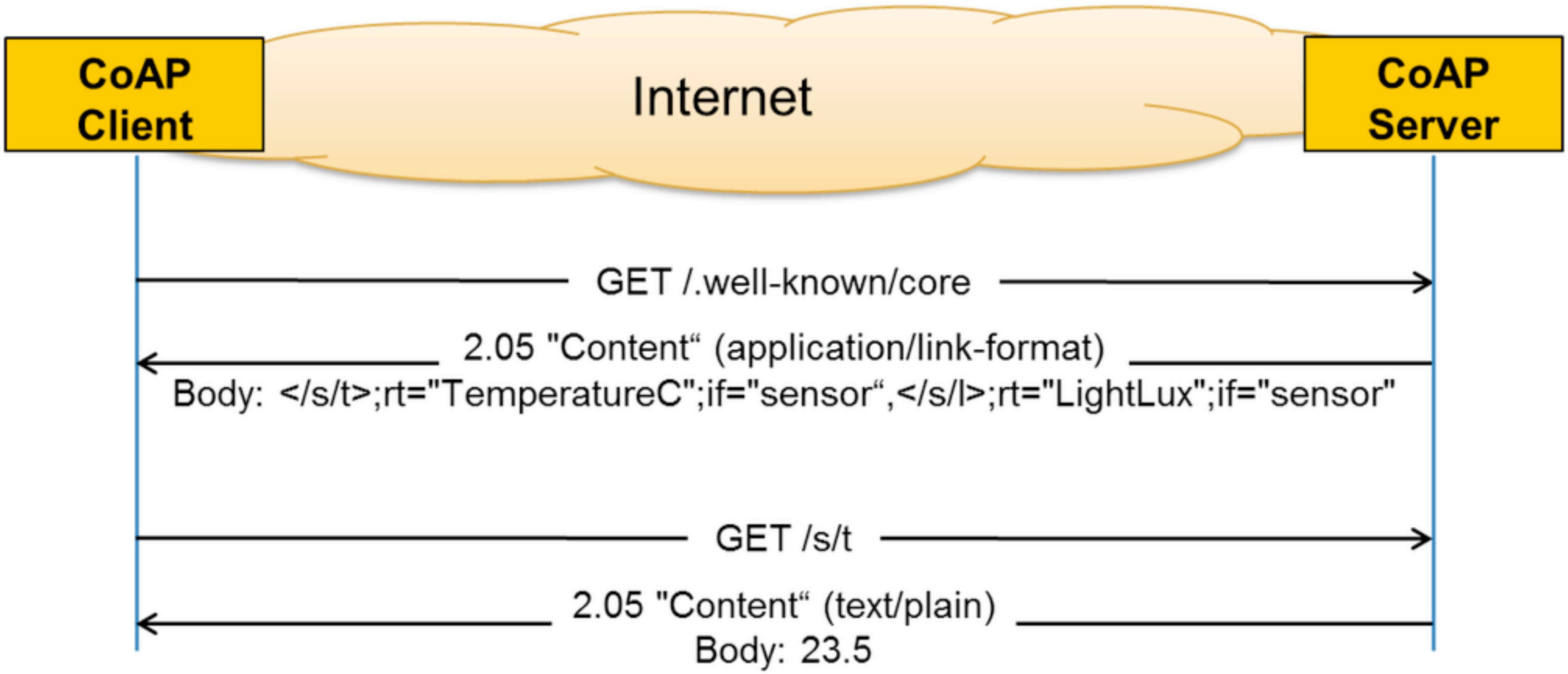
CoAP: Constrained Application Protocol	CoAP / HTTP
UDP, TCP?	TCP, UDP
RPL Routing Protocol for Low power & Lossy Networks	Internet Routing Protocols: RIP, OSPF, BGP,…
6LowPan 802.15.4	IPv4, IPv6

IPv6 egde router

LBR (6lowPAN)

3G 4G Lte WiFi

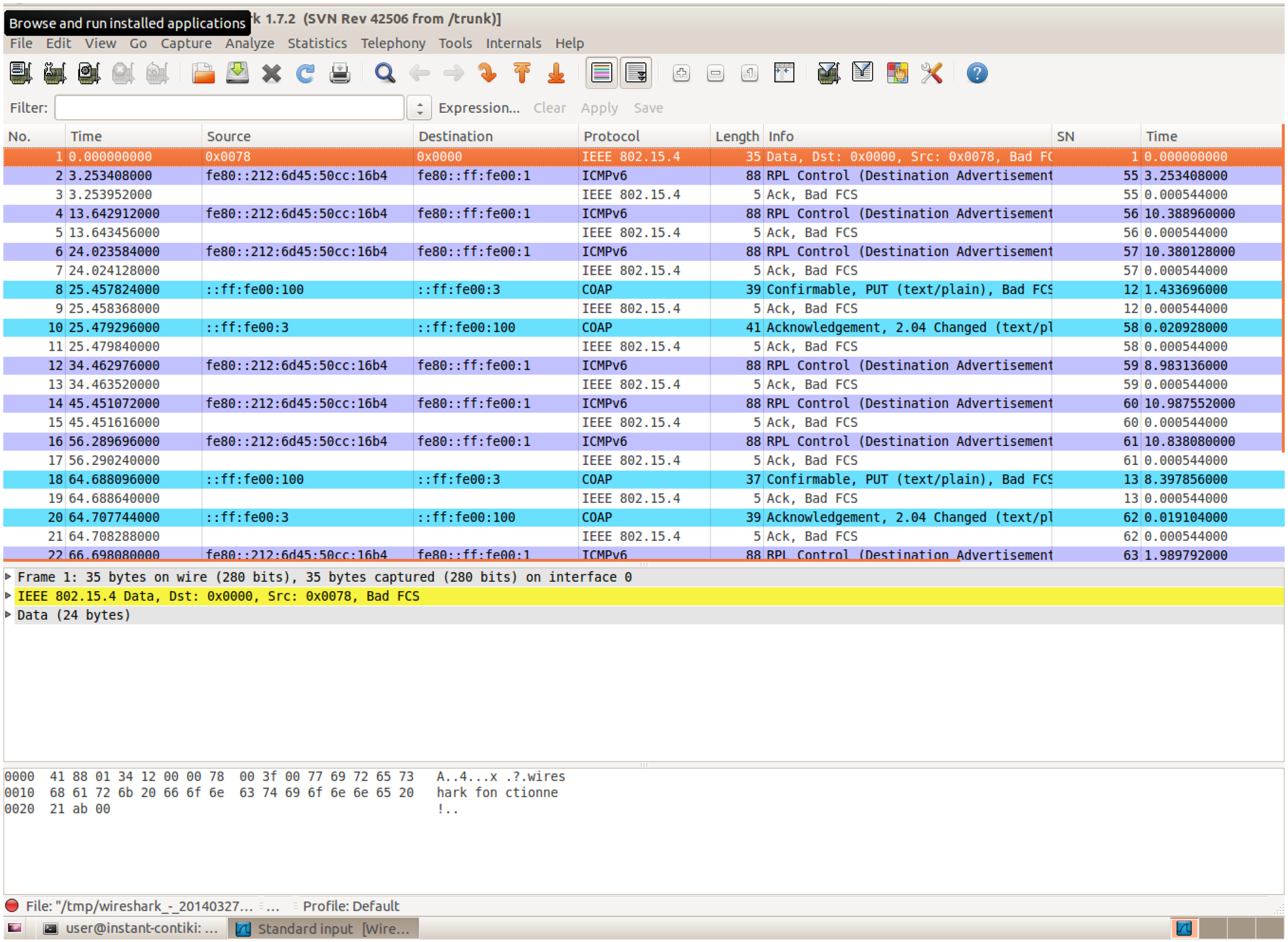
DATA = RESOURCES



From Isam Ishaq et al. “Flexible Unicast-Based Group Communication for CoAP-Enabled Devices”, MDPI *Sensors* **2014**, *14*(6), 9833-9877

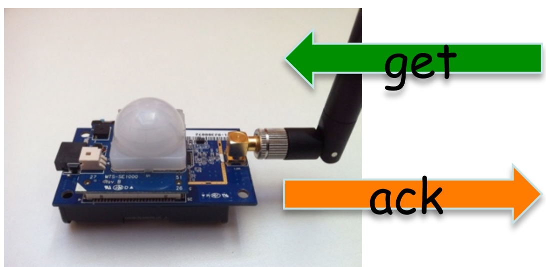
112	106.575520000	fe80::212:6d45:50b7:6a0f	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
113	106.576064000			IEEE 802.15.4	5	Ack, Bad FCS
114	106.576608000			IEEE 802.15.4	5	Ack, Bad FCS
115	113.692576000	fe80::212:6d45:50b7:7575	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
116	114.080416000	fe80::212:6d45:50b7:7575	[illegible]	[illegible]	94	RPL Control (Destination Advertisement Object),
117	[illegible]			IEEE 802.15.4	5	Ack, Bad FCS
118	116.008352000	2001:620:607:5b10::a	::ff:fe00:28	COAP	60	Confirmable, GET, End of Block #15, Bad FCS
119	116.008896000			IEEE 802.15.4	5	Ack, Bad FCS
120	116.292576000	::ff:fe00:28	2001:620:607:5b10::a	COAP	65	Acknowledgement, 2.05 Content, End of Block #[illegible]
121	[illegible]			IEEE 802.15.4	5	Ack, Bad FCS
122	116.544800000	[illegible]	[illegible]	[illegible]	94	RPL Control (Destination Advertisement Object),
123	116.545344000			IEEE 802.15.4	5	Ack, Bad FCS
124	116.545888000			IEEE 802.15.4	5	Ack, Bad FCS
125	116.546432000			IEEE 802.15.4	5	Ack, Bad FCS
126	121.702624000	fe80::212:6d45:50b7:7e21	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
127	121.703168000			IEEE 802.15.4	5	Ack, Bad FCS
128	123.968480000	fe80::212:6d45:50b7:7575	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
129	123.969024000			IEEE 802.15.4	5	Ack, Bad FCS
130	127.058048000	fe80::212:6d45:50b7:69b3	fe80::212:6d45:50b7:6a0f	ICMPv6	94	RPL Control (Destination Advertisement Object),
131	127.058592000			IEEE 802.15.4	5	Ack, Bad FCS
132	127.344416000	fe80::212:6d45:50b7:6a0f	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),

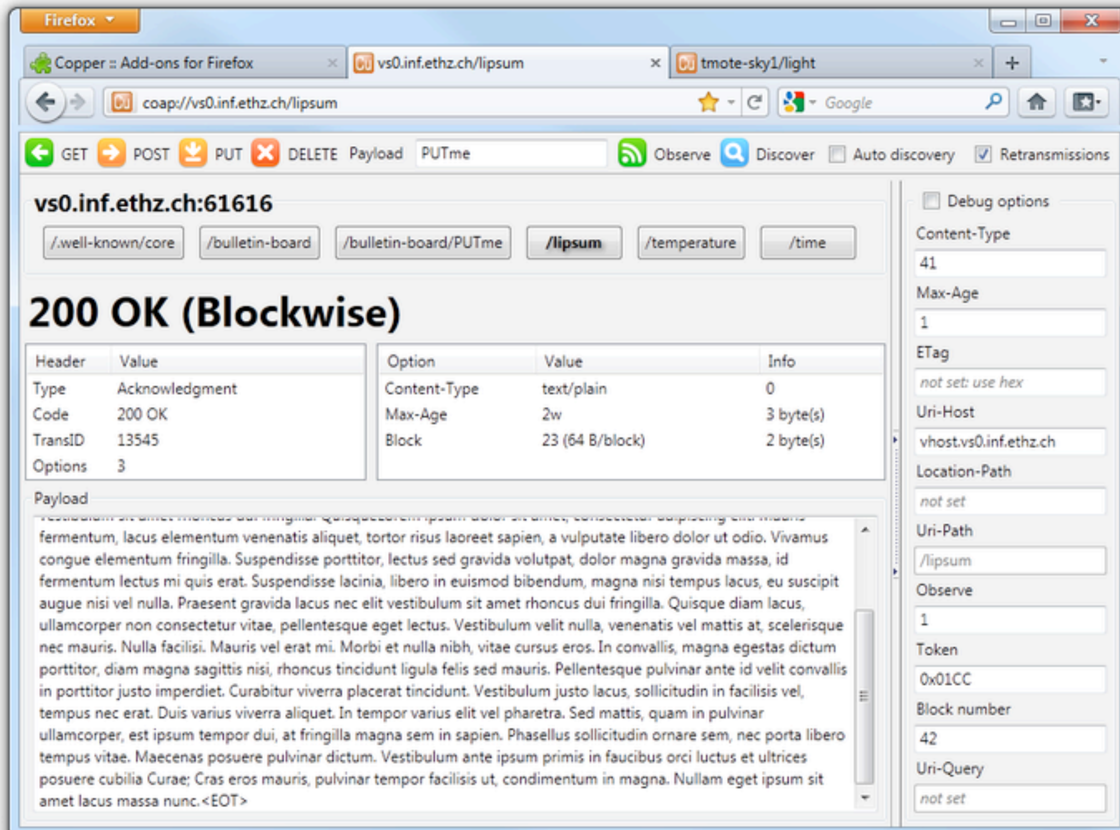
RPL and CoAP exchanges



Copper for Firefox

- CoAP pluggin to query CoAP nodes in an http-like fashion





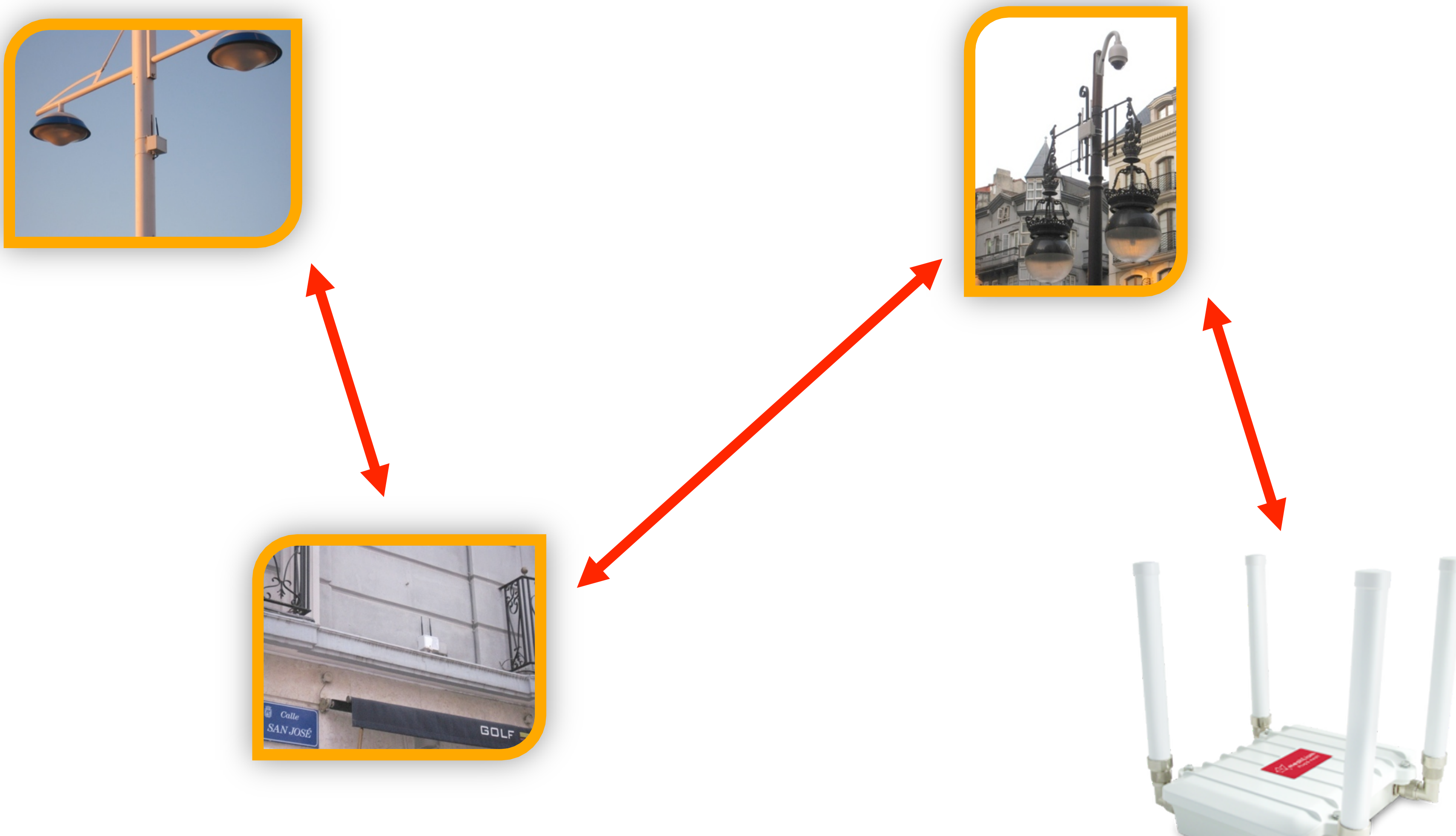
Short-range communications in practice?

SmartSantander test-bed

Gateways

Pictures are taken in the context of the EAR-IT project

Limit the number of hops to gateways

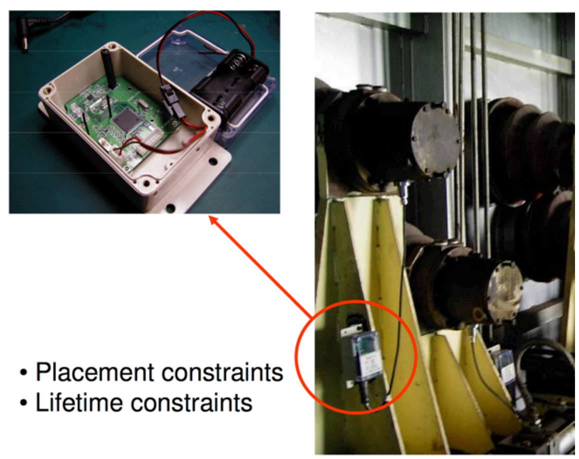


3 to 5 hops maximum

Academics vs Industries
Let's go back to reality!

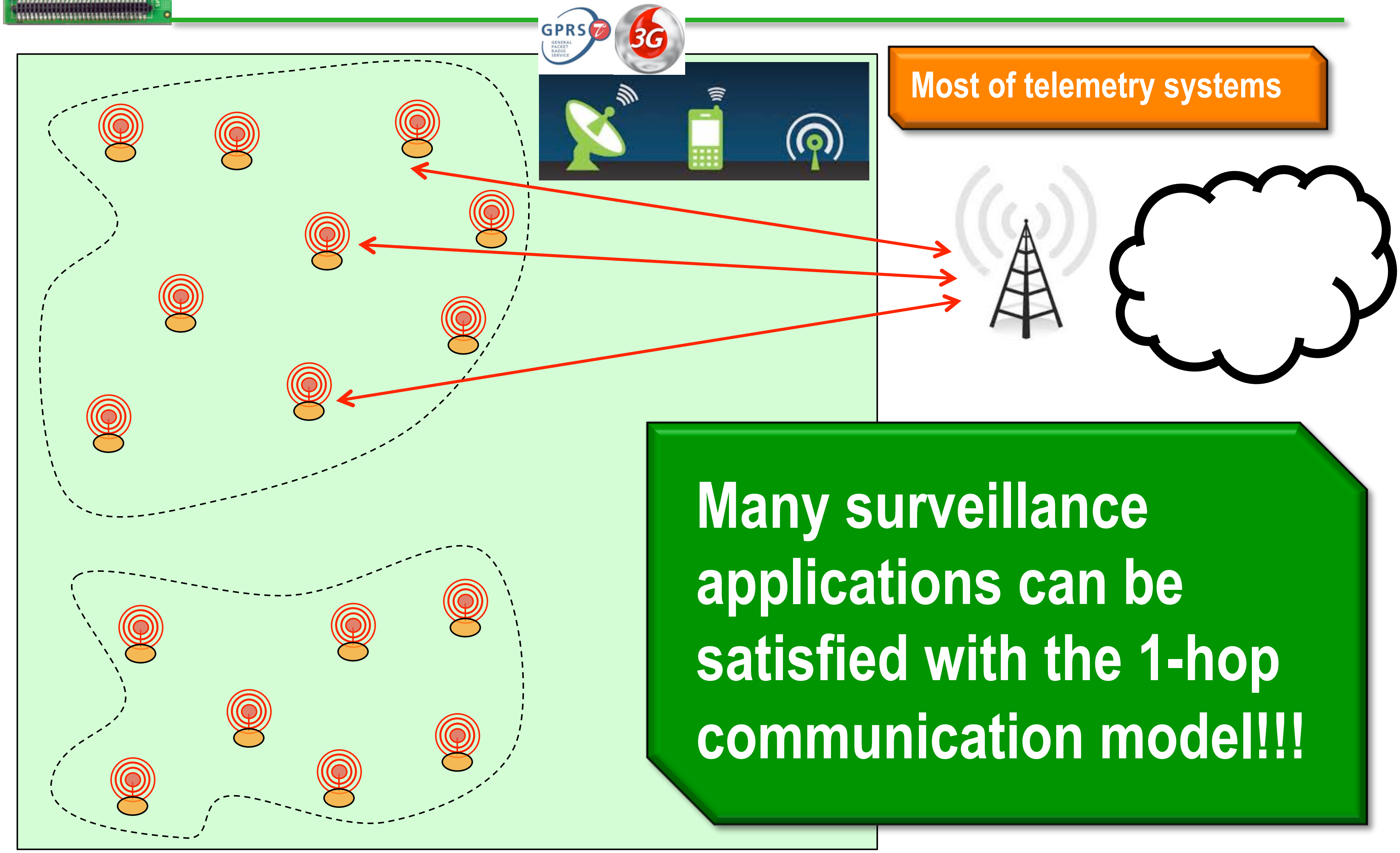
Millions of sensors, self-organizing, self-configuring, with QoS-based multi-path routing, mobility, and …

50 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?



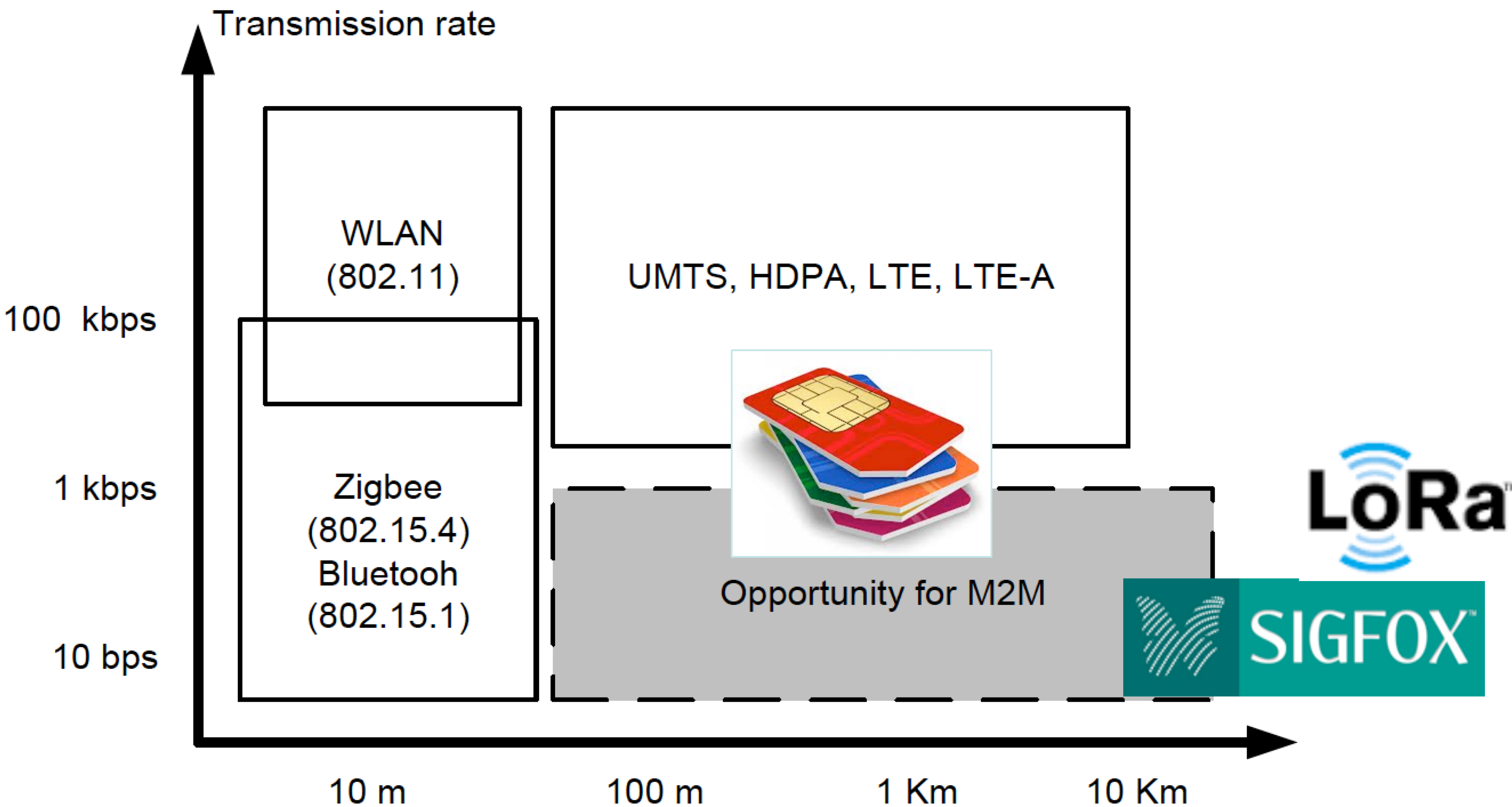
From Peng Zeng & Qin Wang

Do I need multi-hop for my app?



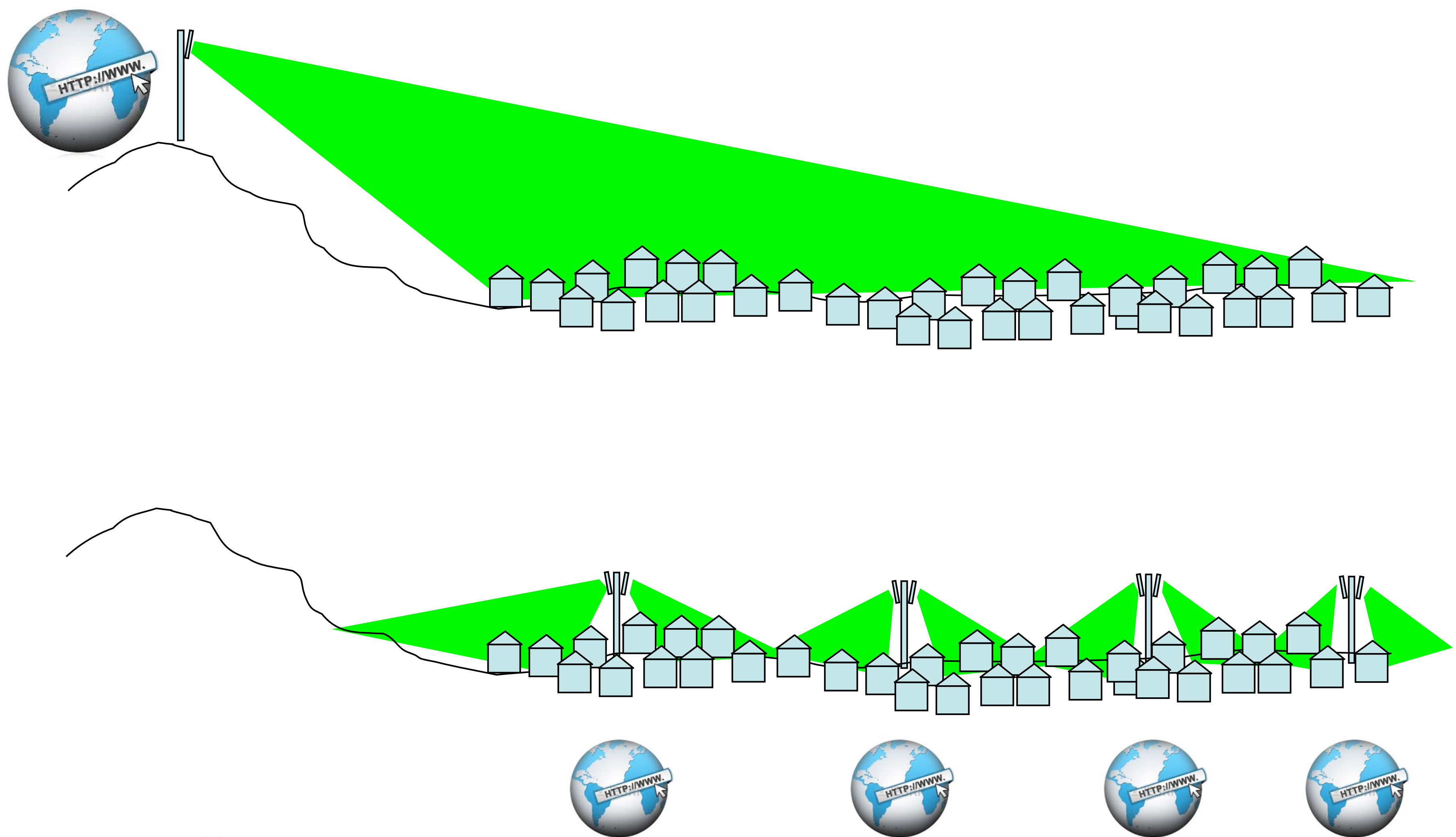
Many surveillance applications can be satisfied with the 1-hop communication model!!!

Low-power and long-range?



Enhanced from M. Dohler "M2M in SmartCities"

Back to the cellular model



Typical scenarios

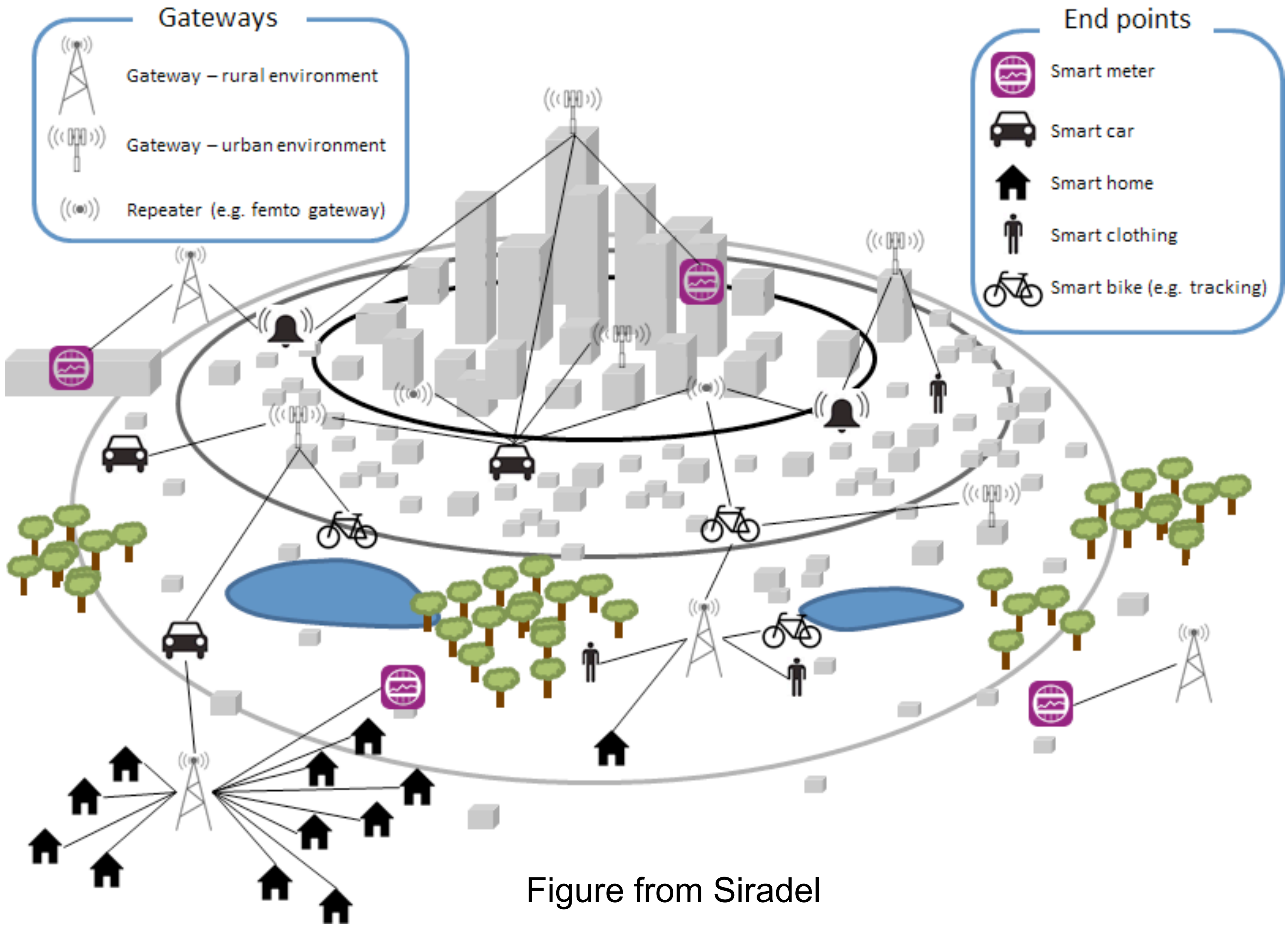


Figure from Siradel

Simple loss in signal strength model

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

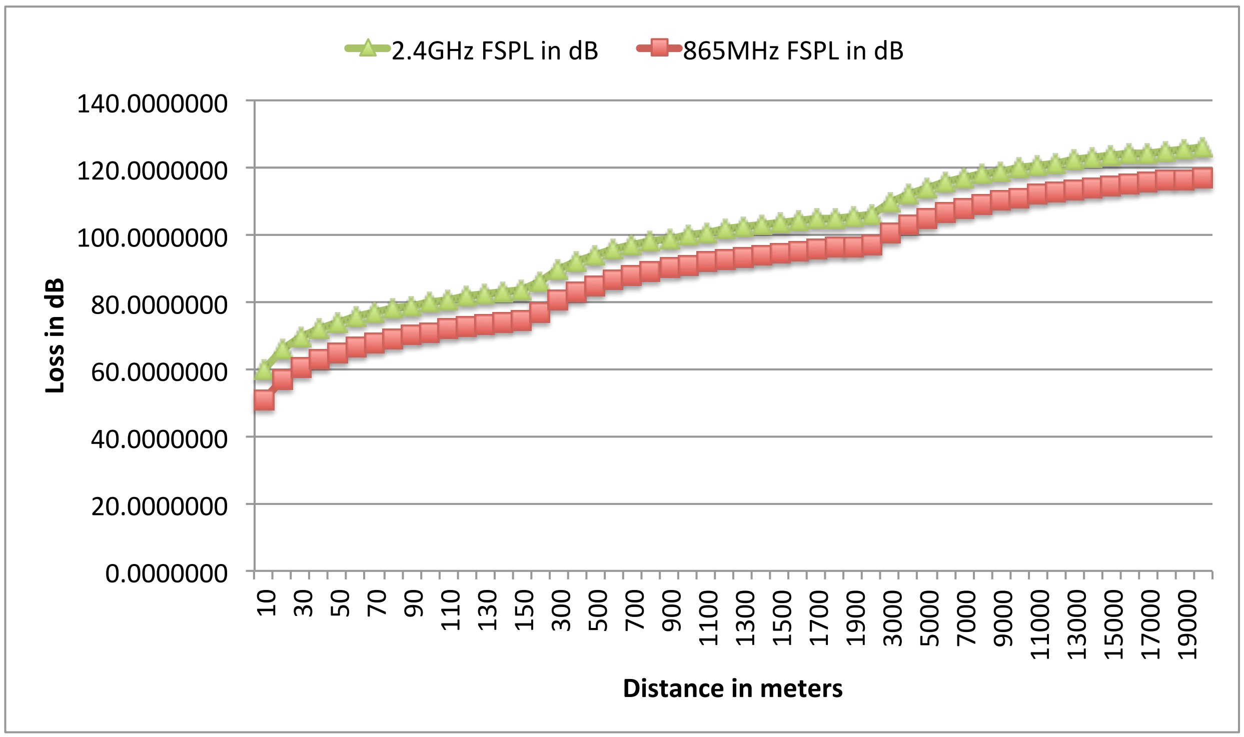
$$FSPL = \frac{P_t}{P_r} G_t G_r$$

- 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 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!
- In results, you can go much farther!
- In a conventional WLAN system, signal-to-noise ratio (SNR) is 20 dB or greater in order to achieve the maximum data rate

LoRa vs Sigfox

LoRa uses spread spectrum while 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

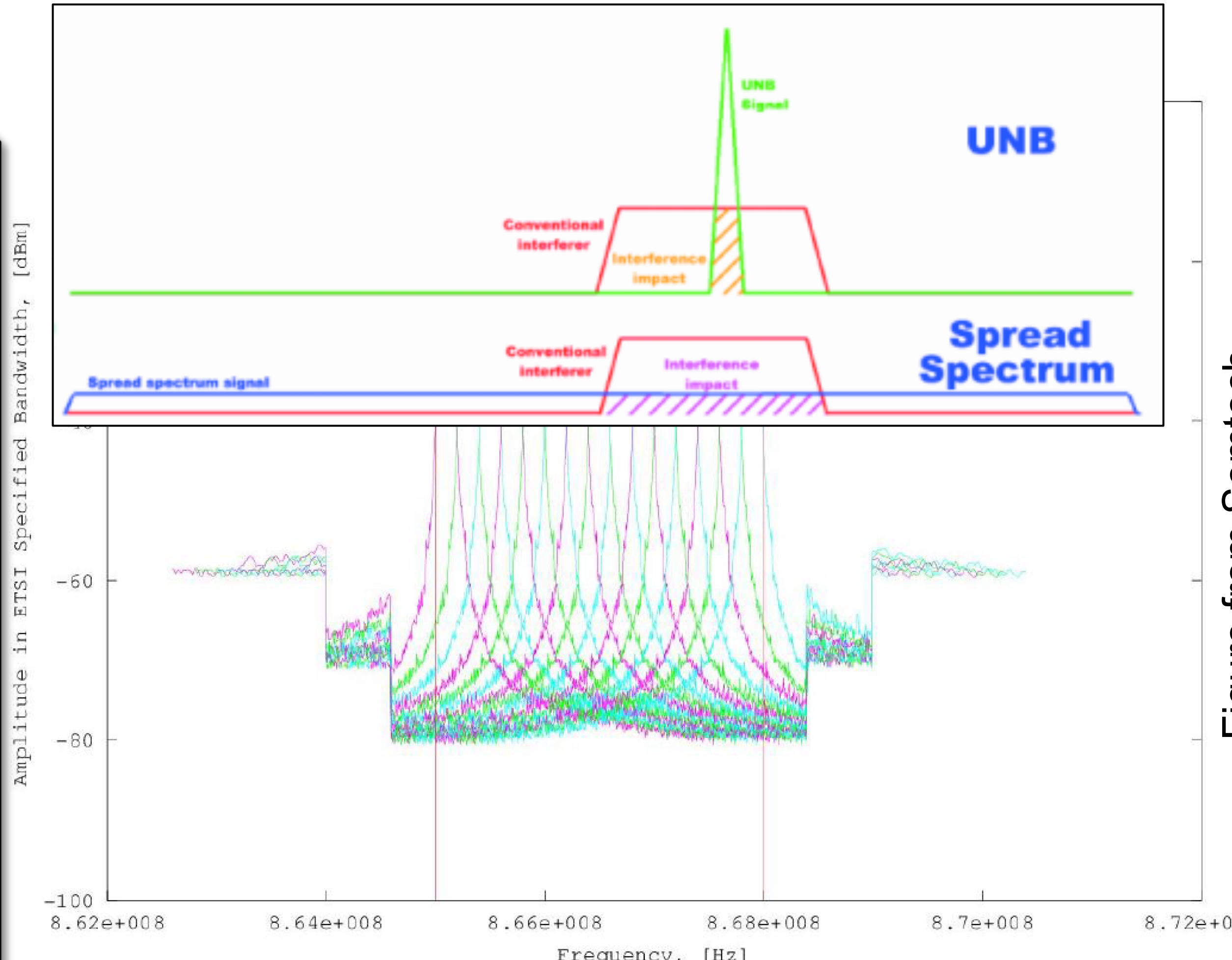
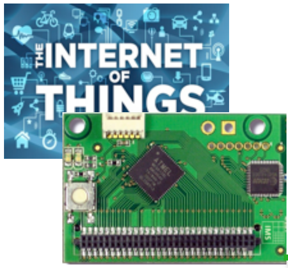


Figure 3. Band G (Note 7) 6 dBm RF Output Power 125 kHz Bandwidth

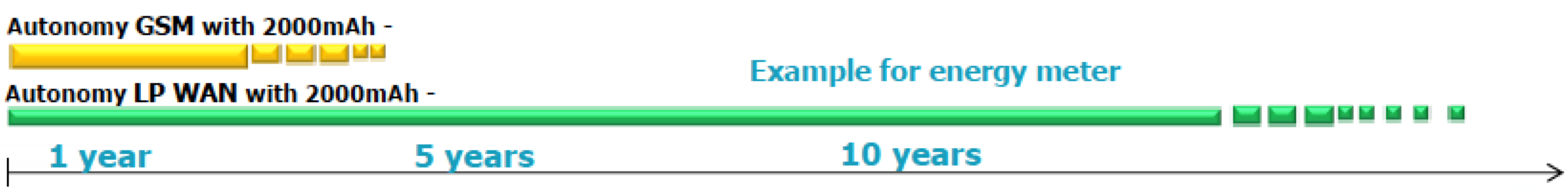
Figure from Semtech



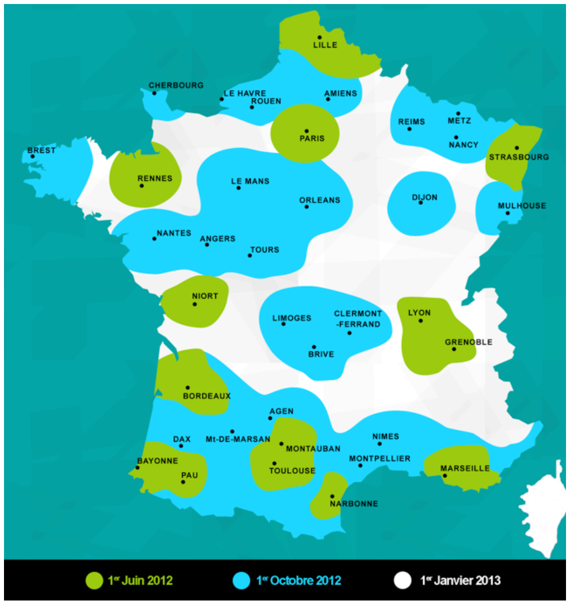
Power consumption rough comparison

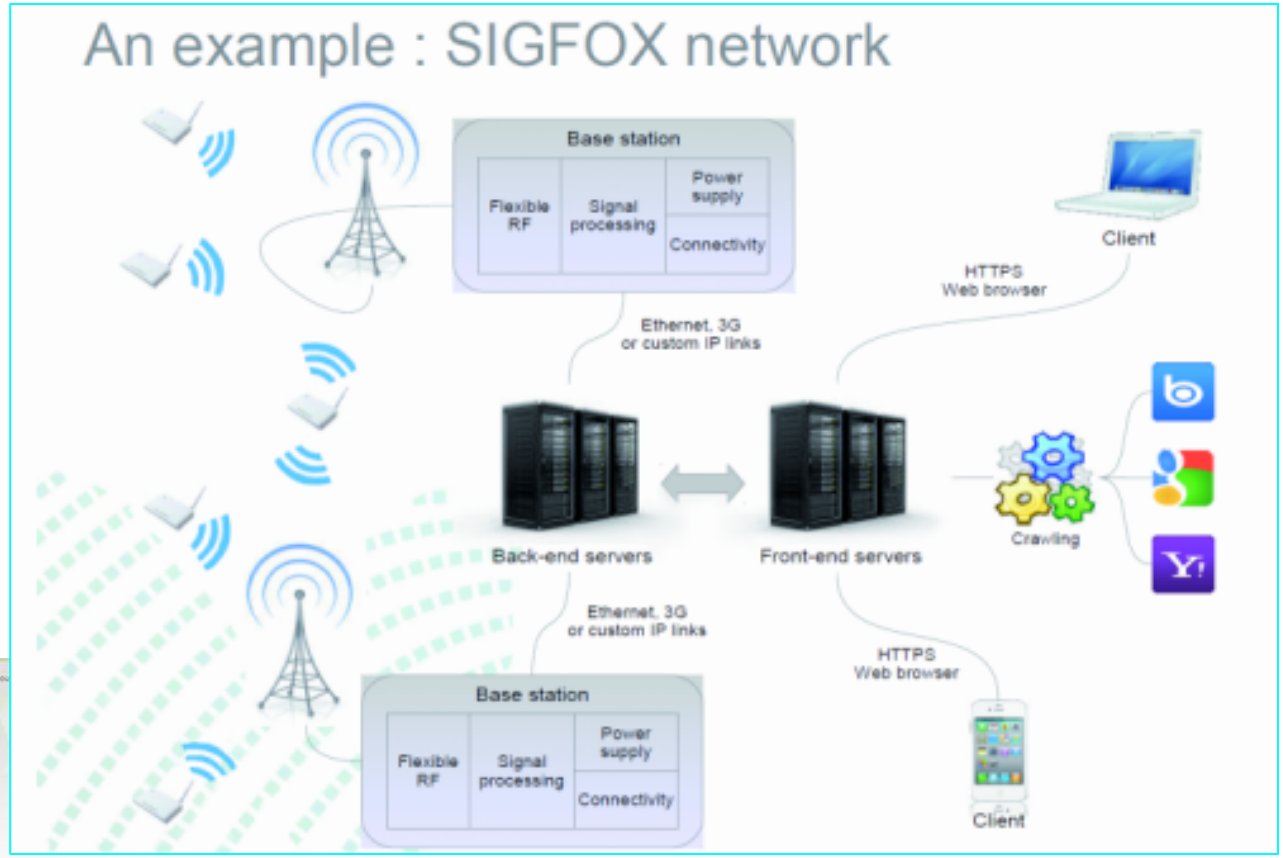
Tables from Semtech

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	200-500mA	500-1000mA	50-100mA	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 $



Sigfox model for M2M: the operator approach



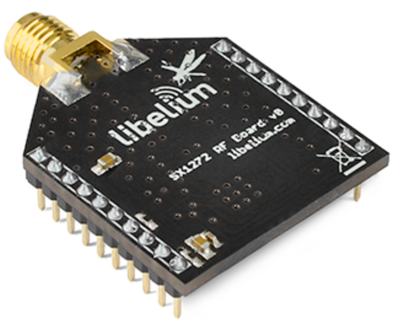


Figures from SigFox

LoRa proposes DIY long range communications

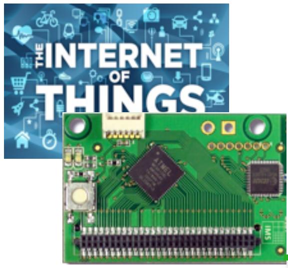
License-free sub-GHz band

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

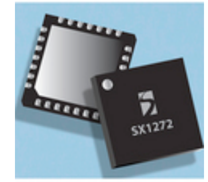


Libelium LoRa is based on Semtech SX1272 LoRa
863-870 MHz for Europe
Data rate from 200bps to 20kbps

DORJI DRF1278DM is based on Semtech SX1278 LoRa 433MHz



Semtech's LoRa technology



dBm – **power referred to 1 mW,**

P_{dBm}**=10log(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	-137
250	6	18750	-119
250	12	586	-134
500	6	3750	-116
500	12	1172	-131

Rule of thumb

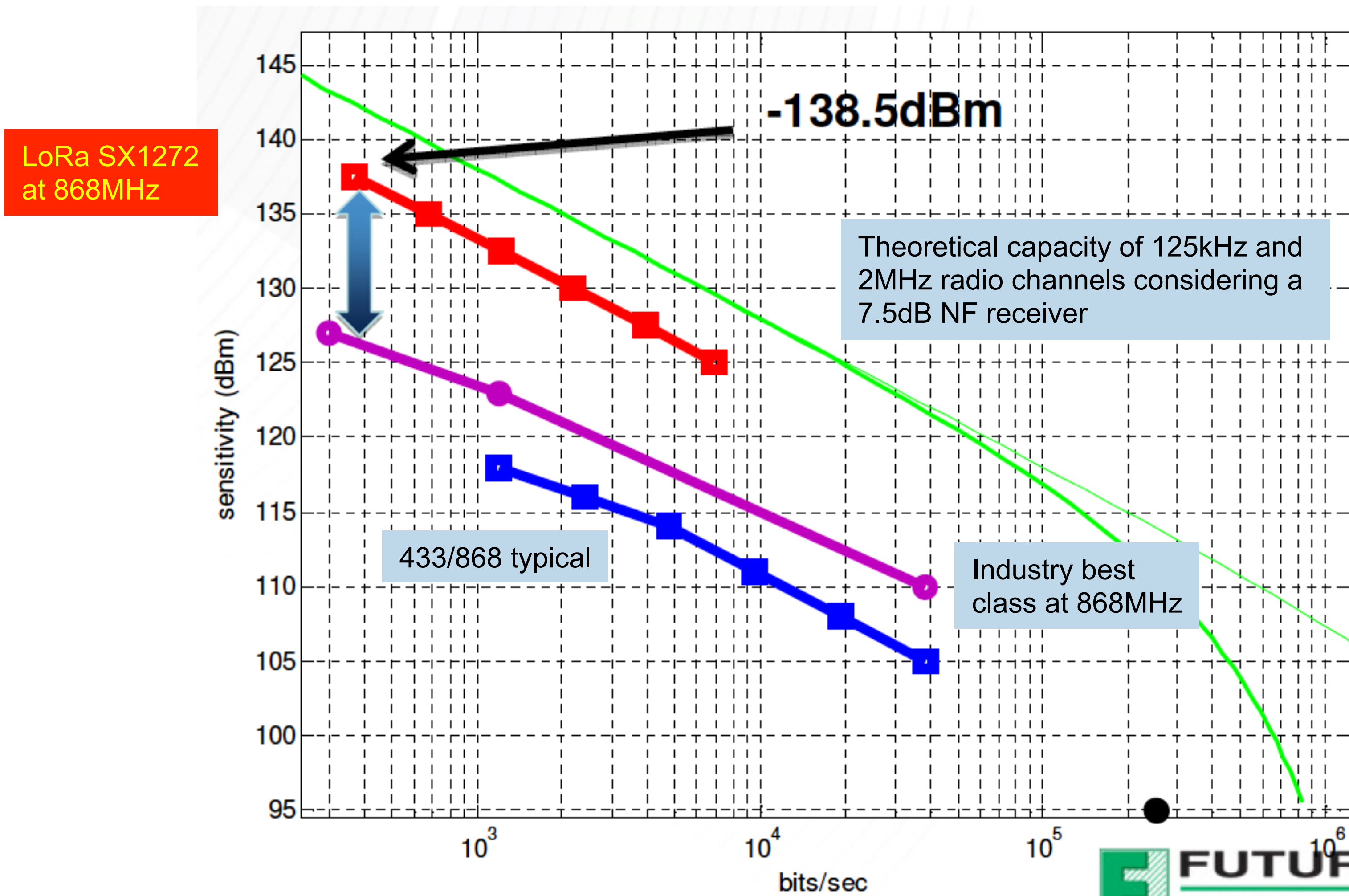
6dB increase = twice the range in LOS

12dB needed for urban areas

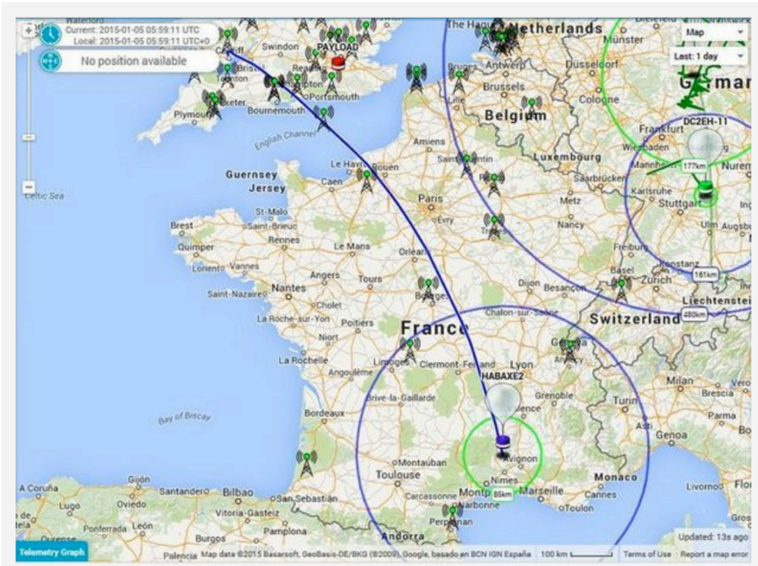
Bandwidth (kHz)	Spreading Factor	Coding rate	Nominal Rb (bps)	Sensitivity (dBm)
125	12	4/5	293	-136
250	12	4/5	586	-133
500	12	4/5	1172	-130

Tables from Semtech

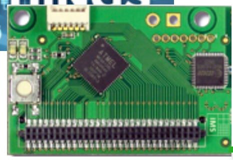
WHY THE LORA REVOLUTION?



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



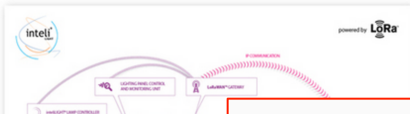
From scoop.it

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

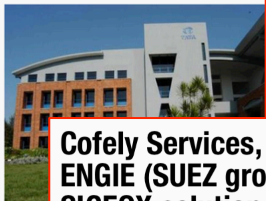
LoRa™ technology to be integrated into FLASHNET's street lighting management solution, inteliLIGHT



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 ... 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

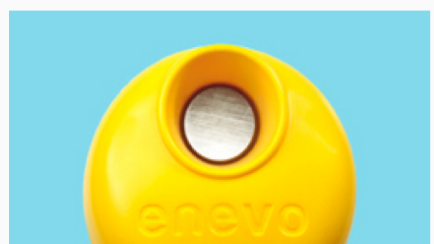
" A preliminary market battle has been brewing over the past year between technologies to connect IoT devices via wireless wide area networks. These cellular-type networks allow very low power battery devices to transmit small amounts of data over several miles, a solution...

A... IoT city network

From www.meterin...

determine the "best" wireless network...

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



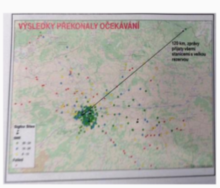
From www.enevo.com - March 6, 4:12 PM

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

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

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

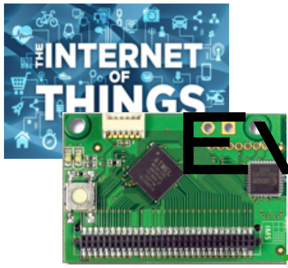
T-Mobile to cover the Czech Republic with the SIGFOX network for the Internet of Things



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

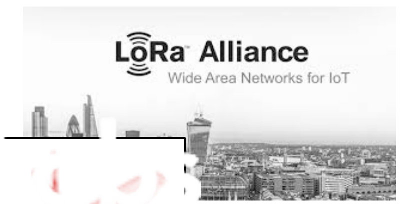
TST

TEXAS INSTRUMENTS

LoRa™

SEMTECH

MULTITECH



IBM®

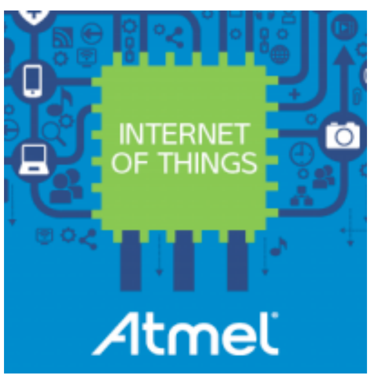
libelium

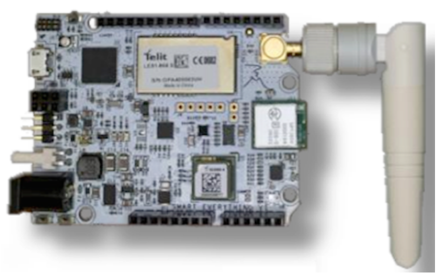
Froggy FACTORY

actility
Making Things Smart

Wi6LABS

ThingPark Wireless





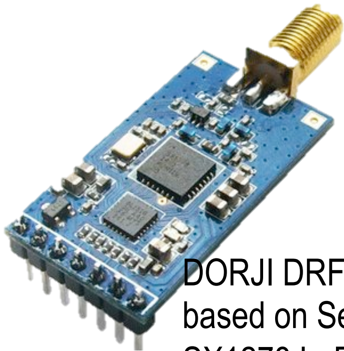
Bouygues Telecom

IMST

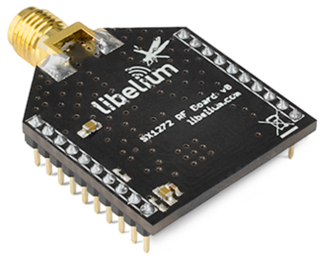
kerlink
m2m technologies

LinkLabs

LoRa radios (mostly based on SX1272/76 chip)



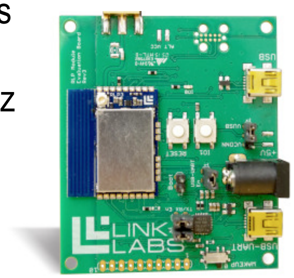
DORJI DRF1278DM is based on Semtech SX1278 LoRa 433MHz



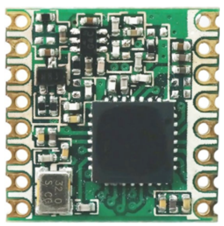
Libelium LoRa is based on Semtech SX1272 LoRa 863-870 MHz for Europe

Froggy Factory LoRa module (Arduino)

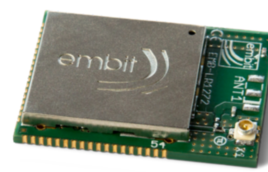
IMST IM880A-L is based on Semtech SX1272 LoRa 863-870 MHz for Europe



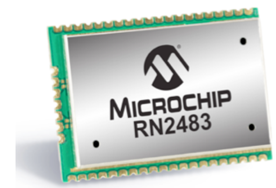
LinkLabs Symphony module



HopeRF RFM series



Embit LoRa

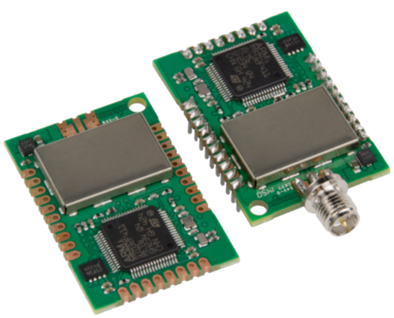


LoRa™ Long-Range Sub-GHz Module (Part # RN2483)

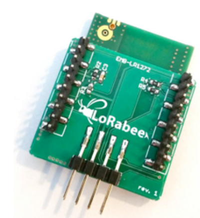
Microship RN2483

habSupplies

Adeunis ARF8030AA- Lo868

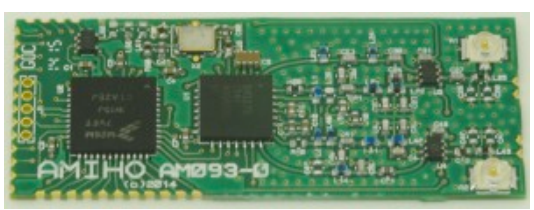


Multi-Tech MultiConnect mDot



SODAQ LoRaBee Embit

SODAQ LoRaBee RN2483



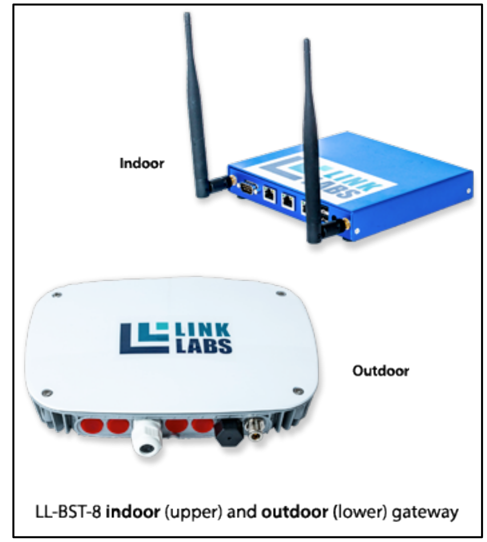
AMIHO AM093

LoRa Gateways
(non exhaustive list)

Multi-Tech Conduit

Embedded Planet
EP-M2M-LORA

Ideetron Lorank 8



LinkLabs Symphony

PicoWAN from
Archos

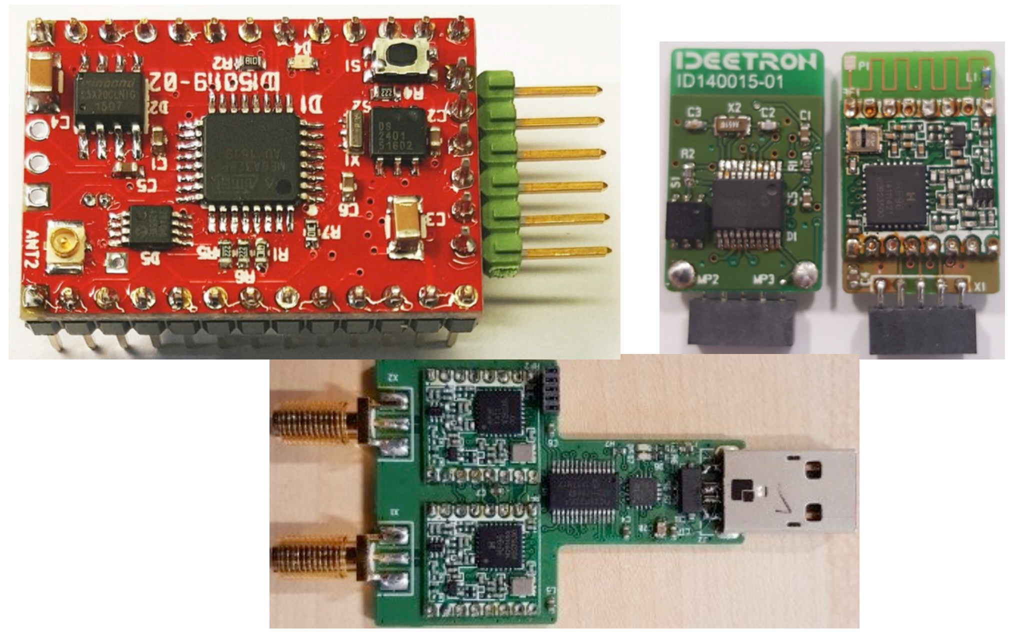
TheThingNetwork

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

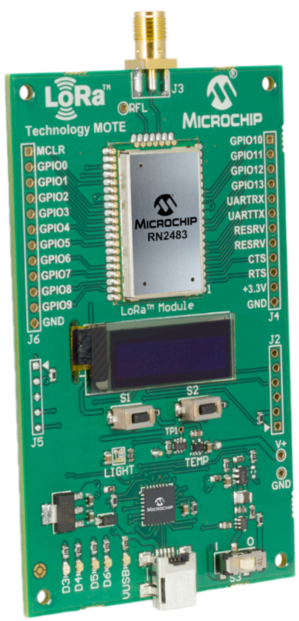
Kerlink IoT Station

Ready-to-use LoRa devices

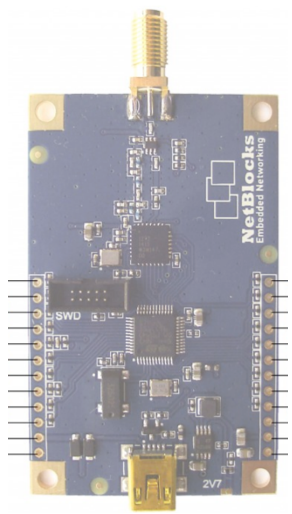
LoRa Mote from Semtech



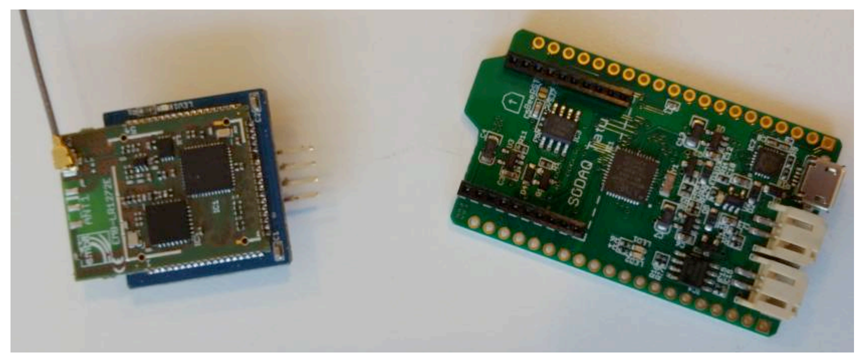
HopeRF/Ideetron motes



Microchip LoRa mote



NetBlocks XRange

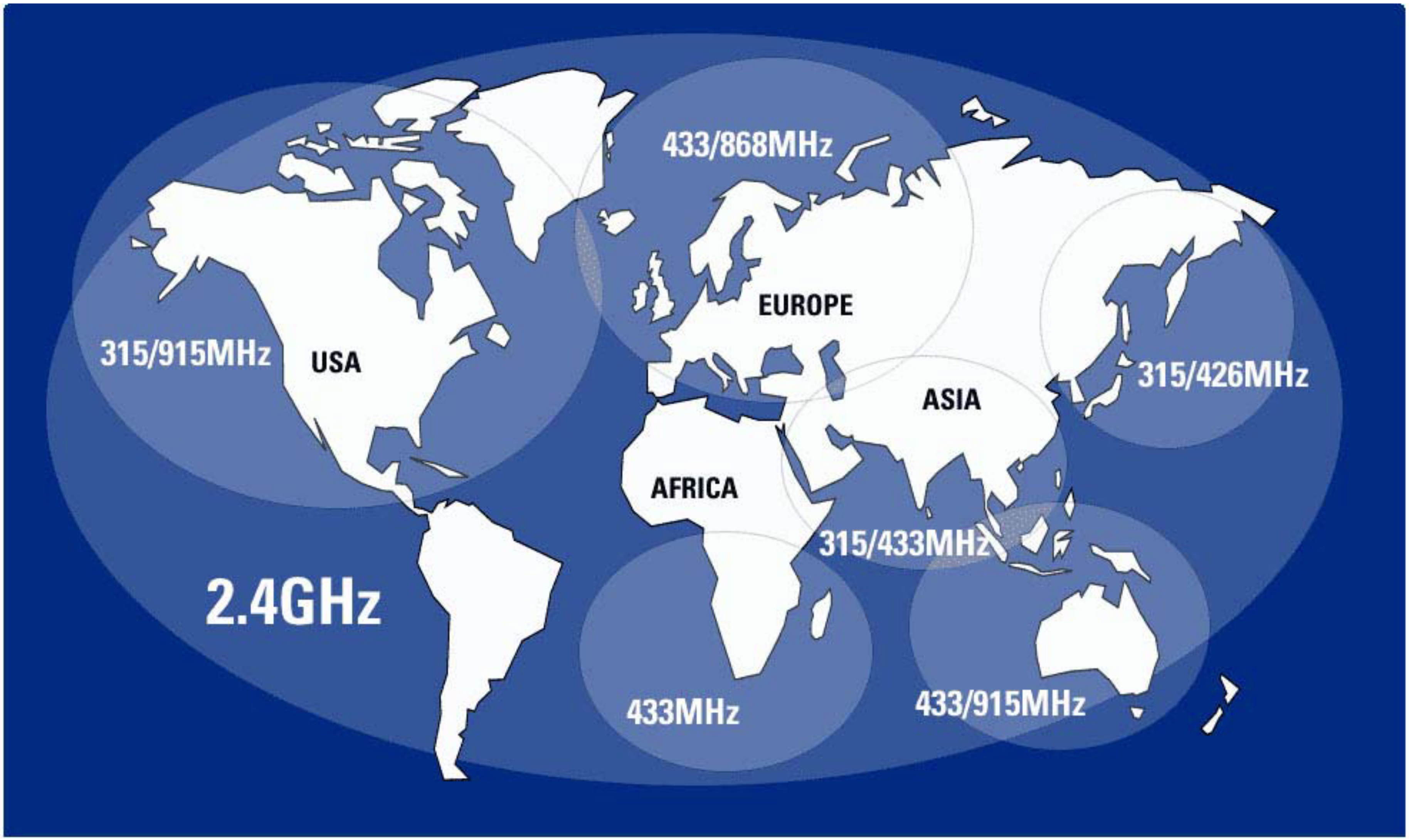


SODAQ Tatu with LoraBee (Embit)

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		

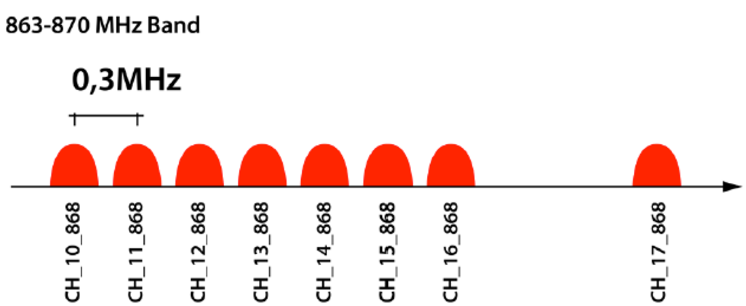
The ISM/SRD License-Free Frequency Bands



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% 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

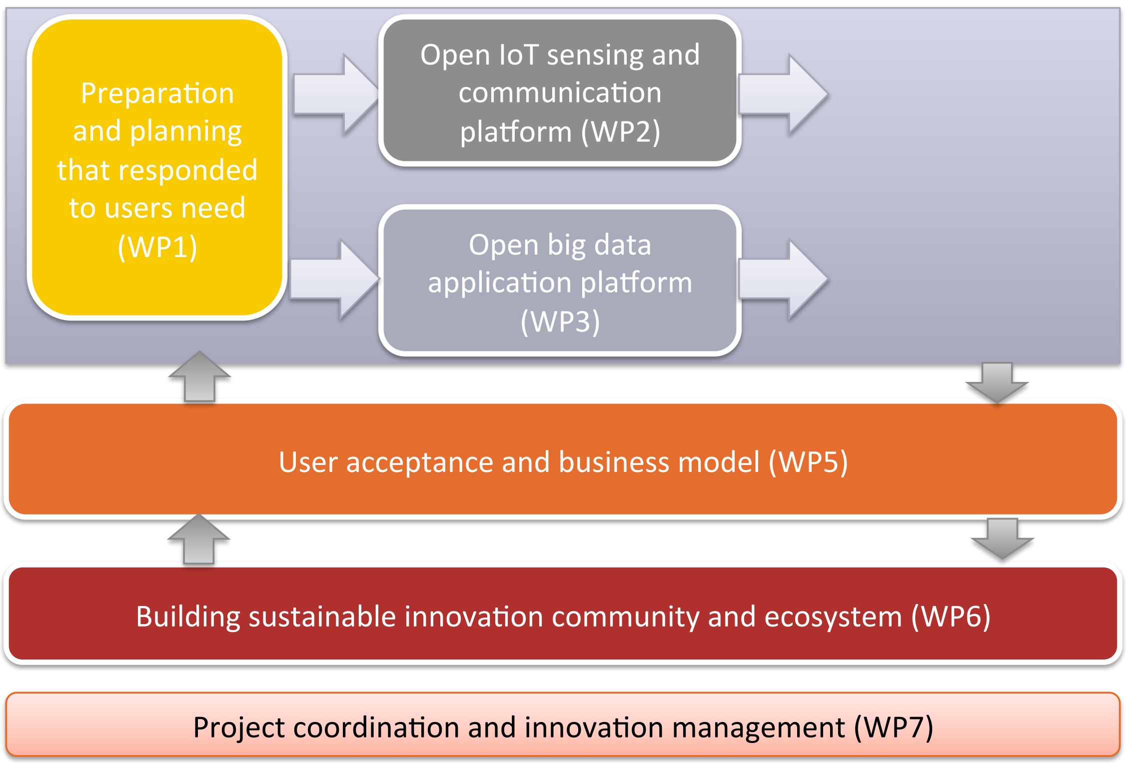
Time on air for various Libelium LoRa mode

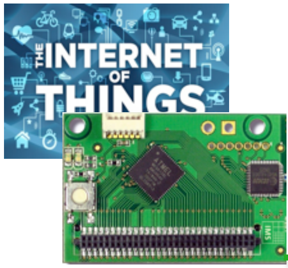
Range ↑ / Throughput ↓

				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

WAZIUP CONTRIBUTION

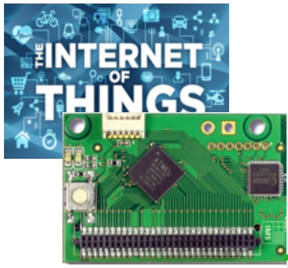
- WAZIUP contributes to long-range networks with WP2





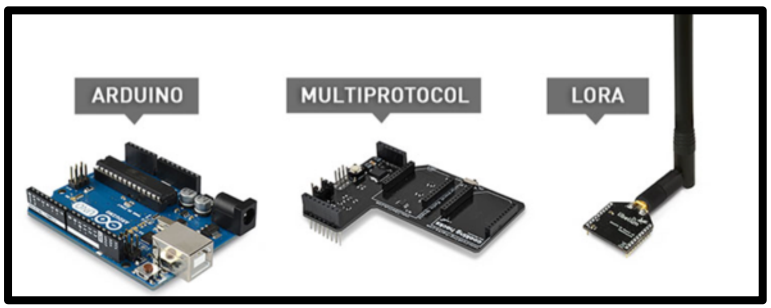
WAZIUP's WP2

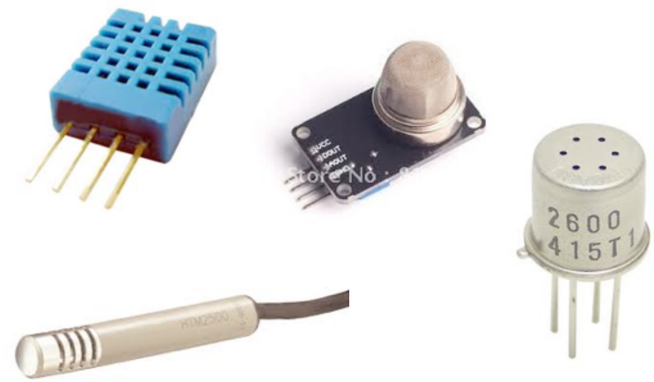
- UPPA (LIUPPA/T2I) leads WP2
  - T.2.1 Design and adaptation of sensing systems considering societal and environmental threat (UI)
  - T2.2 Design and integration of heterogeneous IoT networking (UPPA)
  - T2.3 Low-latency and low-energy MAC protocols (UPPA)
  - T2.4 Open IoT test-bed and benchmark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



T2.1
Design and adaptation

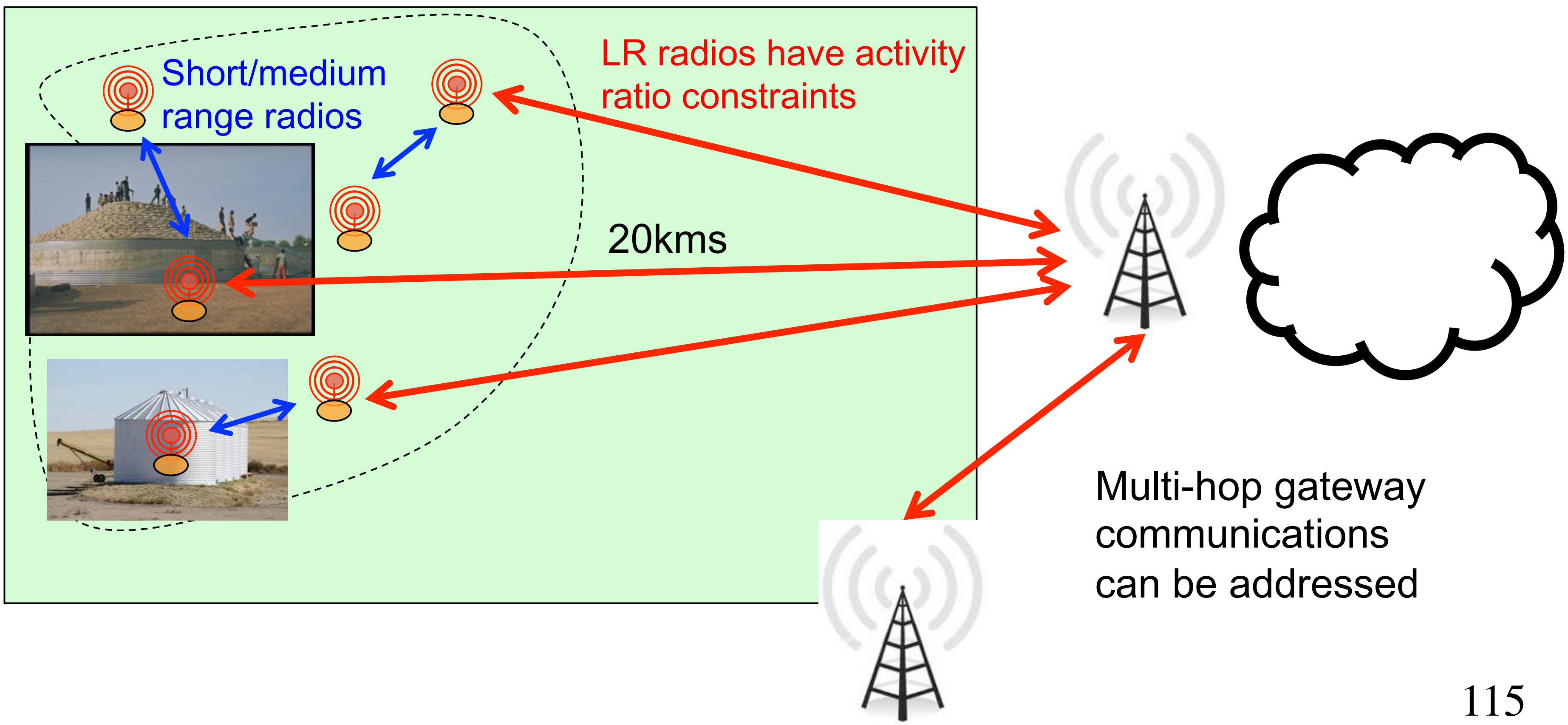
- Build low-cost, low-power, Long-range enabled generic platform
- Methodology for low-cost platform design





T2.2
Heterogeneous IoT Networking

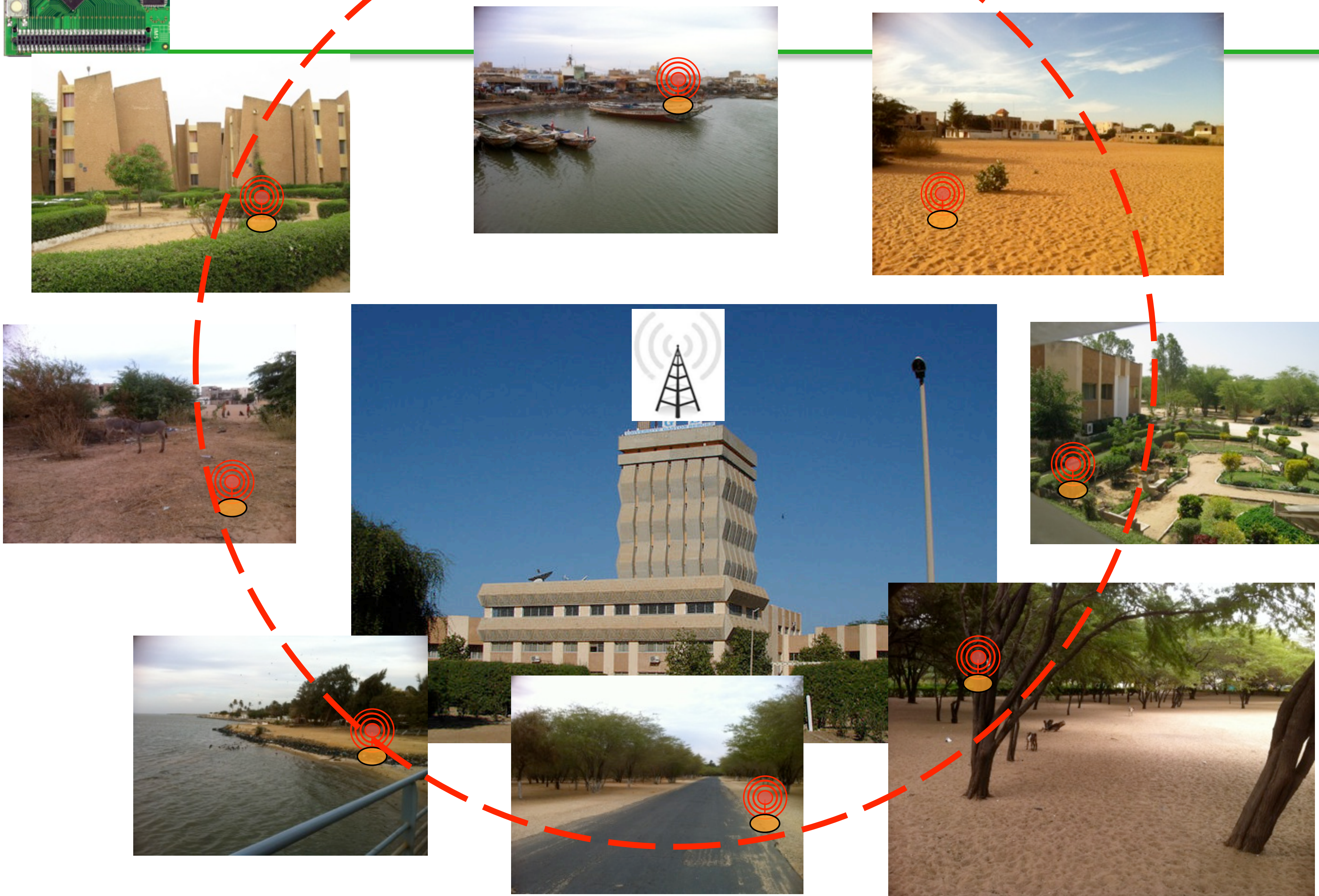
- Seamless integration of short-range & long-range, intermittent connectivity

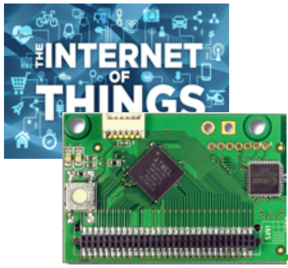


T2.3
MAC protocols

- 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

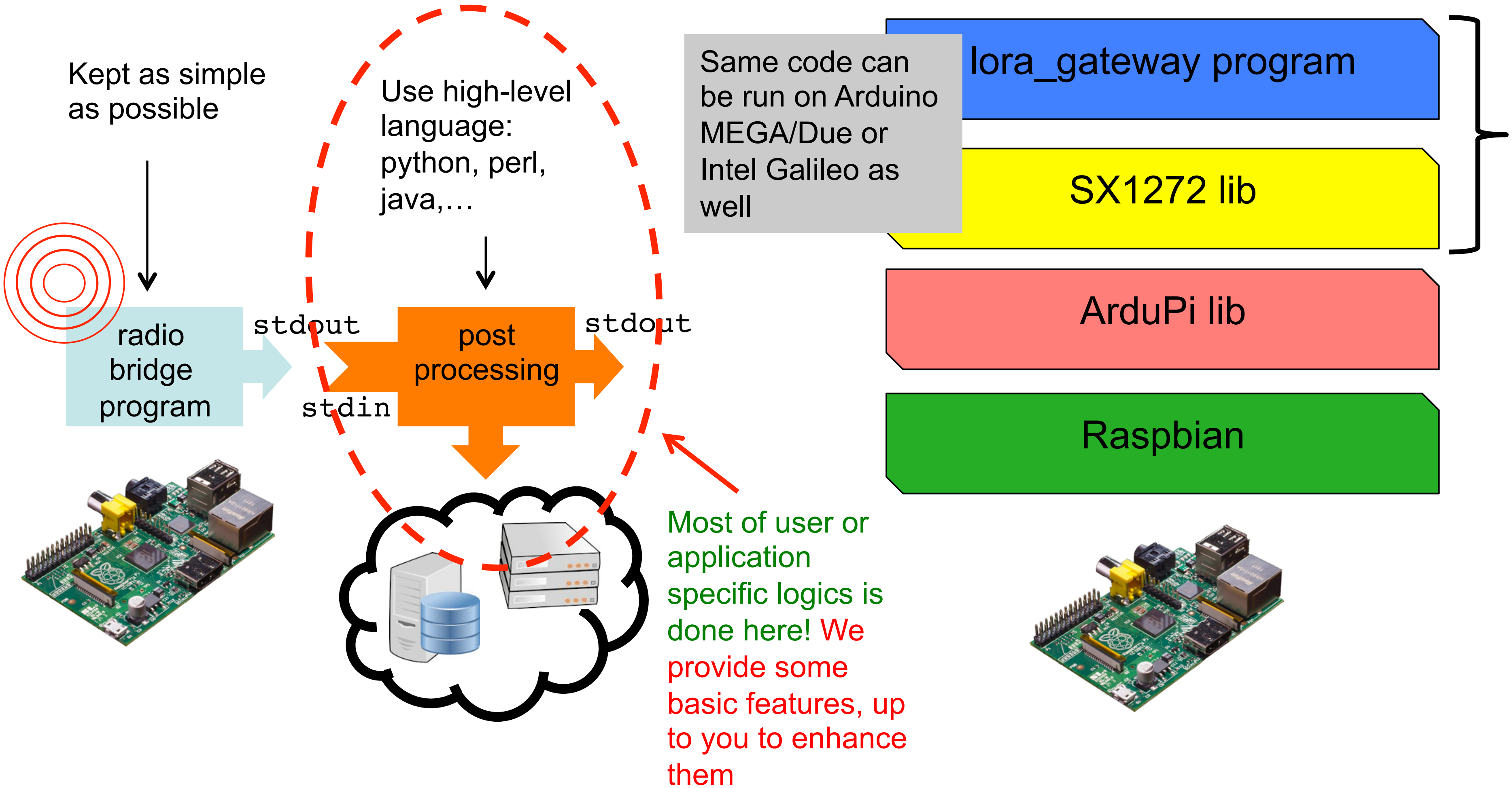




LoRa gateways

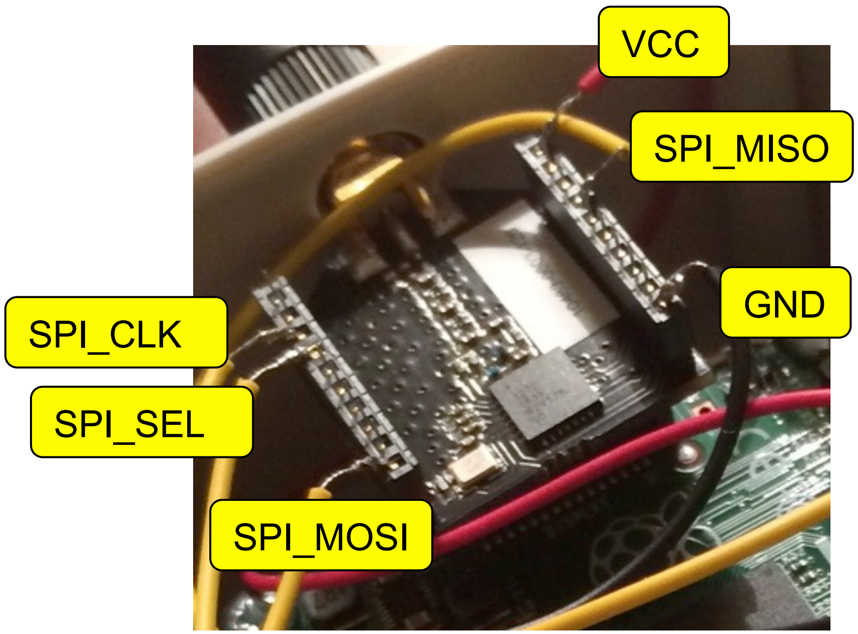
- WAZIUP will deploy already-packaged gateways such as Kerlink and MultiTech gateways
- WAZIUP will also provide low-cost gateways based on off-the-shelves platforms for minimum cost, maximum customization and flexibility
  - Arduino (MEGA, DUE)
  - Intel Galileo
  - Raspberry PI

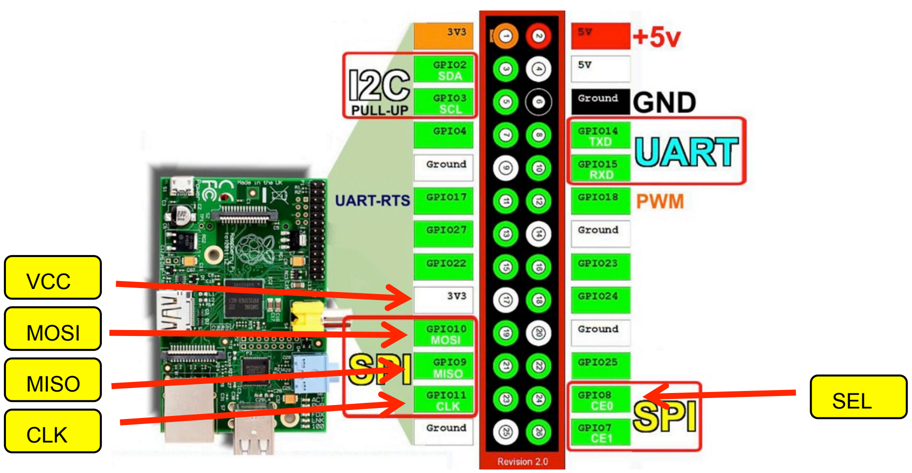
Our Low-Cost gateway approach



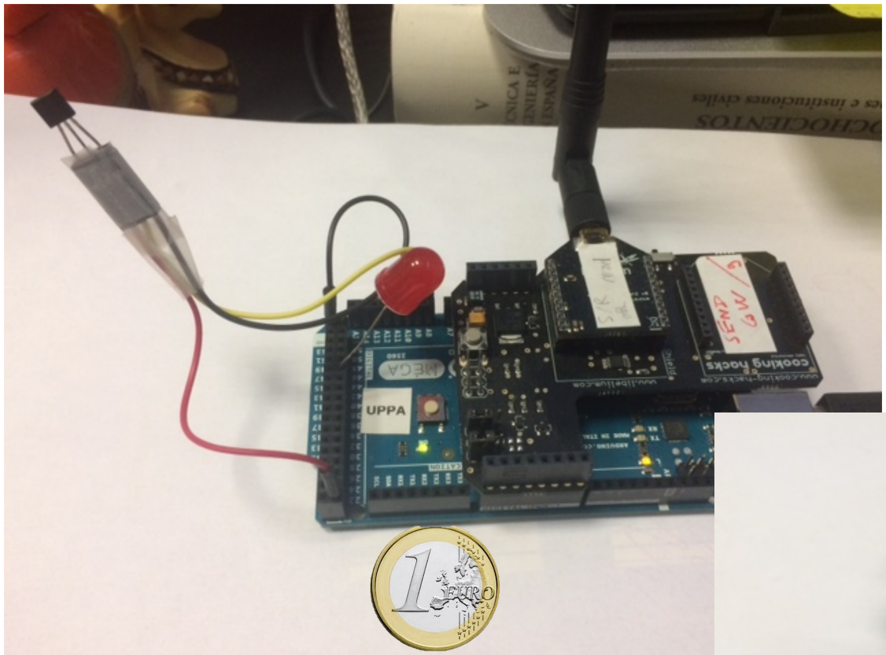

```
g++ -lpthread -lrt lora_gateway.cpp arduPi.cpp SX1272.cpp -o lora_gateway
```

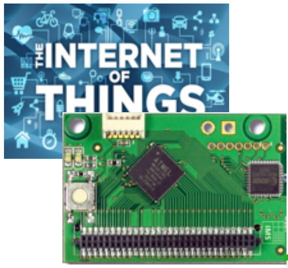
First prototype





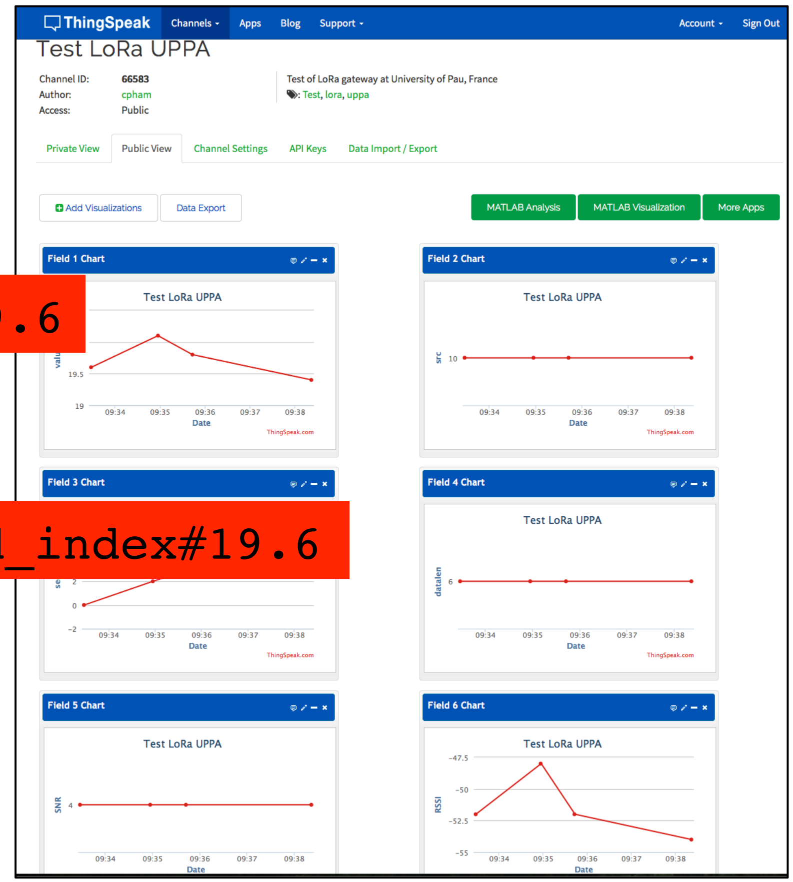
LoRa end-device: temperature sensor

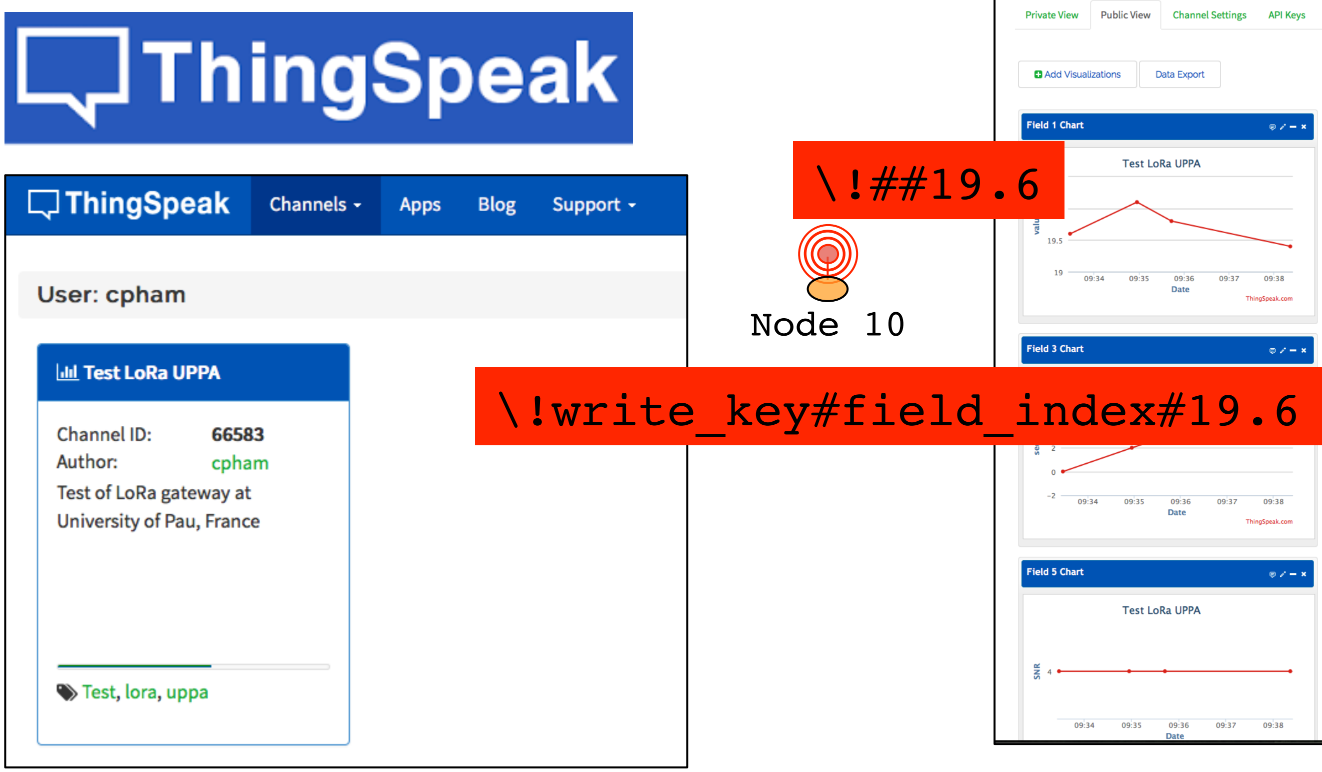




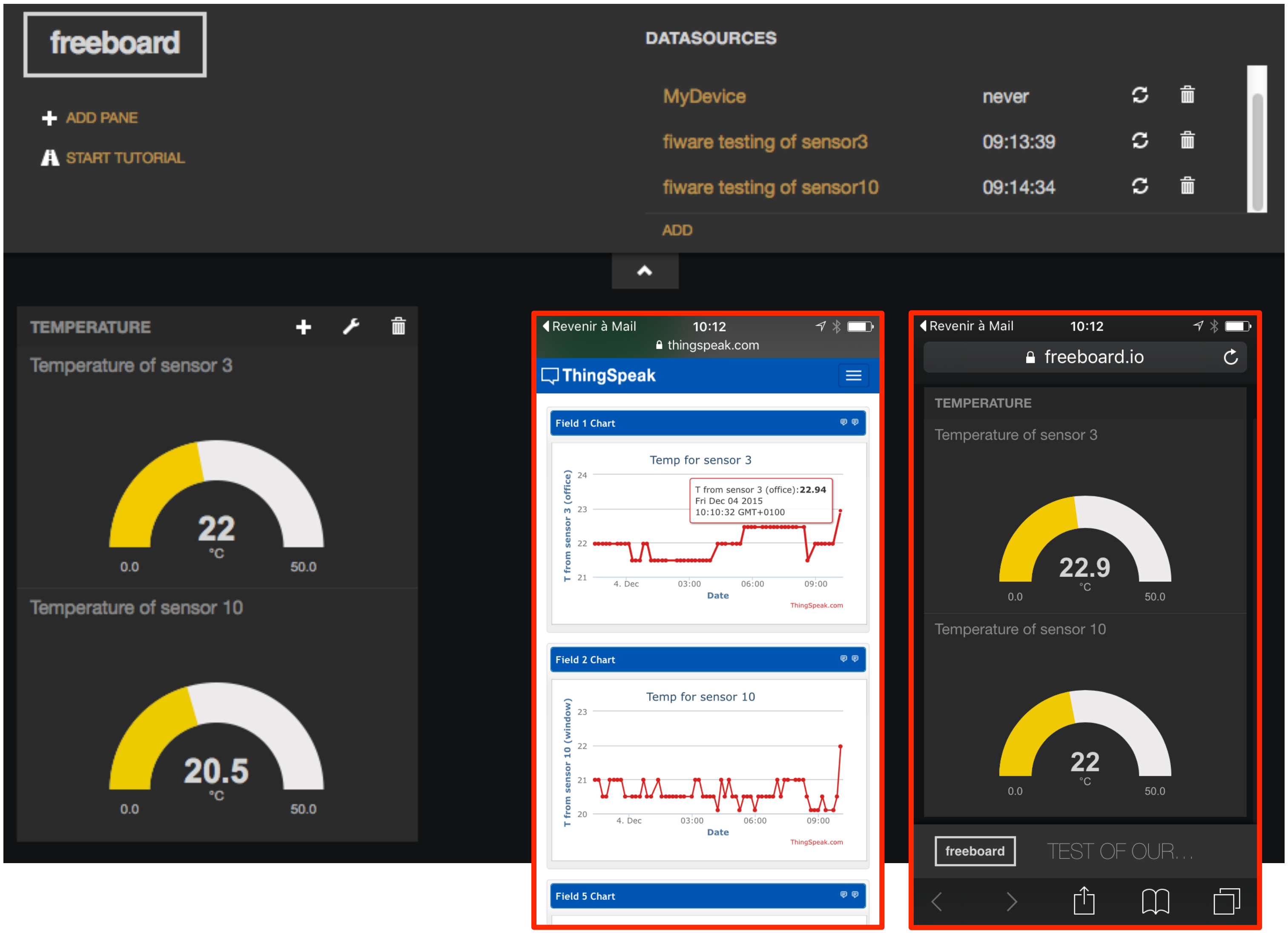
Using ThingSpeak

- A message starting with '\!' is logged in a ThingSpeak channel

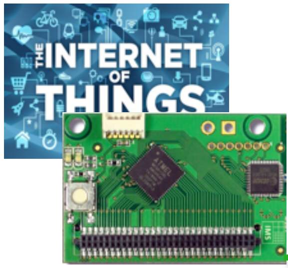




Freeboard IoT cloud with FIWARE



More to come with demo



Conclusions

- Internet of Things, like Wireless Sensor Networks are the foundation of pervasive surveillance infrastructures for smarter, context-aware applications
- Connecting them, collecting data and providing seamless internet connectivity is challenging but many standards have emerged
- IoT devices are foreseen to go beyonds the number of traditional internet hosts
- New long-range radio technologies is boosting IoT deployment as it never has been!!