Réseaux de capteurs sans fil de la théorie à la pratique



21 octobre 2014

UGB, Saint-Louis, Sénégal



Prof. Congduc Pham

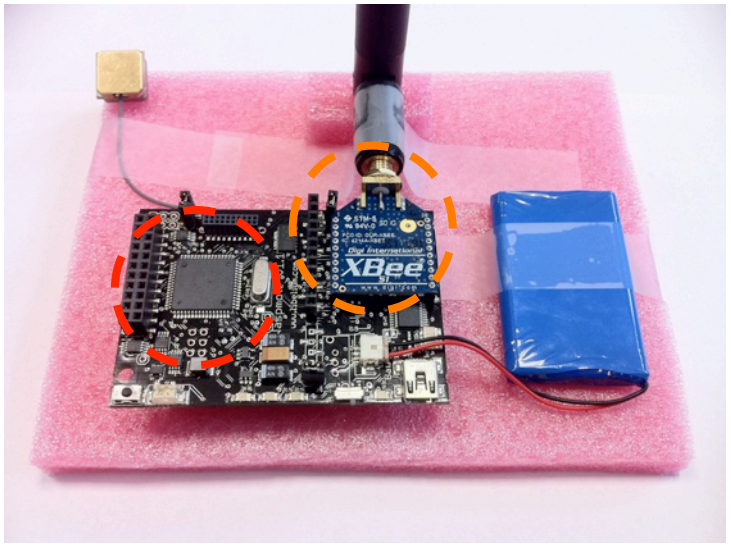
http://www.univ-pau.fr/~cpham

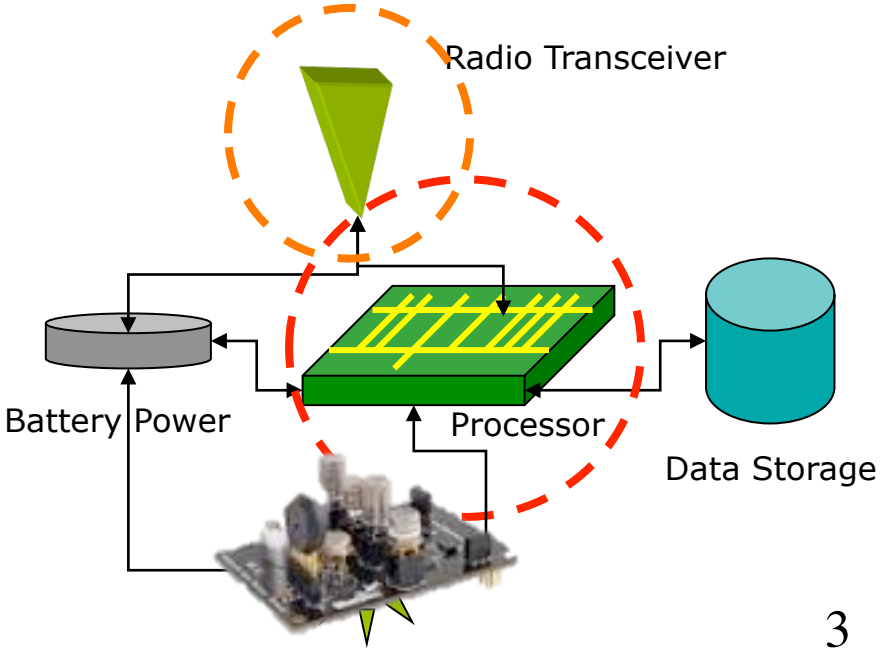
Université de Pau, France



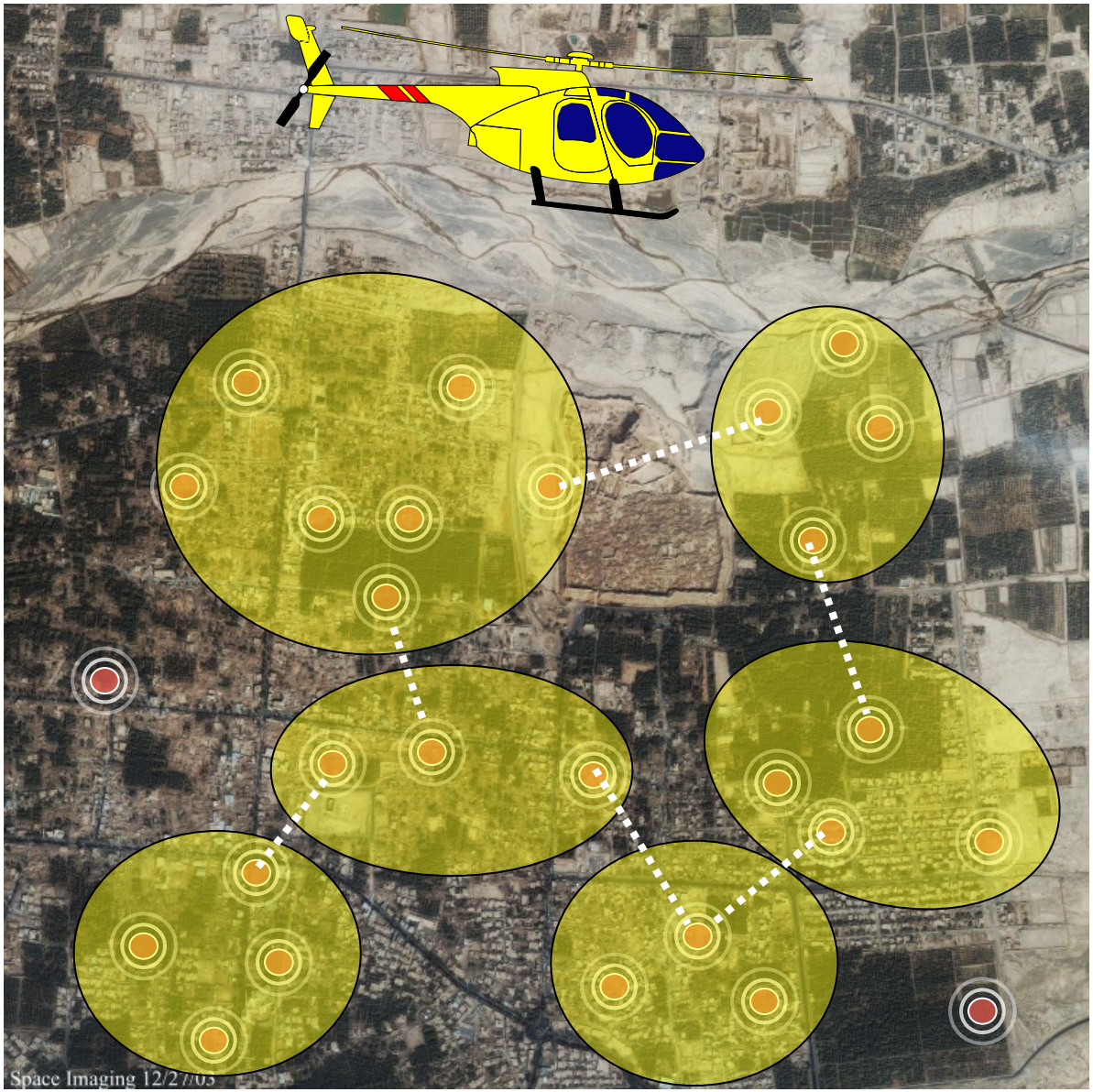
Wireless autonomous sensor

- Wireless Sensor Nodes or embedded Linux still remain the main IoT development platform
- In general: low cost, low power (the battery may not be replaceable), small size, prone to failure, possibly disposable

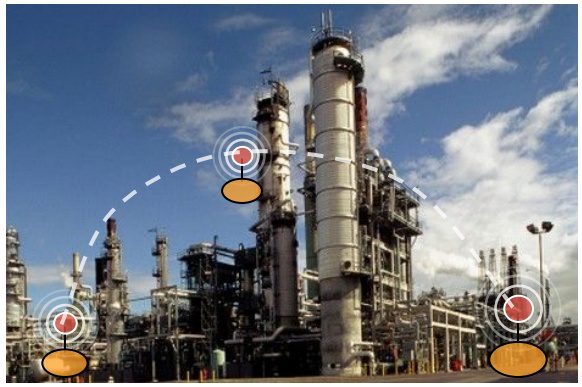




LARGE SCALE DEPLOYMENT



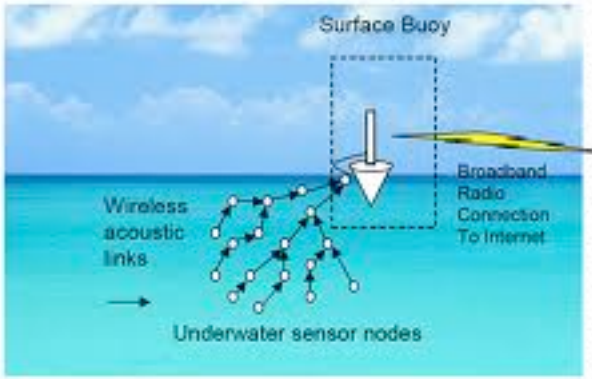
« Naturally » well suited for Monitoring/Surveillance

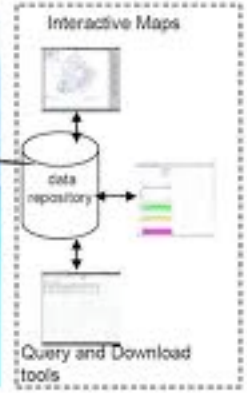








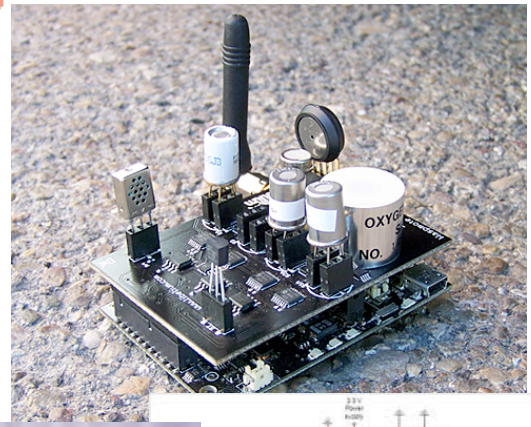








Energy consideration





18720 Joules

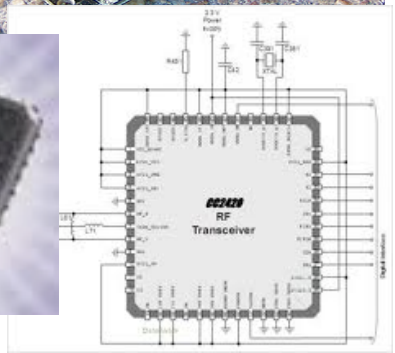
TX power 0dbm: 17.4mA

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

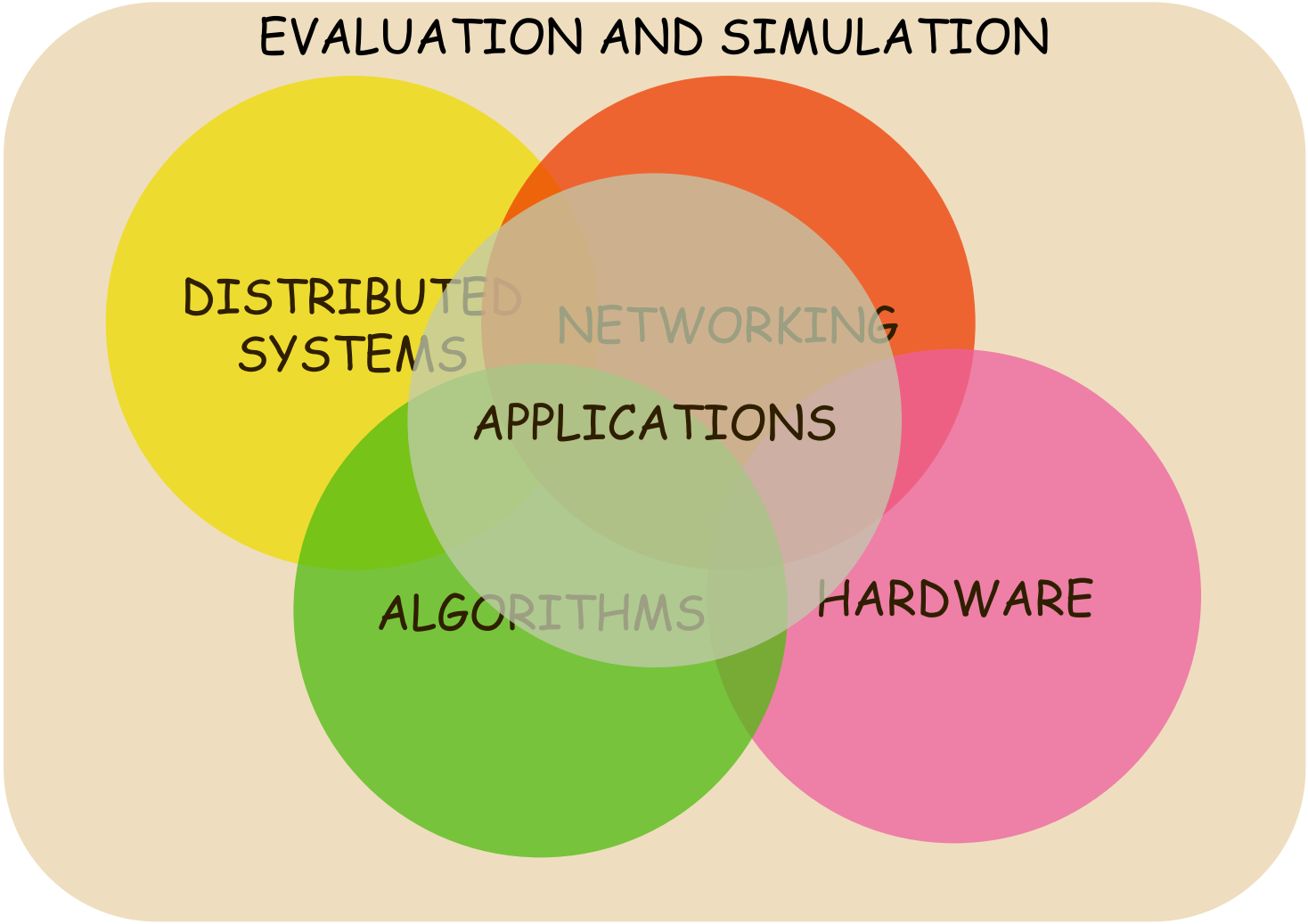
CC2420

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	

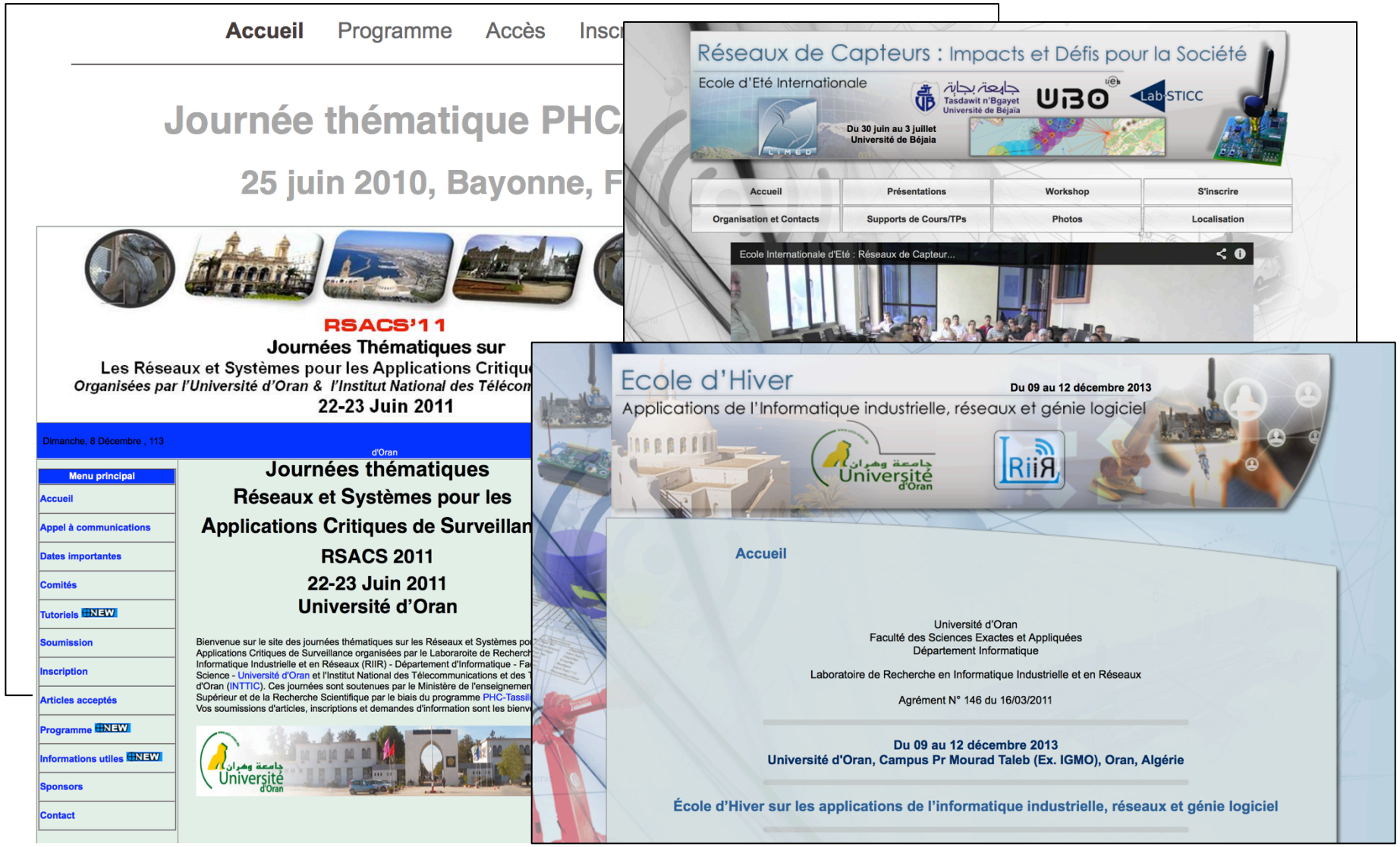
Haven't considered:

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

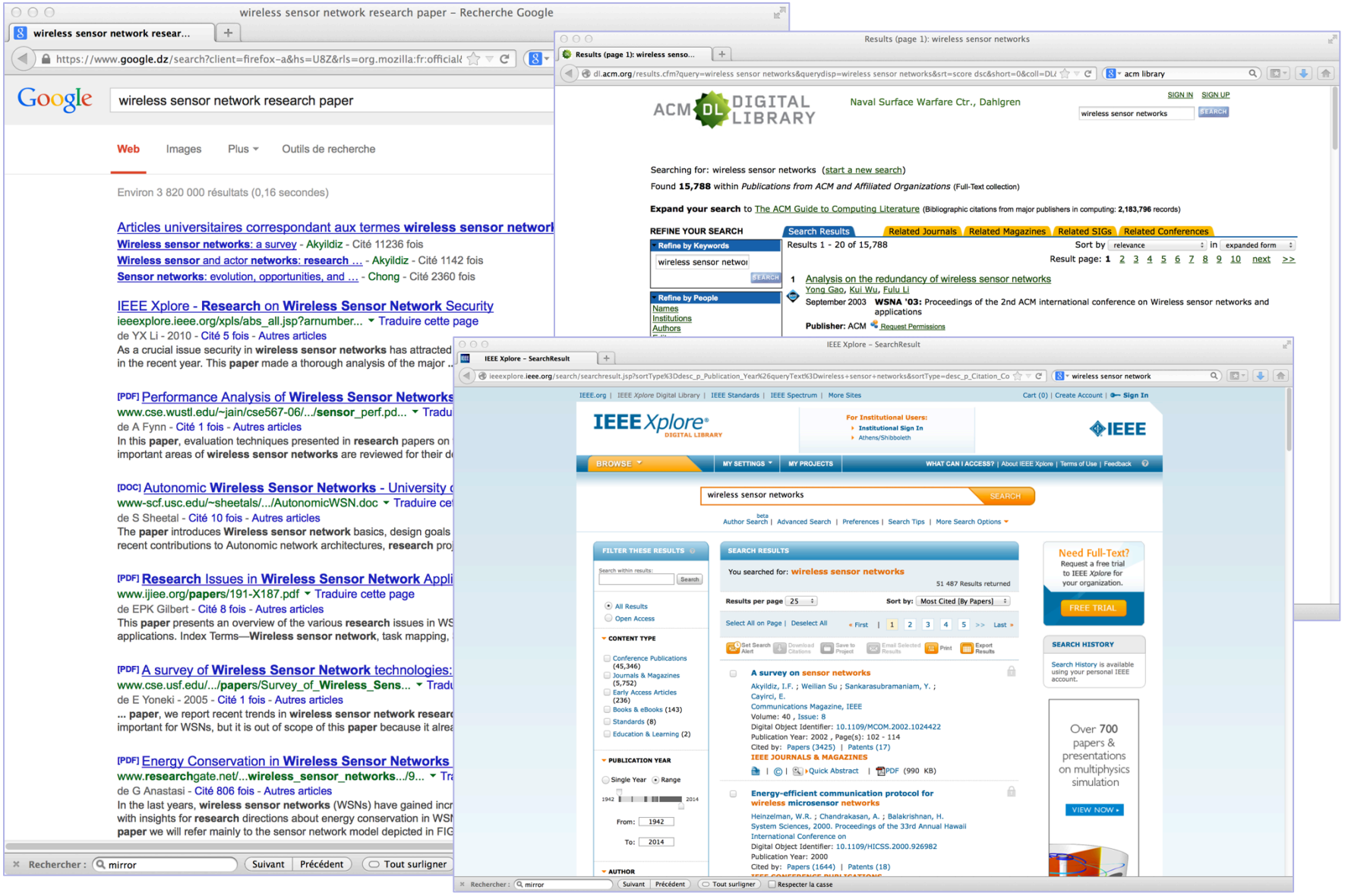
MULTIDISCIPLINARY RESEARCH



RESSACS 2010, 2011, 2012, 2013, 2014. RSAC 2011. Brest 2012. Béjaia 2013. Oran 2013, CDTA Algier 2014, ...

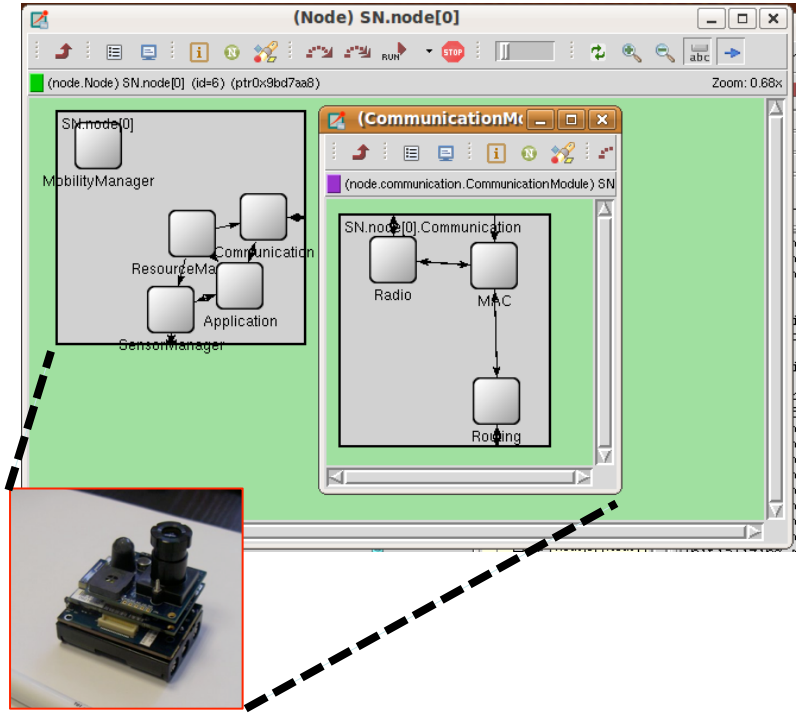


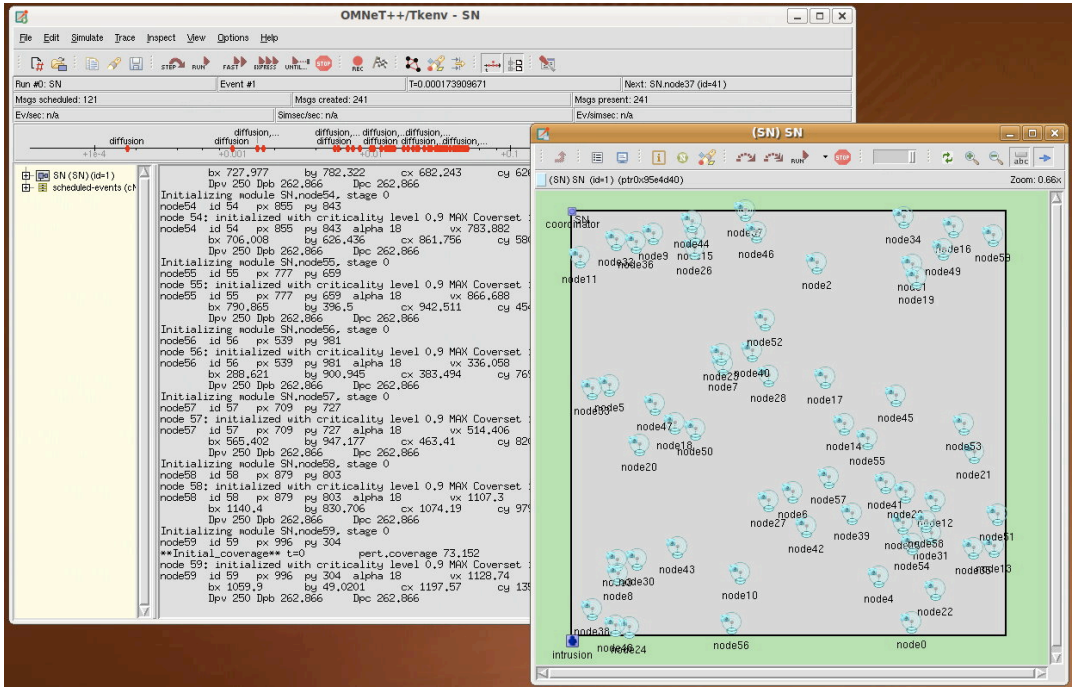
Huge amount of contributions...



...BUT LOT'S OF (TOO MUCH?) SIMULATION STUDIES

- Simulation models
- NS-2, NS-3, OMNET++, Castalia, Wsim/WSNet
- Too many studies stay at « simulation » level

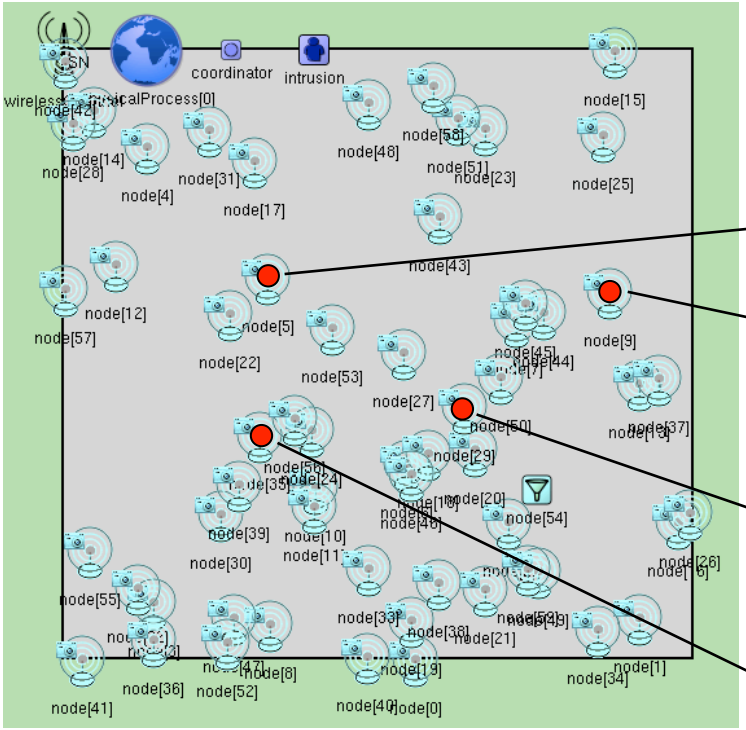




Search & Rescue, Situation awareness



Studies on Scheduling, Routing, MAC, ...



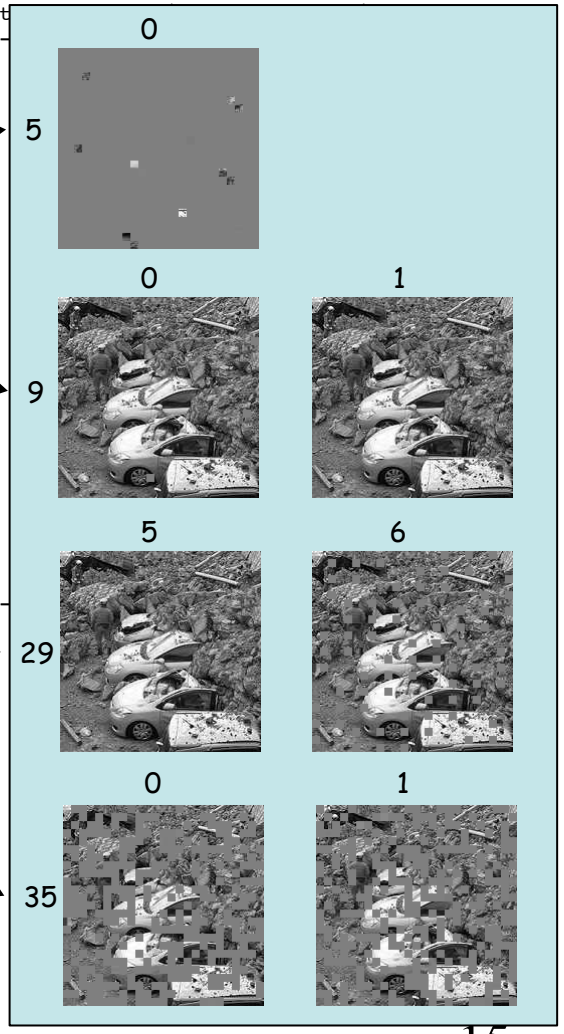
60 IMAGE SENSOR NODES
75MX75M
1 SINK (NODE 54)

Application:Image sent

	Images	Packets	by coverset
node=2	1	206	0
node=5	4	824	0
node=9	2	412	2
node=10	6	1236	6
node=12	1	206	0
node=15	2	412	2
node=17	1	206	0
node=19	3	618	0
node=22	4	824	0
node=23	2	412	0
node=24	6	1236	0
node=26	1	206	1
node=27	6	1236	0
node=29	7	1442	6
node=33	6	1236	6
node=35	12	2472	0
node=37	5	1030	0
node=40	8	1648	3
node=46	2	412	2
node=48	2	412	0
node=50	2	412	2

Application:Image displayed

	all	complete	truncated
index=-1	39	21	18
index=5	1	0	1
index=9	2	1	1
index=10	6	3	3
index=23	2	0	2
index=24	3	0	3
index=27	4	4	0
index=29	7	6	1
index=33	3	3	0
index=35	4	0	4
index=37	5	3	2
index=50	2	1	1



From simulation to test-beds







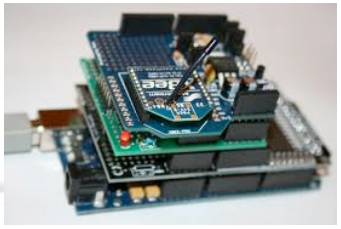


DISCOVER NEW PROBLEMS…

…THAT DO NOT EVEN EXISTS?

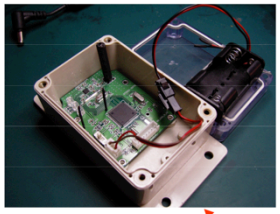
Academics vs Industries

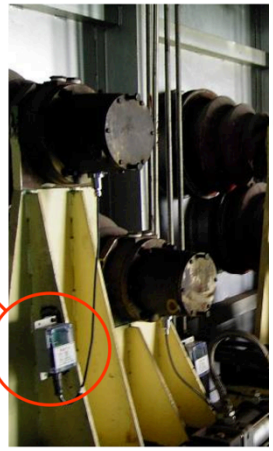
Millions of sensors, self-organizing, self-configuring, with QoS-based multi-path routing, mobility, and …





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?









- Placement constraints
- Lifetime constraints

From Peng Zeng & Qin Wang

Towards WSN mass-market

NOW

Zolertia

libelium
comunicaciones inalámbricas distribuidas

ARDUINO

TST

MICROCHIP

Genet
Generation Next
Technology Laboratories

Jennic
TECHNOLOGY FOR A CHANGING WORLD

2000-2007

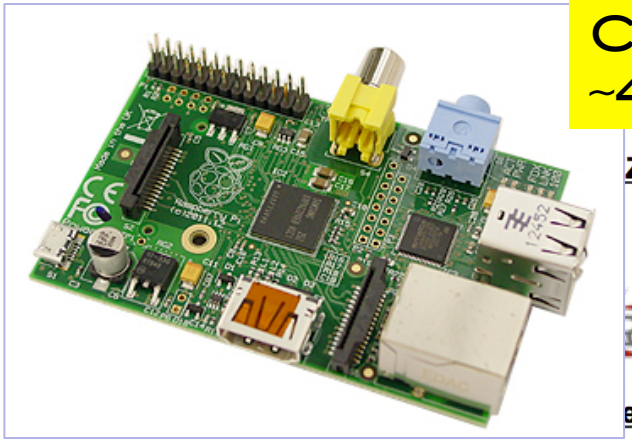
...AND CHEAP POWERFULL EMBEDDED SYSTEMS

Arduino™

CUBLOC

Beagleboard

Raspberry Pi

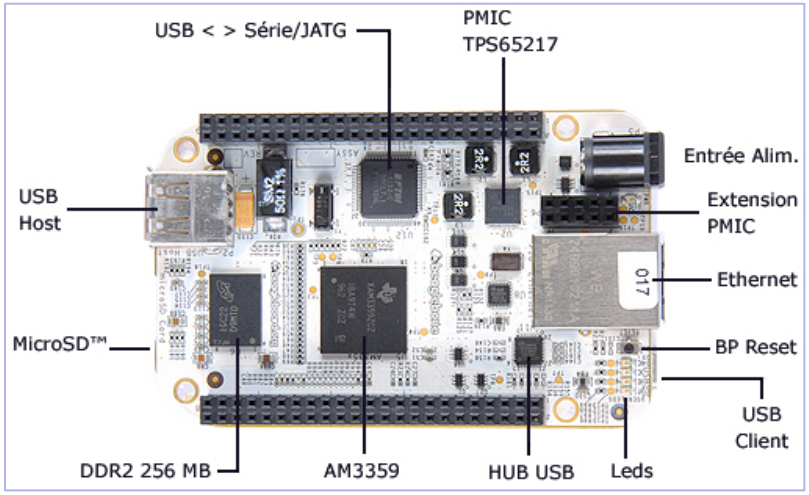


Cost: ~40€

Z/Gadgeteer

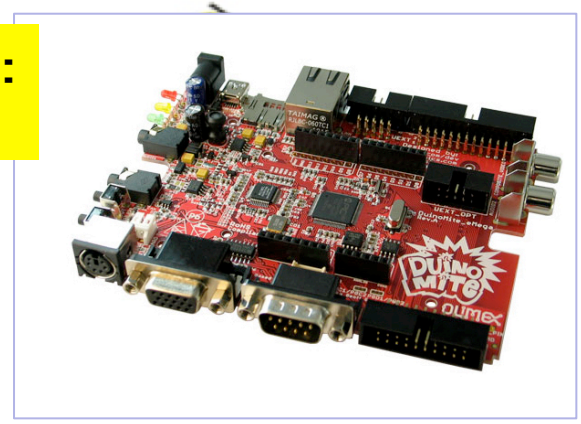
edded Artists

Cost: ~80€



Cost: ~50€

DuinoMite



What size is right for a test-bed?

- Have enough nodes for multi-hop scenario
  - 10 hops is already challenging!
  - If it works at 10 hops, adding more hops will most of the time simply add latency
- 15 nodes can suit most of validation requirements
- Better have diversity than quantity
- Better have real deployment environment than expensive, non realistic test-beds

Real test-bed? Not so difficult!



What if I really need large scale validation?

- In wireless networks, LOCALITY is an important property
- In realistic deployment the NEIGHBORHOOD SIZE IS LIMITED
- Get back to simulation with realistic measures/parameters from experimentations
  - Processing time
  - Memory size
  - Energy consumption
  - Transmission range in LoS conditions

What if I really need realistic large scale experimentations?

- Do you really need it?
  - Why 15 nodes is not enough?
  - Why realistic simulation is not enough?
  - What do you want to prove?
  - What do you expect?
- Select a realistic test-bed!

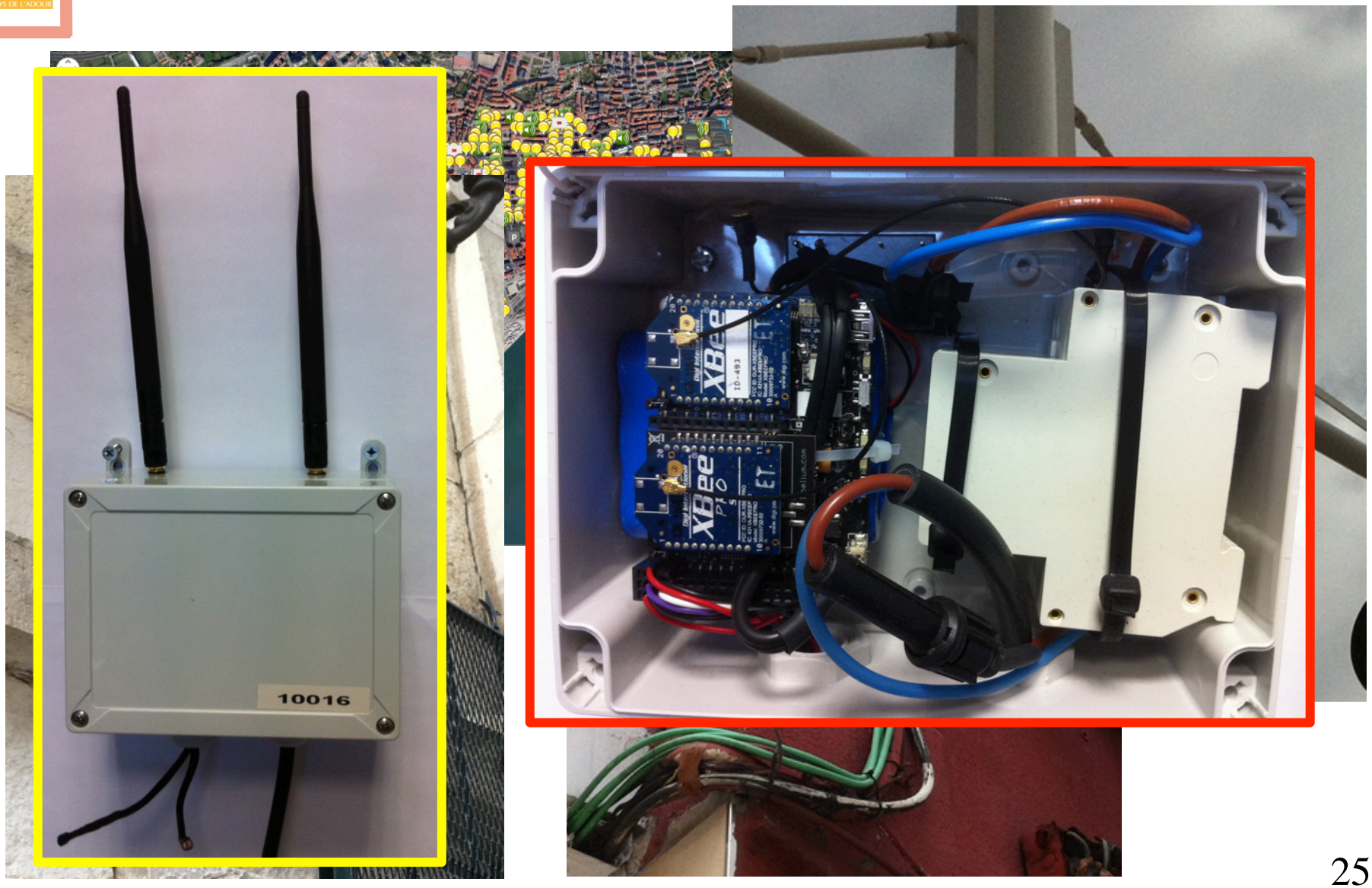


SmartSantander

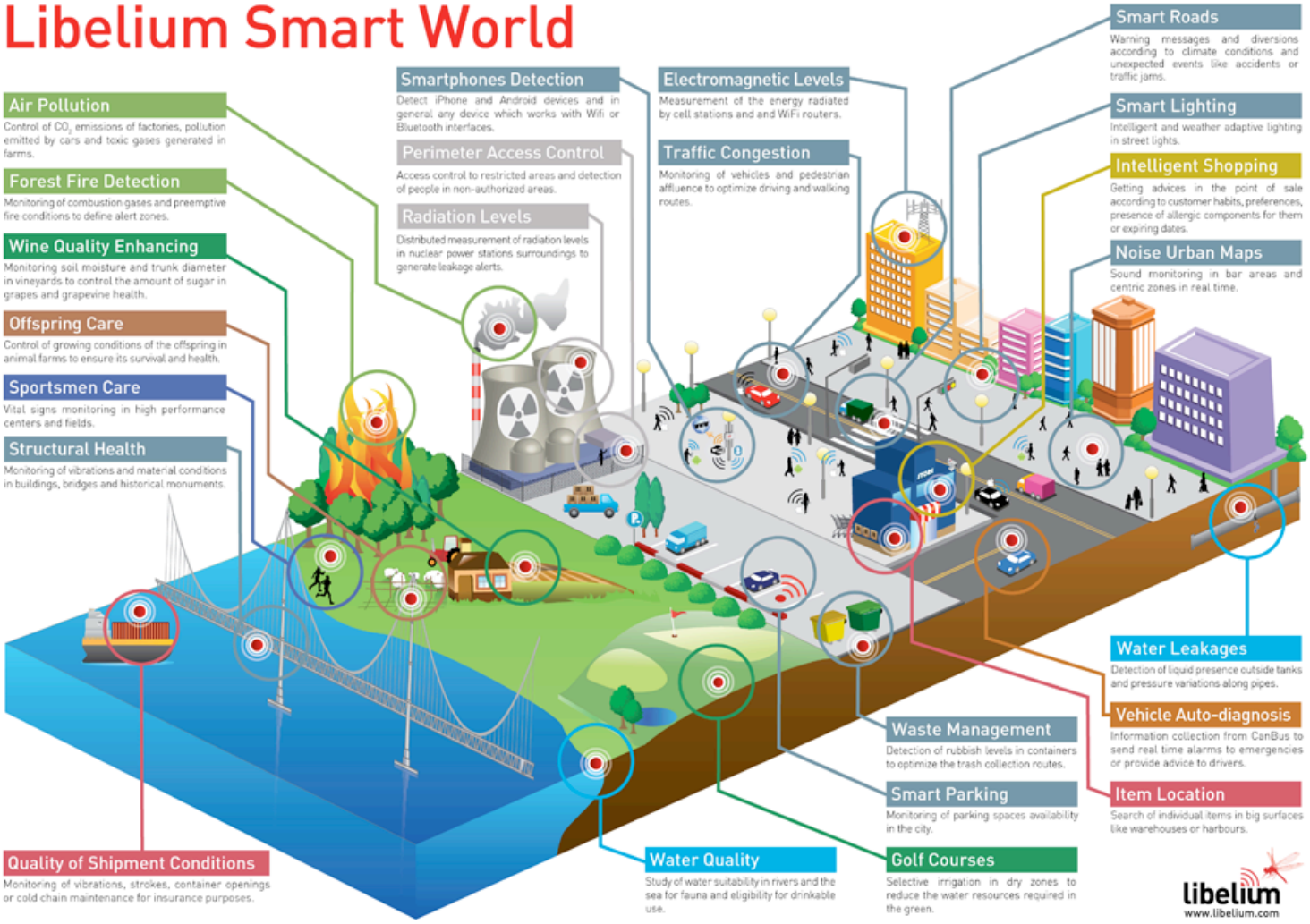
www.smartsantander.eu



SmartSantander nodes



Smart Cities



CONTROL, OPTIMIZE & INSTRUMENT !





DATA ANALYSIS, OPTIMIZATION & CONTROL

PERVASIVE SYSTEMS

SENSING

PEOPLES, INFRASTRUCTURES, BUILDINGS, VEHICULES

Beyond Sensor Networks: Communicating Objects!

- Native communication:





- Added communication
  - Active communication















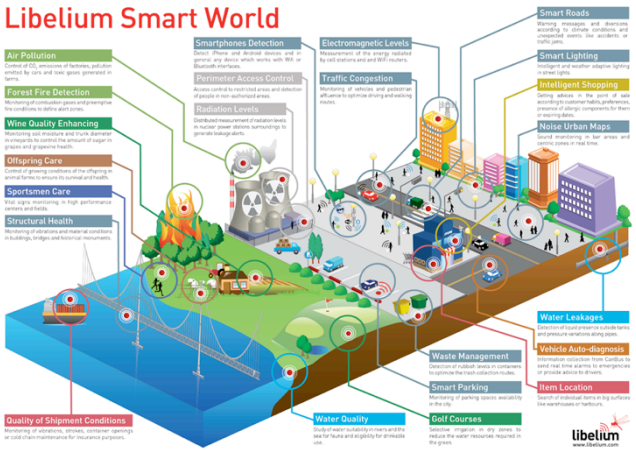
  - Passive communication







A BUSINESS MODEL IN SMARTCITIES





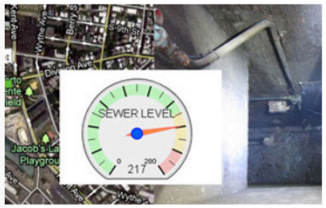
KEEP STREETS CLEAN

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



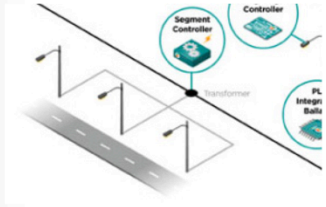
RECEIVE POLLUTION WARNINGS

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

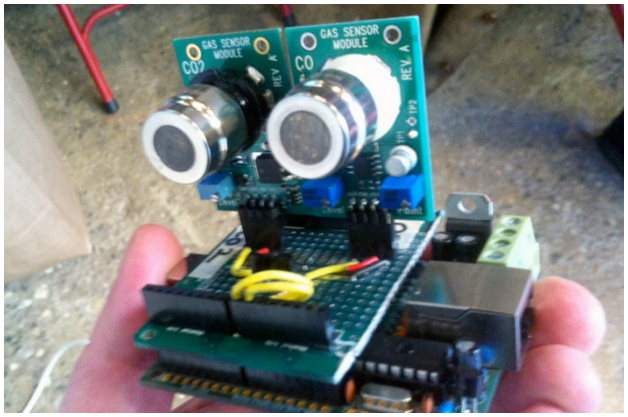


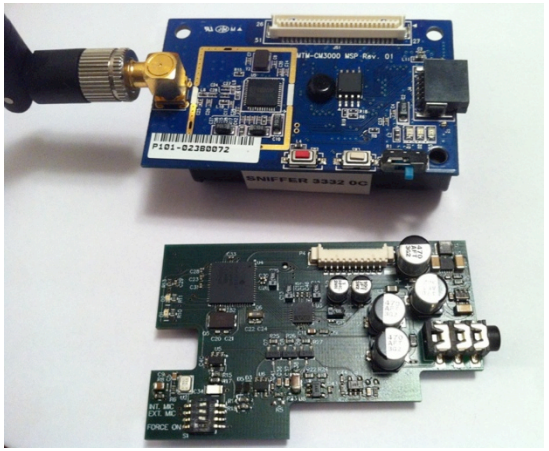
SHARE YOUR FINDINGS

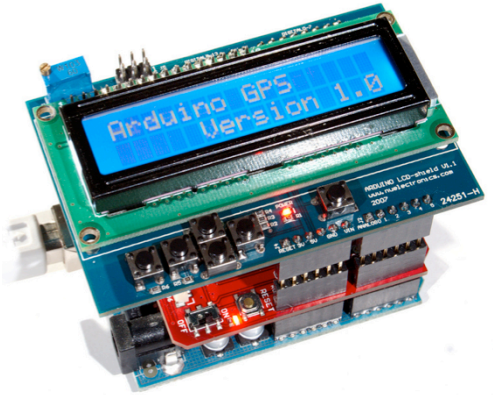
AirCasting is a platform for recording, mapping, and sharing health and environmental data using your smartphone. Each AirCasting session lets you capture real-world measurements (Sound levels recorded by their phone microphone; Temperature, humidity, carbon monoxide (CO) and nitrogen dioxide (NO2) gas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

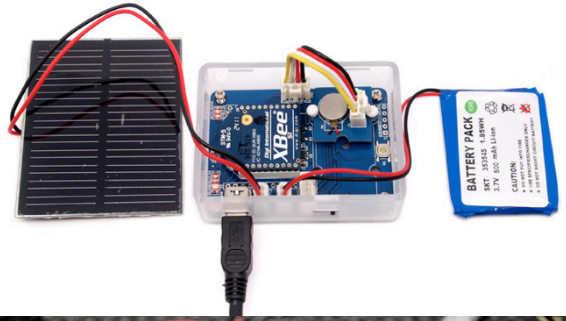
http://www.postscapes.com/internet-of-things-examples/

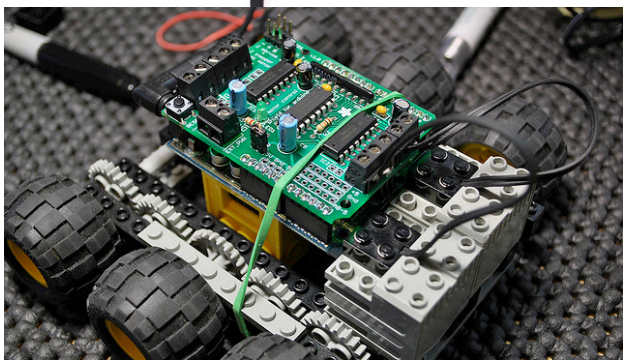
From custom developments...

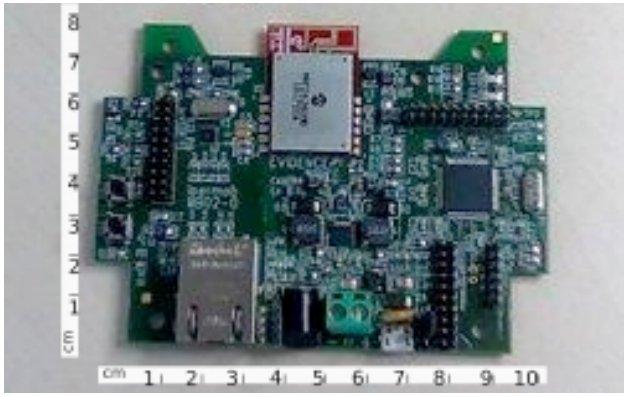














...TO COMMERCIAL PRODUCTS





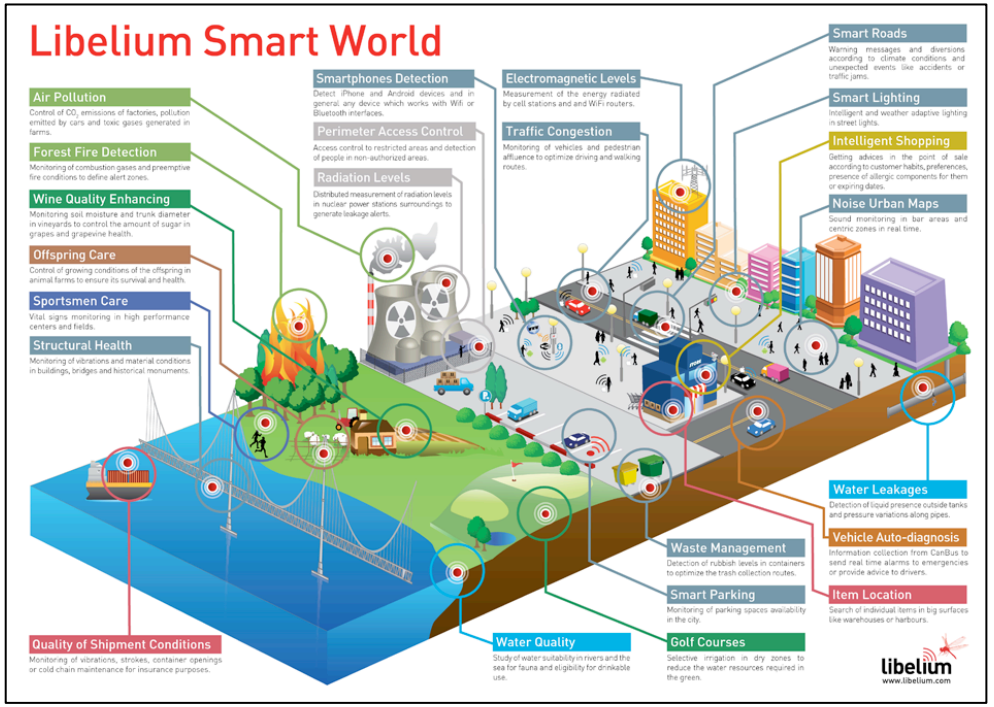


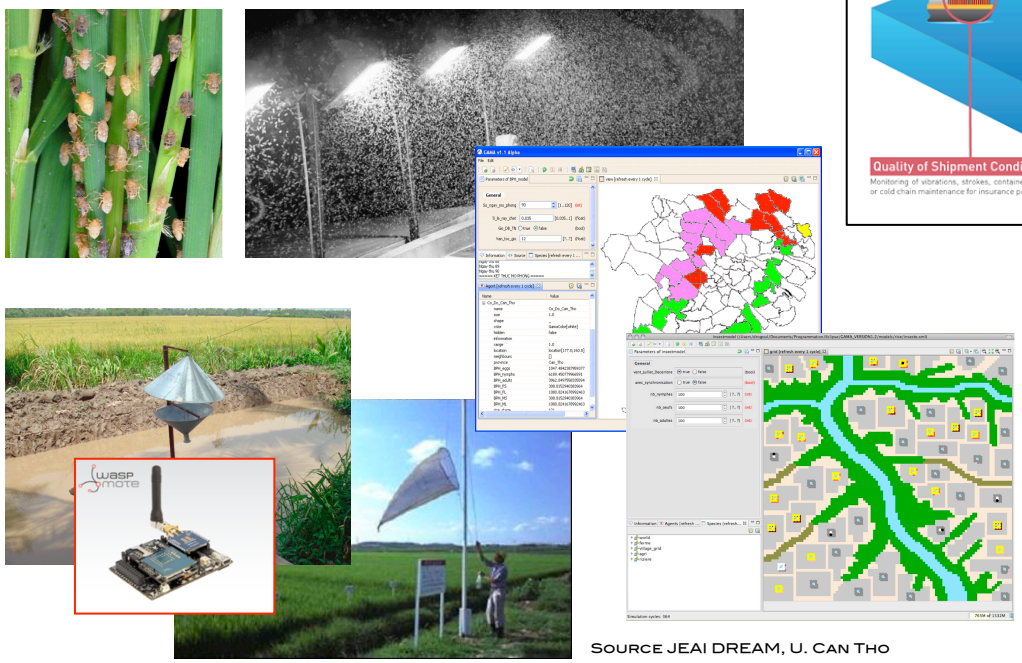




Deployment in practice

- 1 to 50 sensor nodes per cluster
- Gateway can interconnect clusters

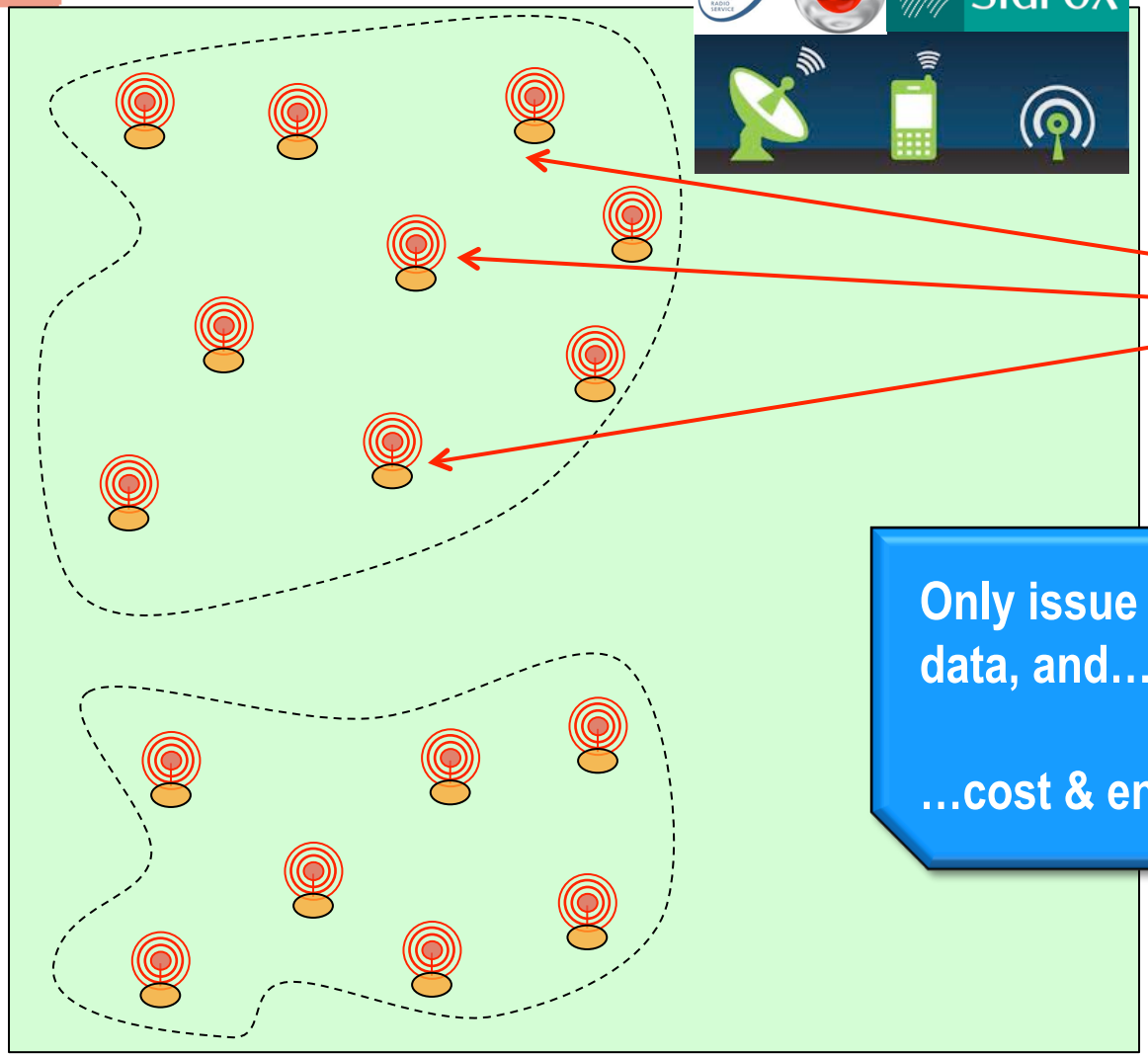




- Sensor <-> Sensor
- Sensor <-> Gateways
- Gateways <-> Internet

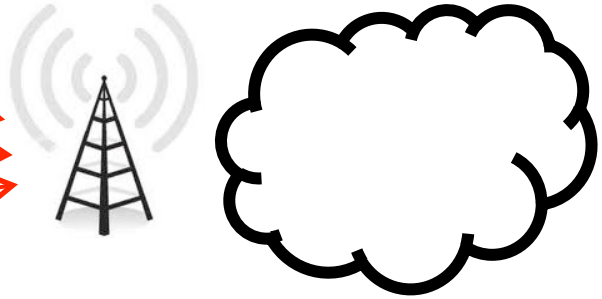
Source JEAI DREAM, U. Can Tho

1-HOP COMMUNICATION (CELLULAR MODEL)





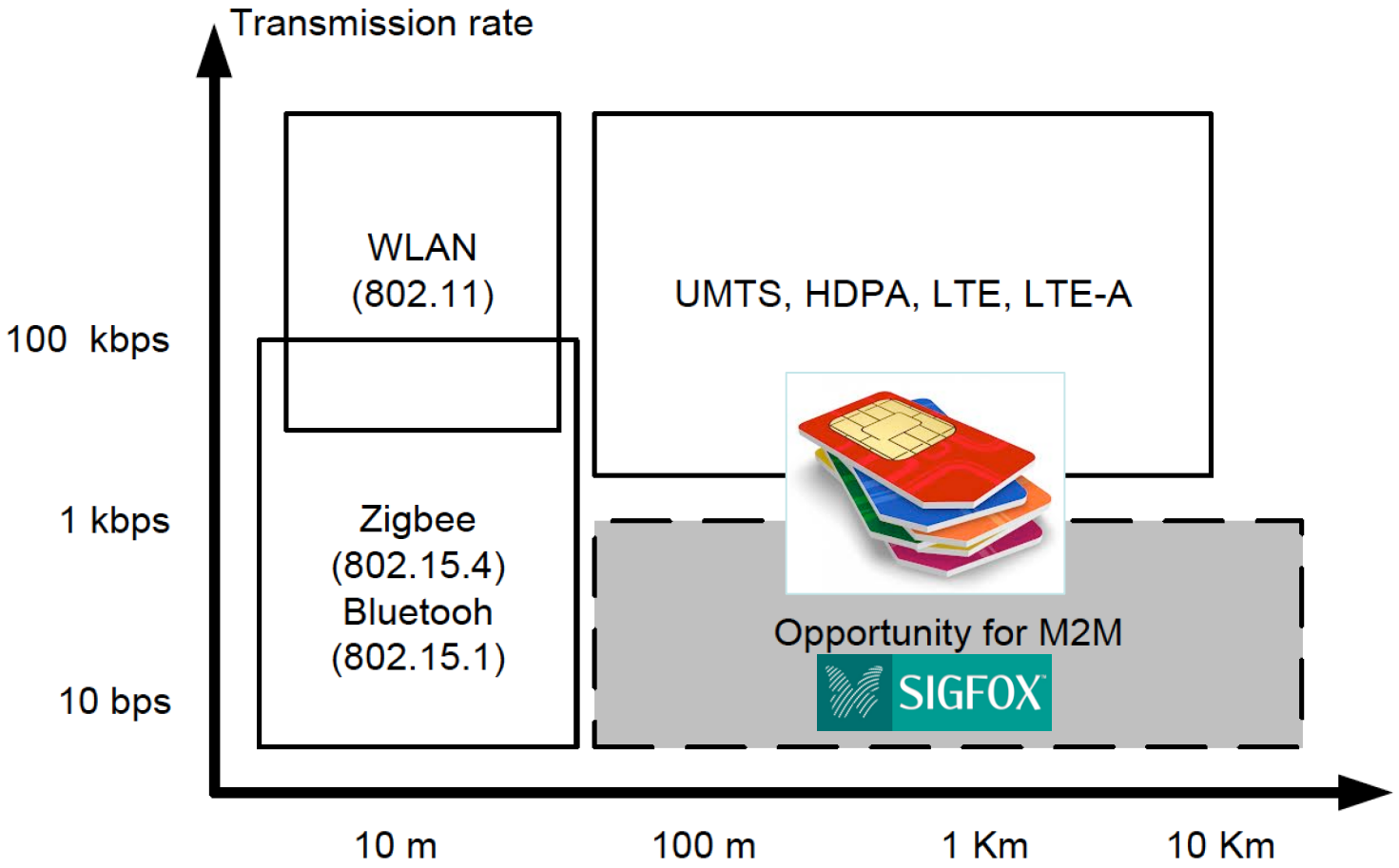
Most of telemetry systems



Only issue is to process data, and…

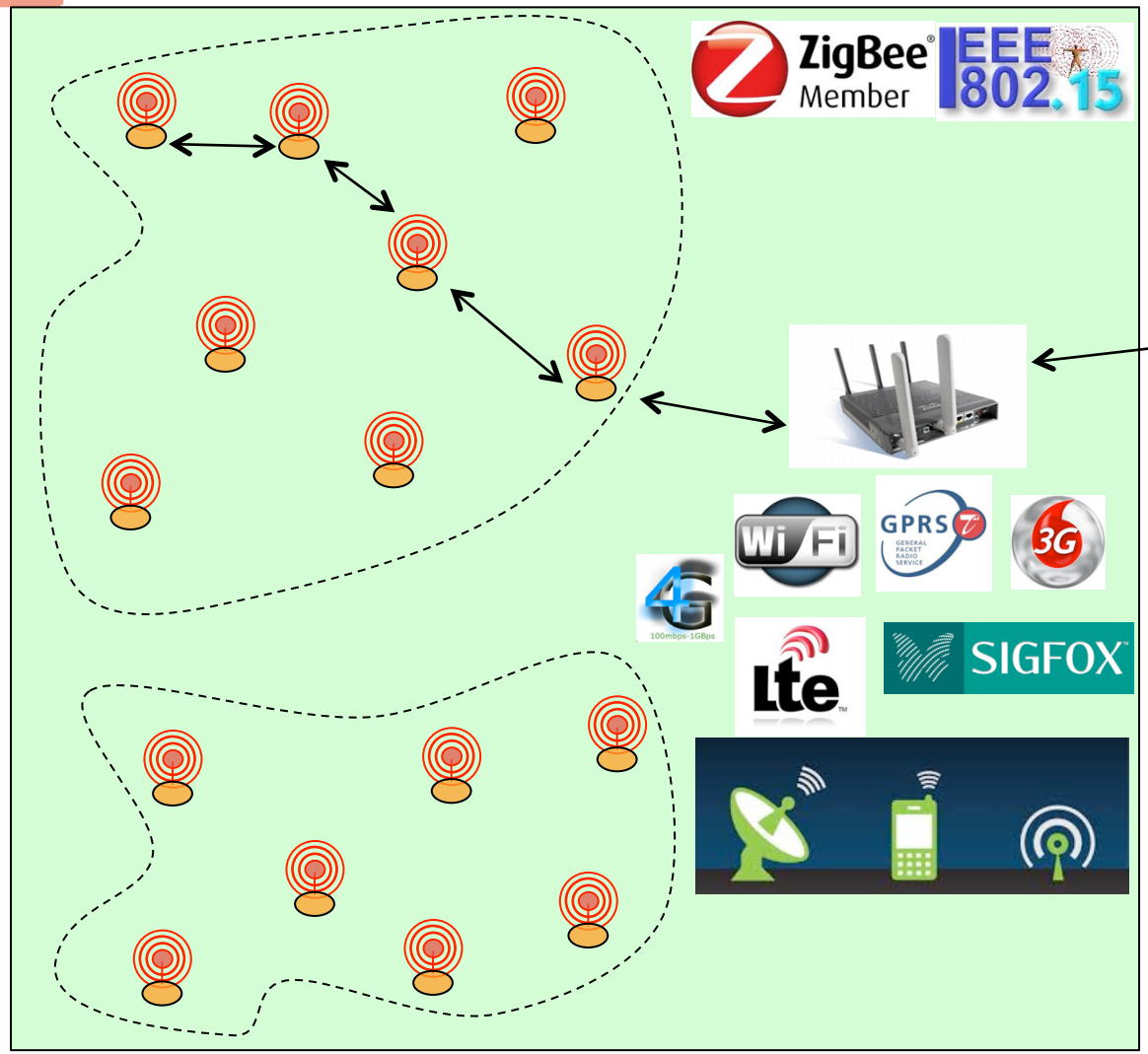
…cost & energy

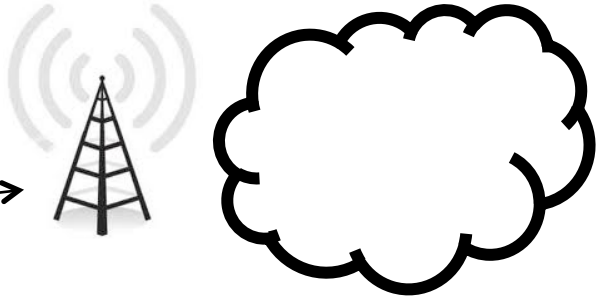
Opportunities for Telco operators & more...



Enhanced from M. Dohler "M2M in SmartCities"

Multi-hop to gateways





MAC & Routing issues, well-known to WSN community…

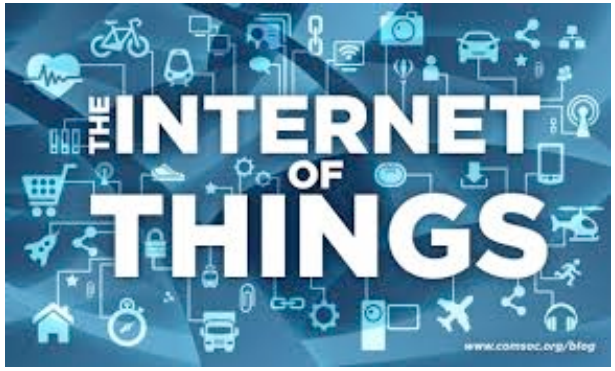
…but can we interoperate?

From « ad-hoc » protocols to « standards »





The benefit of IP



Don't reinvent the wheel!

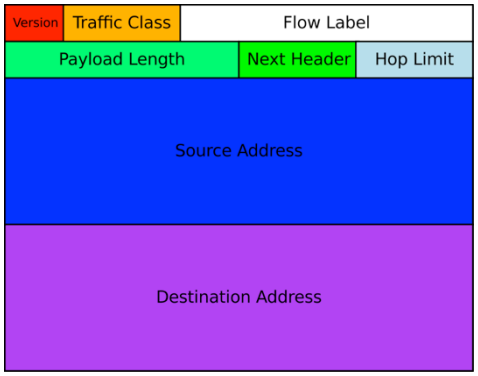
RFC 768	UDP - User Datagram Protocol	[1980]
RFC 791	IPv4 – Internet Protocol	[1981]
RFC 792	ICMPv4 – Internet Control Message Protocol	[1981]
RFC 793	TCP – Transmission Control Protocol	[1981]
RFC 862	Echo Protocol	[1983]
RFC 1101	DNS Encoding of Network Names and Other Types	[1989]
RFC 1191	IPv4 Path 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]



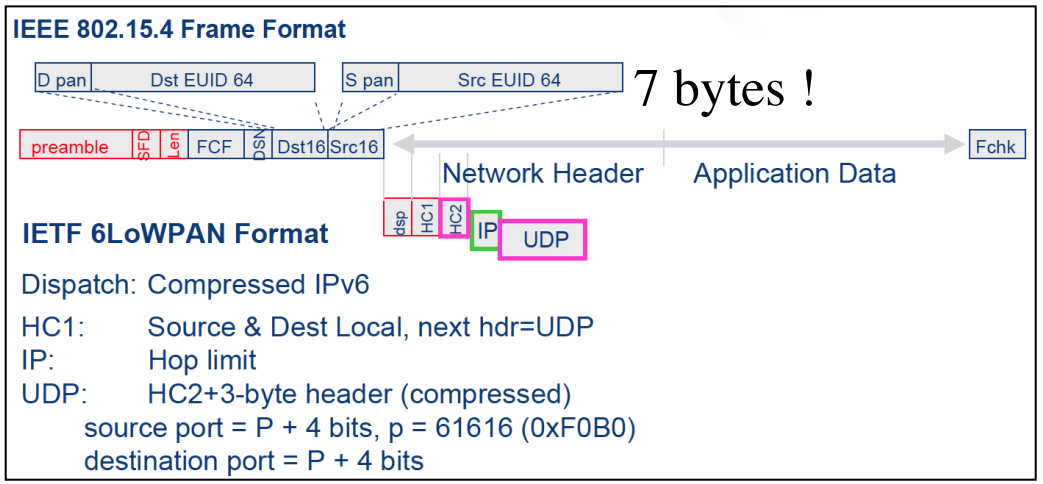
From ArchRock "6LowPan tutorial"

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



Internet for things

CoAP: Constrained Application Protocol

UDP

RPL
Routing Protocol for Low power & Lossy Networks

6LowPan
802.15.4





HTTP

TCP, UDP

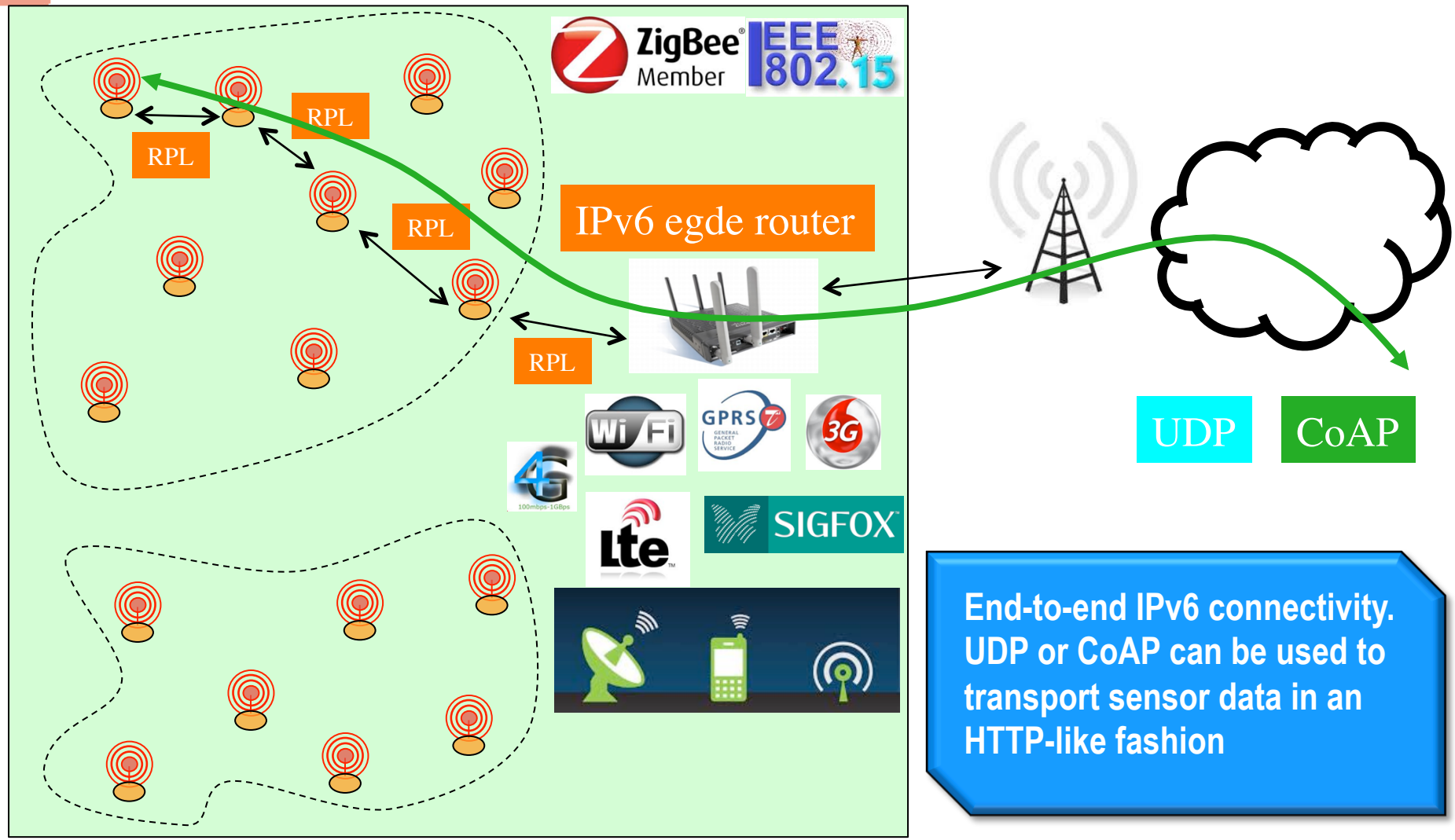
Internet Routing Protocols: RIP, OSPF, BGP,…

IPv4, IPv6

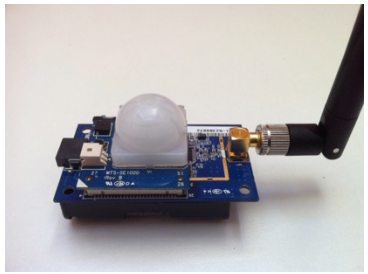




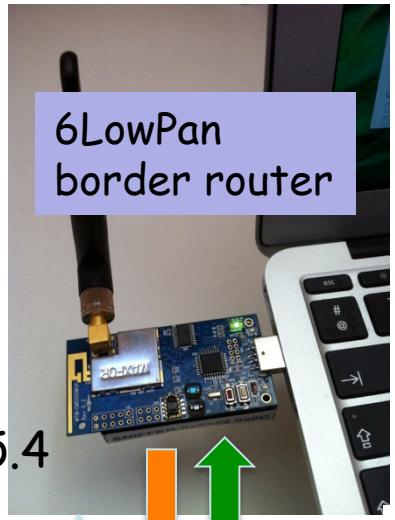
Using IP protocols



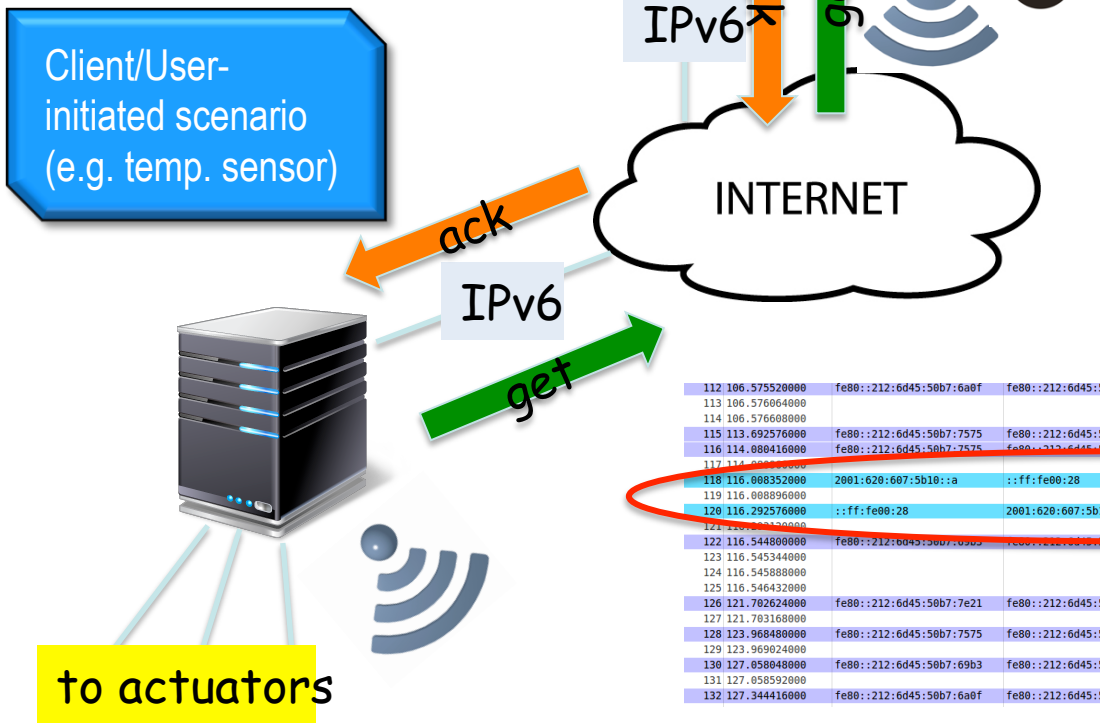
End-to-end IPv6 connectivity. UDP or CoAP can be used to transport sensor data in an HTTP-like fashion





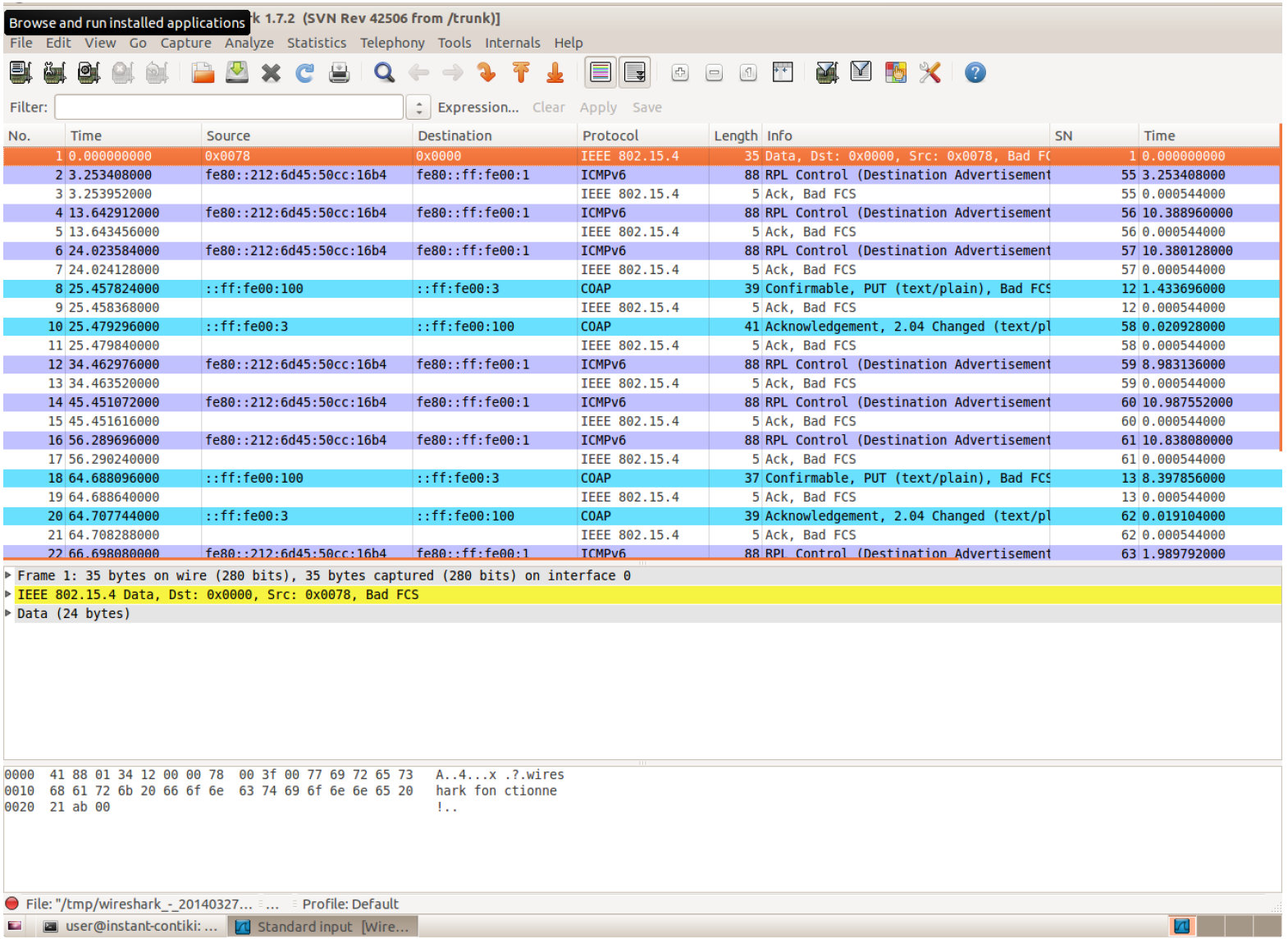


CoAP/6LowPan/IEEE 802.15.4
RPL routing



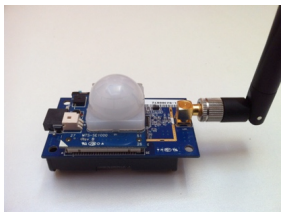
112	106.575520000	fe80::212:6d45:50b7:6a0f	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
113	106.576064000			IEEE 802.15.4	5	Ack, Bad FCS
114	106.576608000			IEEE 802.15.4	5	Ack, Bad FCS
115	113.692576000	fe80::212:6d45:50b7:7575	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
116	114.080416000	fe80::212:6d45:50b7:7575	fe80::212:6d45:5026:34cc	ICMPv6	94	RPL Control (Destination Advertisement Object),
117	114.080960000			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 #15
121	116.293120000			IEEE 802.15.4	5	Ack, Bad FCS
122	116.544800000	fe80::212:6d45:50b7:69b3	fe80::212:6d45:5026:34cc	ICMPv6	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),

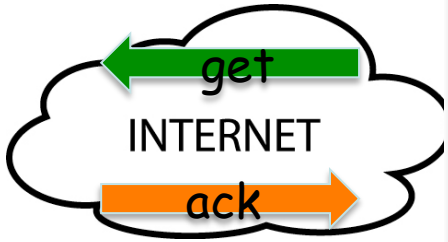
RPL and CoAP exchanges

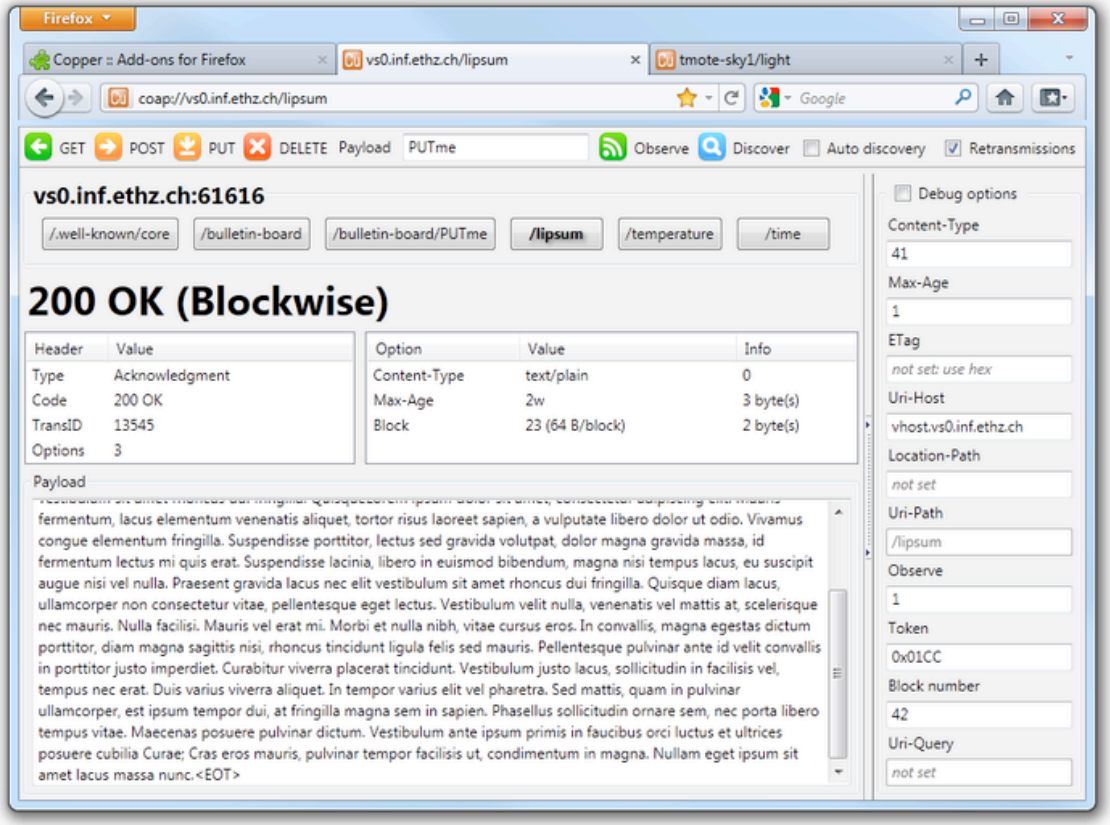


Copper for Firefox

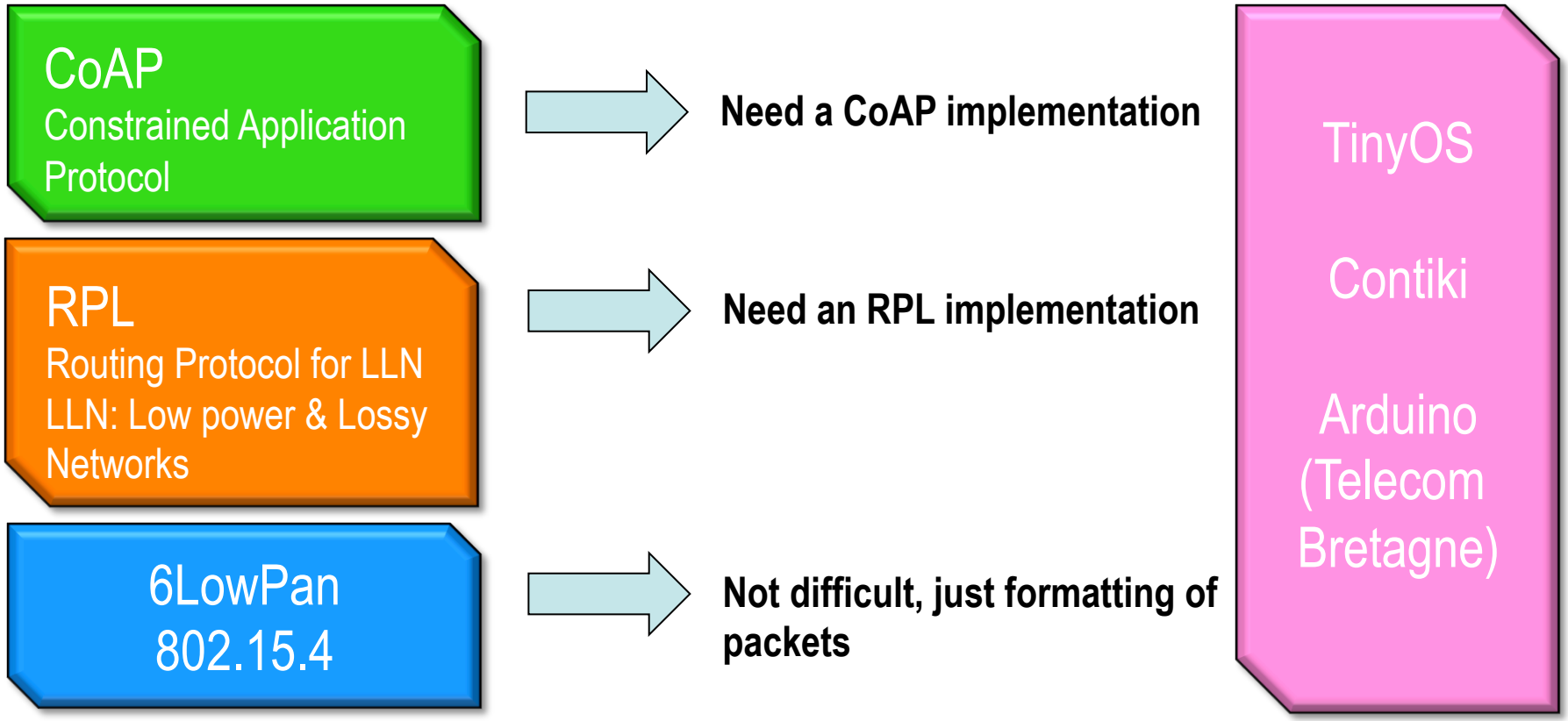
- CoAP pluggin to query CoAP nodes in an HTTP-like fashion







What do you need? Everything is here!



Are you I-o-T or WSN?



- IP integration, WWW
- IPv6
- Inter-operability
- Interactions (all kind)
- Semantic, Ontology
- Data representation
- Data logging
- WebServices



- Organization
- Programmability
- Energy saving
- Scheduling
- Efficient MAC, routing
- Congestion control
- Data transmission

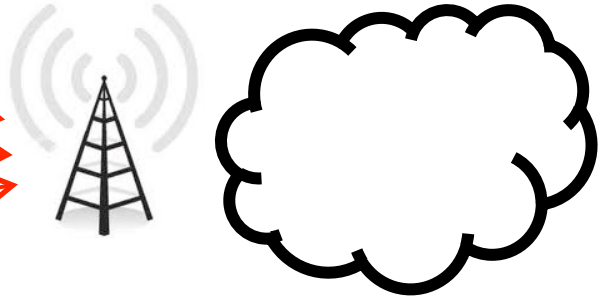
WHO IS CONCERNED?



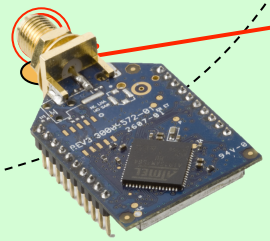
Do I need multi-hop for my app?



Most of telemetry systems







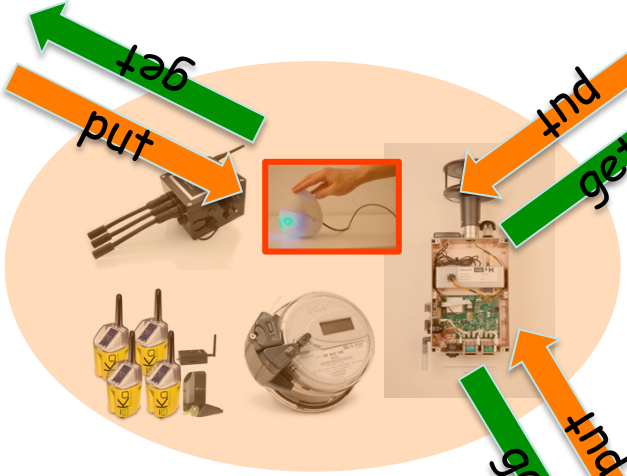
XBee 868MHz
Outdoor LOS range: 40-80kms
2400 bps

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

Not too far from now









Internet of Things for People

Some contributions « from theory to practice »

Multimedia Information



56

Search & Rescue, Situation awareness



EAR-IT: audio surveillance in SmartCities and SmartBuildings











Play/store received audio data

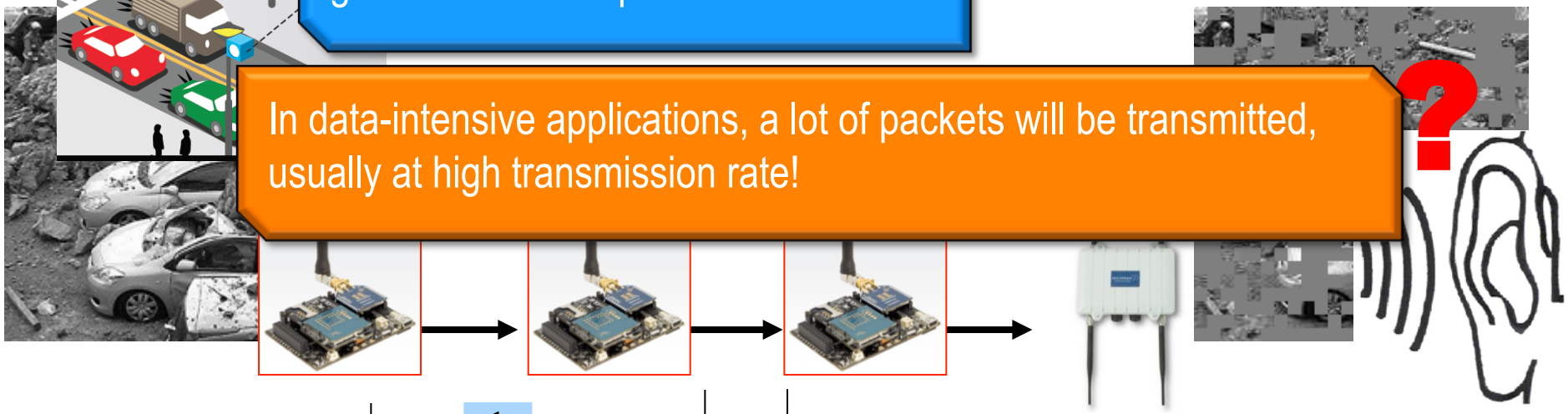
See http://www.ear-it.eu

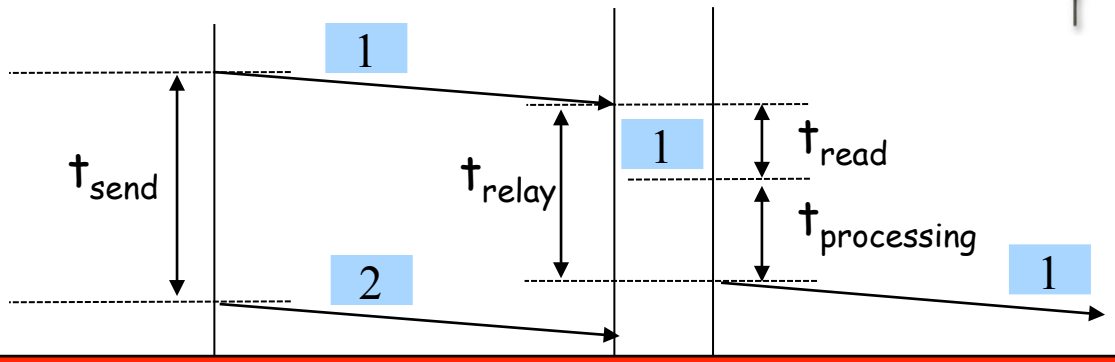
58

Multi-Hop Packet Forwarding

Multi-hop is very costly (routing) and generates lot's of packet losses!

In data-intensive applications, a lot of packets will be transmitted, usually at high transmission rate!





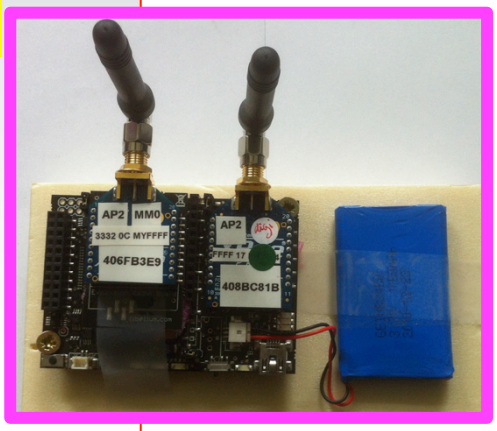
What level of performances can we expect?

Mass-market sensors

8MHz Atmega1281
8kB SRAM, 128kB Flash
Xbee radio

Cost:
~100€





Libelium WaspMote

Cost:
~80€



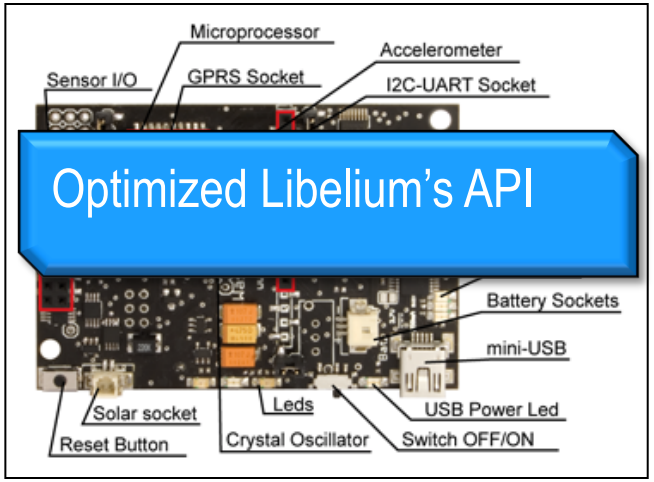
Arduino Mega2560

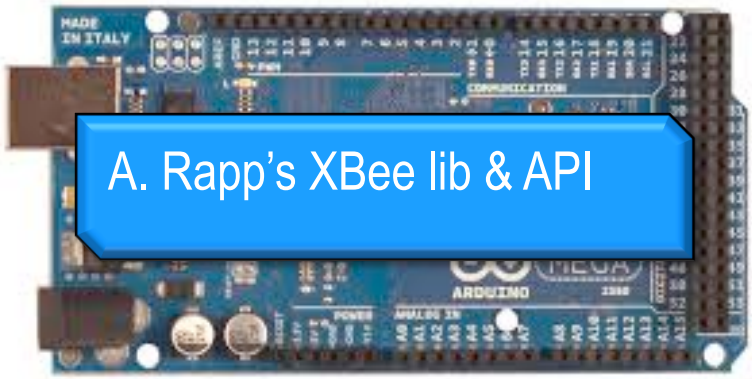
16MHz Atmega1281
8kB SRAM, 128kB Flash
Xbee radio



Sensor's HW&SW

Libelium WaspMote



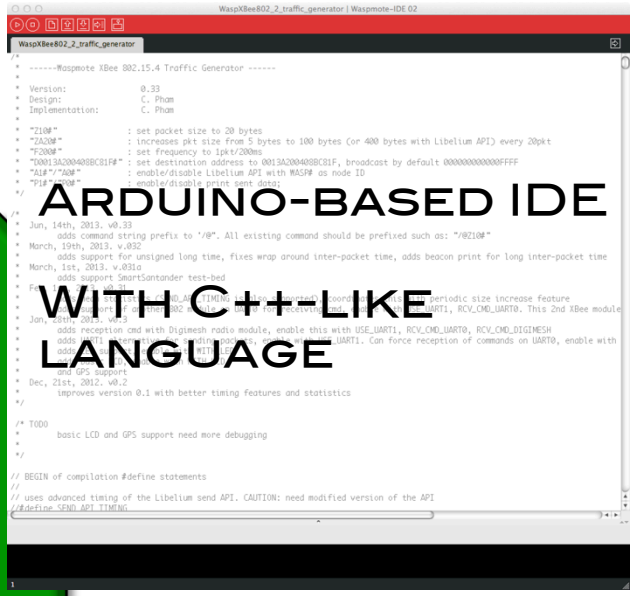


Arduino Mega2560

UART-based connection to micro-controller

Default speed is usually 38400 bauds

Higher baud rate are possible but…



Arduino-based IDE with C++-like language



XBee 802.15.4

« Academic » sensors



iMote2



8MHz Atmega128L
4kB SRAM, 128kB Flash
CC2420 radio

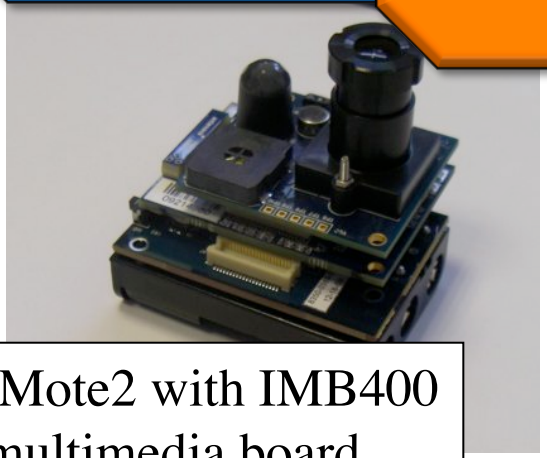
13-416MHz PXA271 X
Wireless MMX DSP
256kB SRAM, 32MB
32MB SDRAM
CC2420 radio

Radio module

Motes are programmed under the TinyOS or the Contiki operating system & lib



AdvanticSys CM5000 & CM3000
TelosB-like mote



iMote2 with IMB400 multimedia board

hundredth kbps



TelosB

8Mhz MSP430F1611
10K SRAM, 48K flash
CC2420 radio

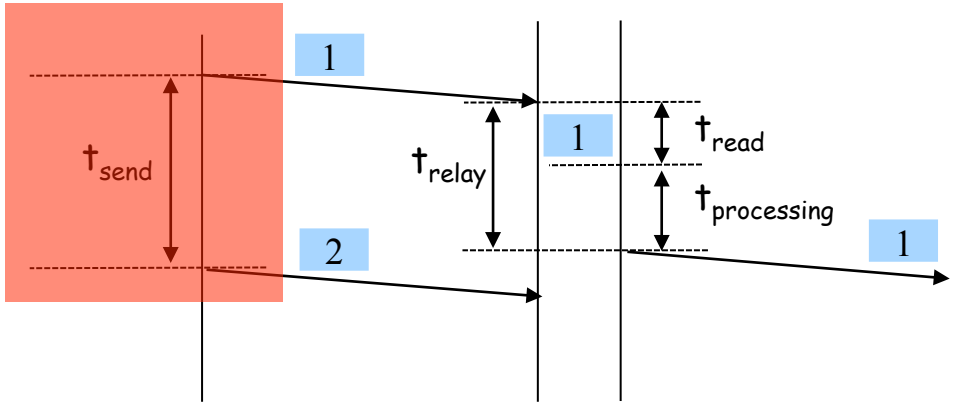
Communication performances

- Application level performances depends on OS, API, hardware architecture
- Usually much lower than radio performances!
- What are min. latencies & max. throughput?
  - For sending?
  - For receiving?
  - For relaying?

C. Pham, "Communication performance of low-resource sensor motes for data-intensive applications ", Proceedings of the IFIP Wireless Days International Conference (WD'2013), Valencia, Spain, November 2013.

C. Pham, "Communication performances of IEEE 802.15.4 wireless sensor motes for data-intensive applications: a comparison of WaspMote, Arduino MEGA, TelosB, MicaZ and iMote2 for image surveillance", Journal of Network and Computer Applications (JNCA), Elsevier, Vol. 46, Nov. 2014

Sending performances



Traffic Generator

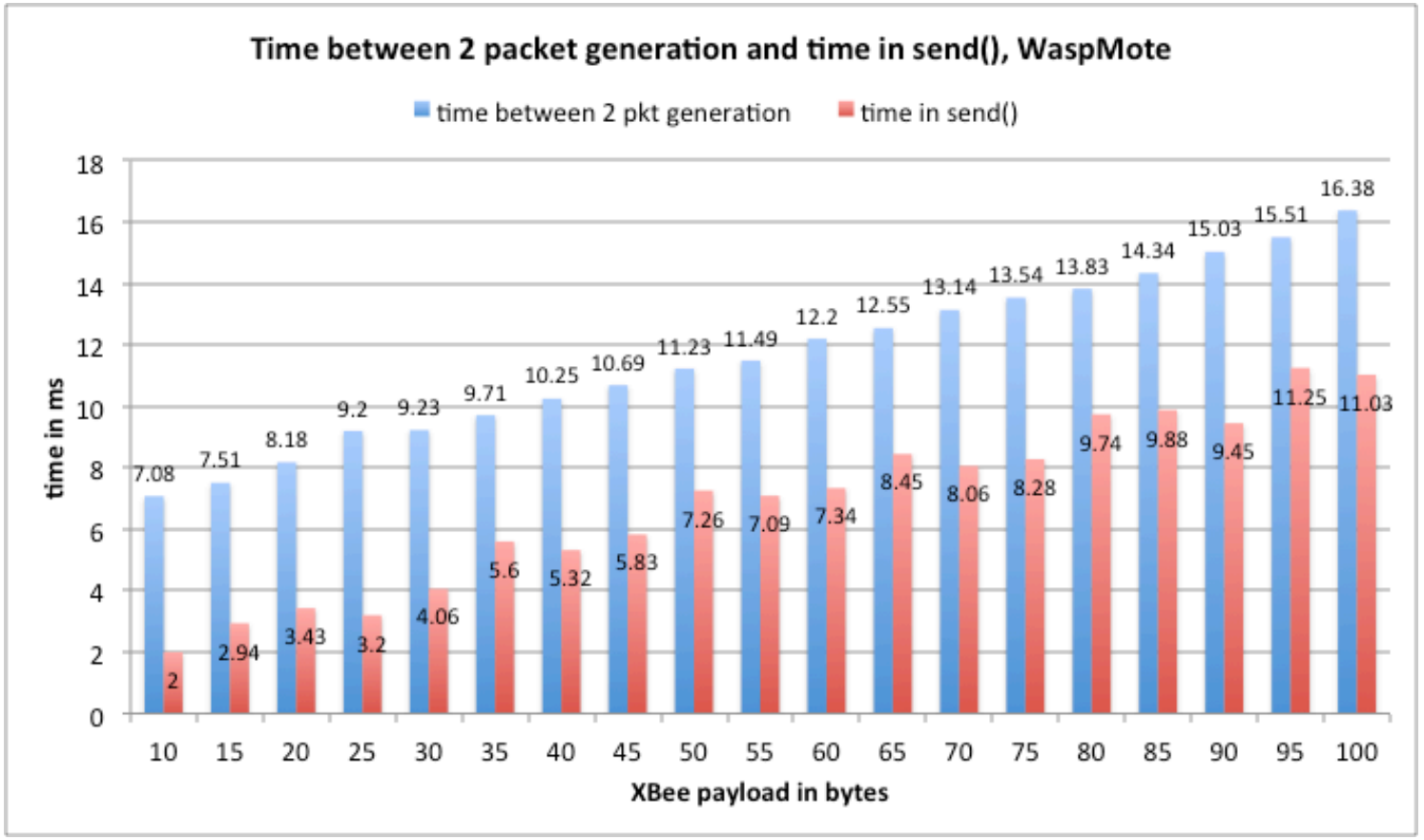
```
void loop() {
        T0;
        L0=T0;
        ...
        T1;
        send(buf);
        T2;
        ...
}
```

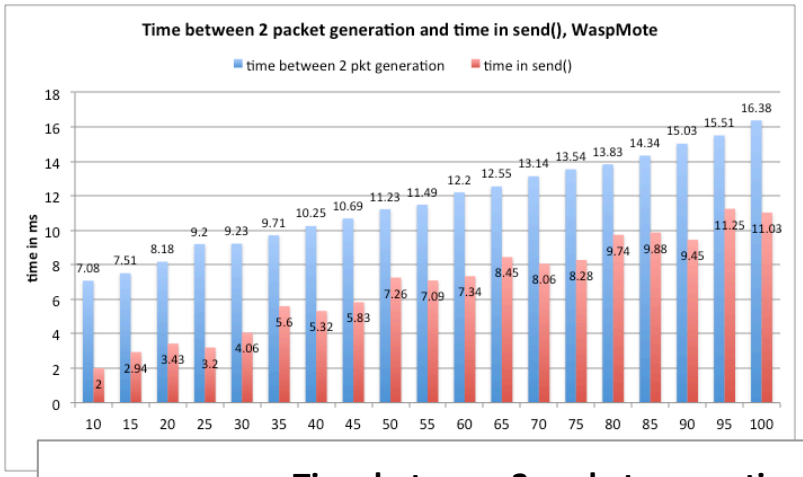
« Time in send() » is T2-T1
« Time between 2 pkt generation » is T0-L0
Time resolution is millisecond
Minimum data manipulation

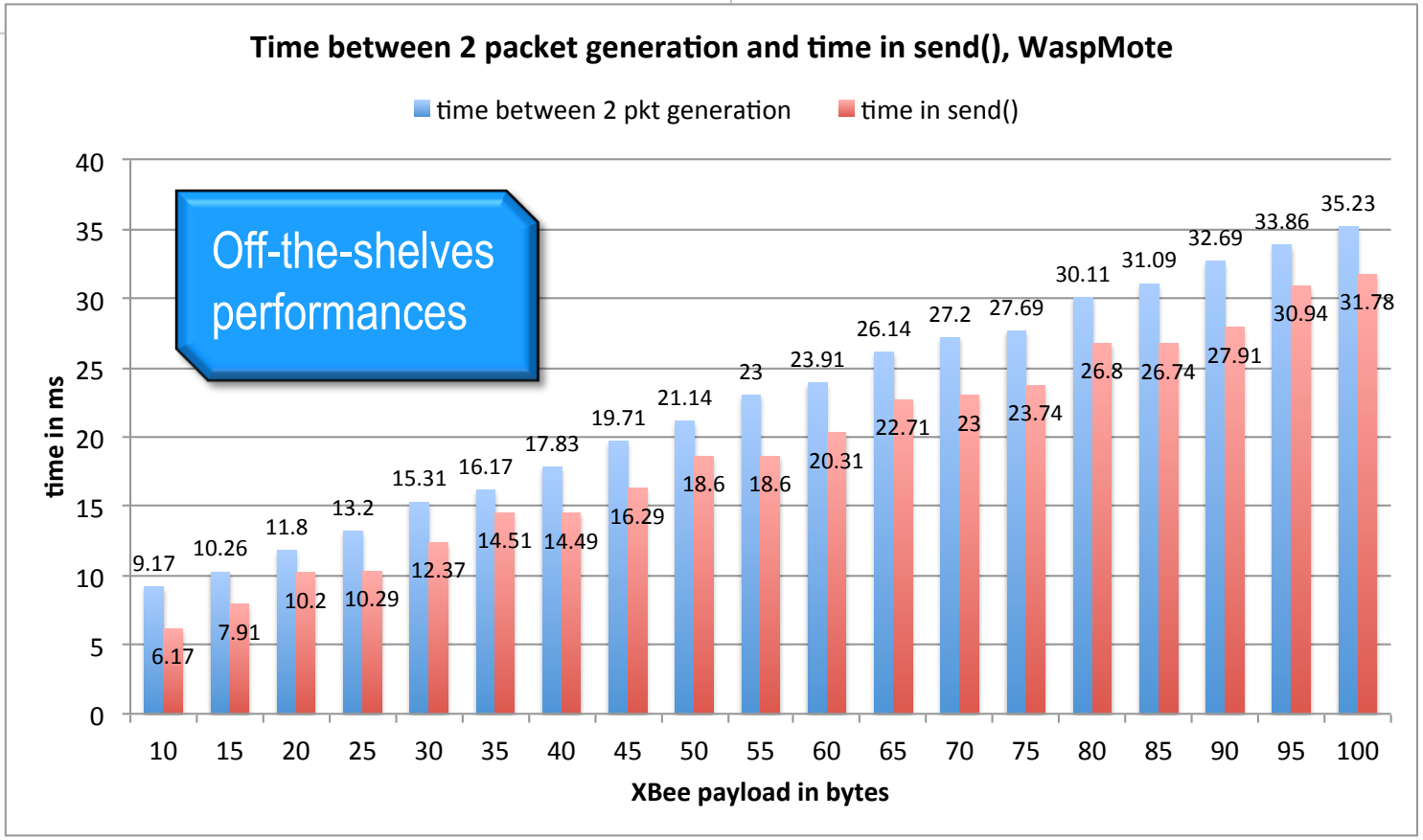
Measure the time in various part of API `send()` when possible.

Sending performances

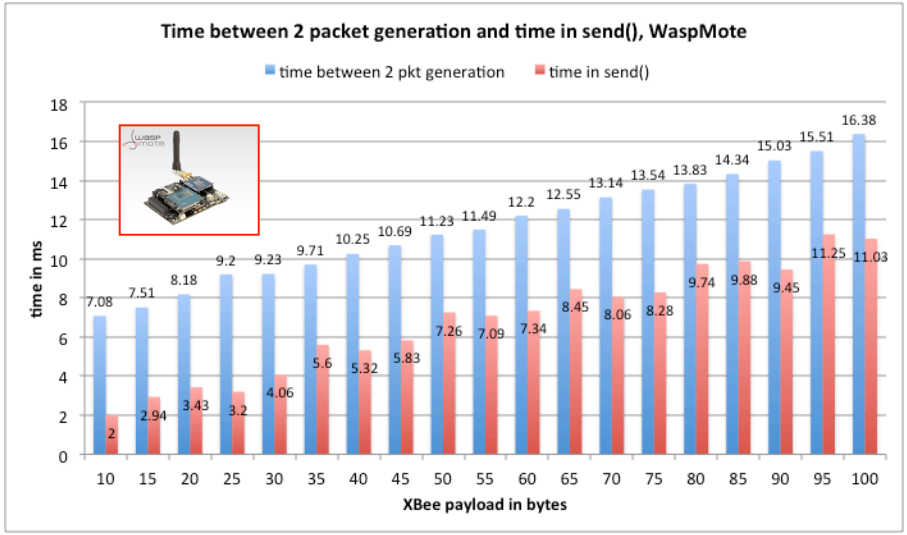


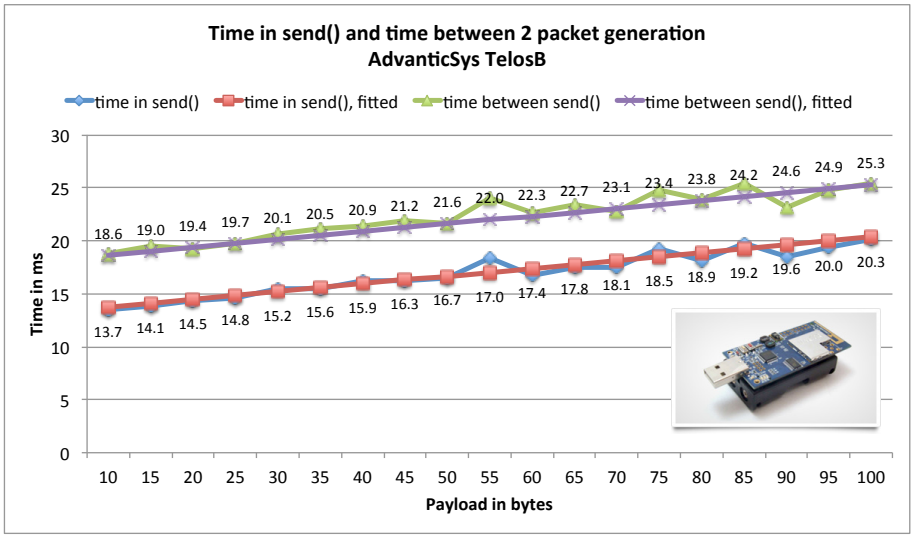


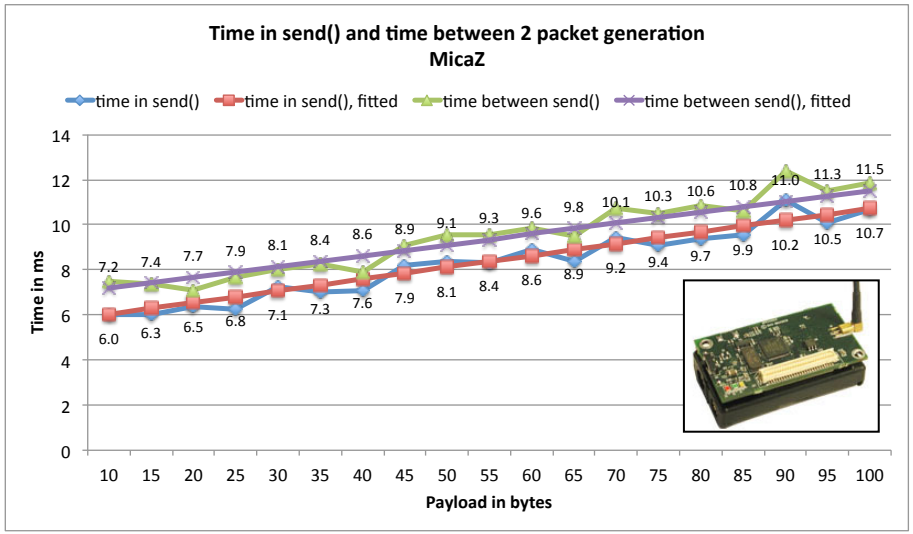

Time between 2 packet generation and time in send(), WaspMote
time between 2 pkt generation
time in send()
time in ms
0
2
4
6
8
10
12
14
16
18
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
7.08 7.51 8.18 9.2 9.23 9.71 10.25 10.69 11.23 11.49 12.2 12.55 13.14 13.54 13.83 14.34 15.03 15.51 16.38
2 2.94 3.43 3.2 4.06 5.6 5.32 5.83 7.26 7.09 7.34 8.45 8.06 8.28 9.74 9.88 9.45 11.25 11.03

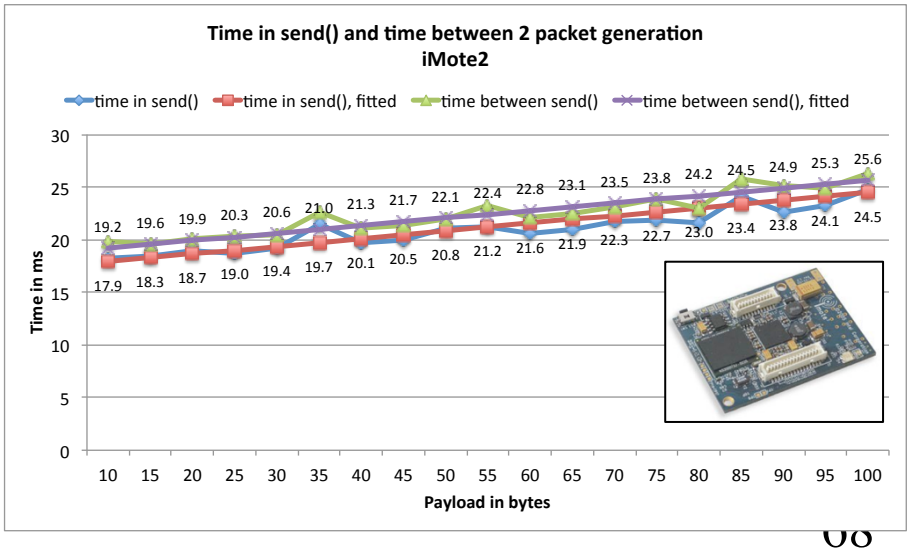

Time between 2 packet generation and time in send(), WaspMote
time between 2 pkt generation
time in send()
Off-the-shelves performances
time in ms
0
5
10
15
20
25
30
35
40
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
XBee payload in bytes
9.17 10.26 11.8 13.2 15.31 16.17 17.83 19.71 21.14 23 23.91 26.14 27.2 27.69 30.11 31.09 32.69 33.86 35.23
6.17 7.91 10.2 10.29 12.37 14.51 14.49 16.29 18.6 18.6 20.31 22.71 23 23.74 26.8 26.74 27.91 30.94 31.78

Sending performances: comparison

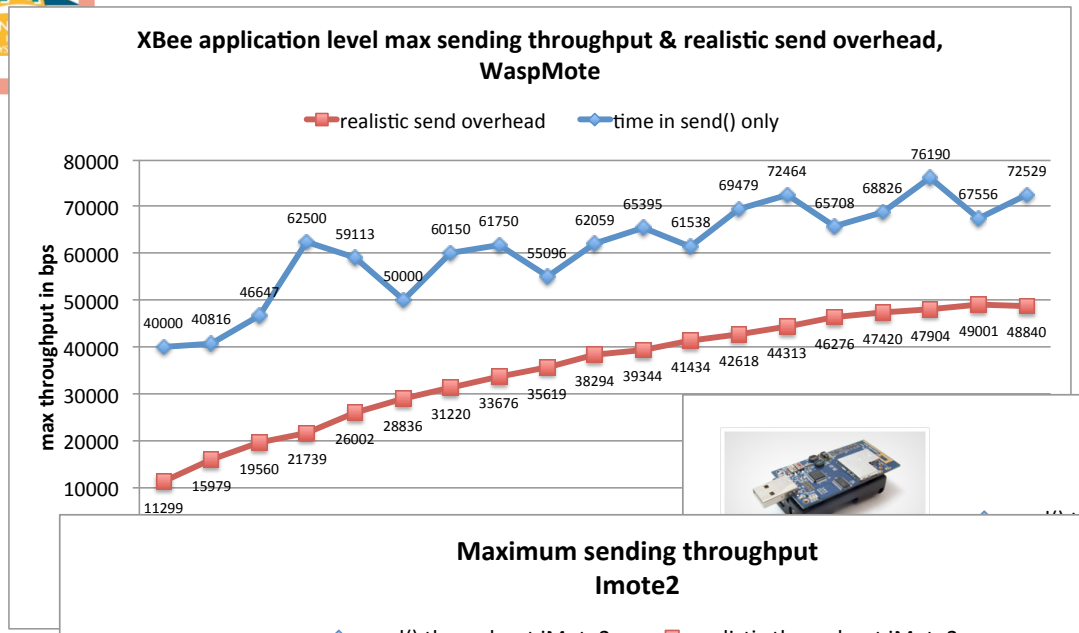


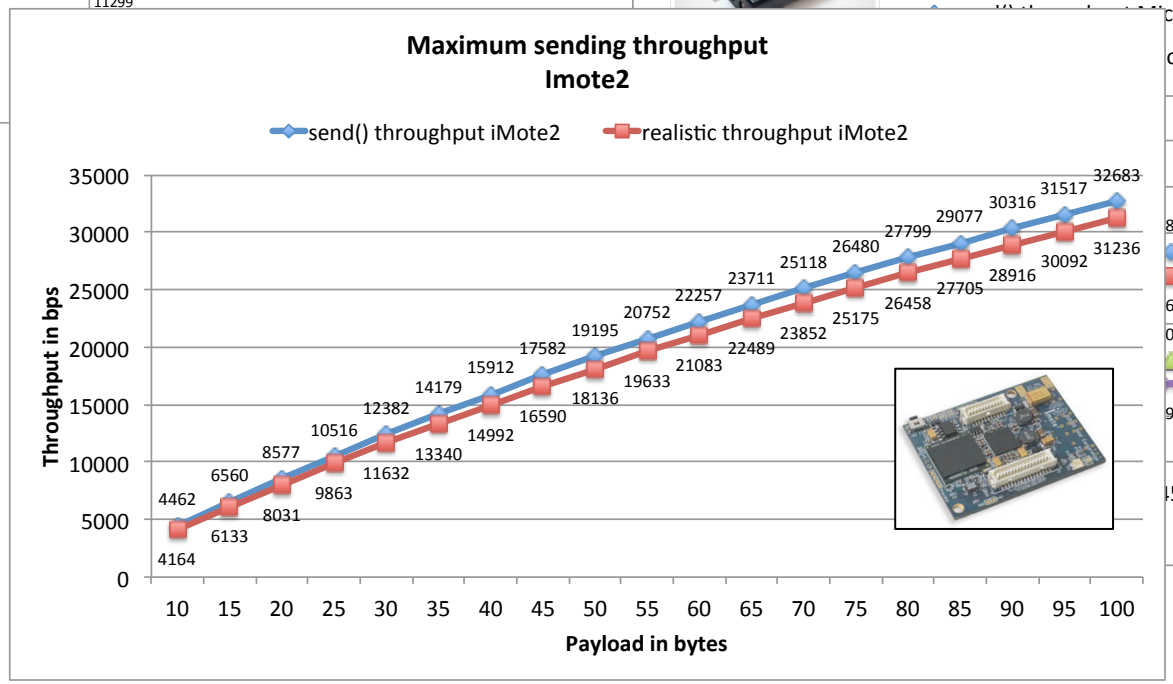


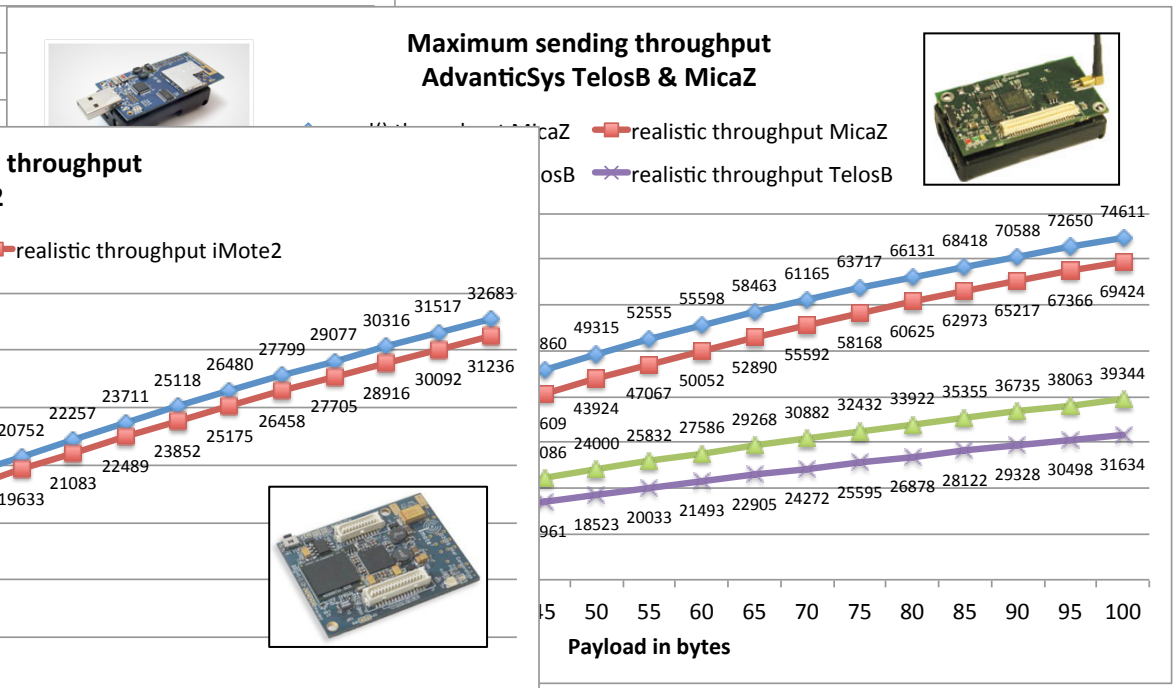




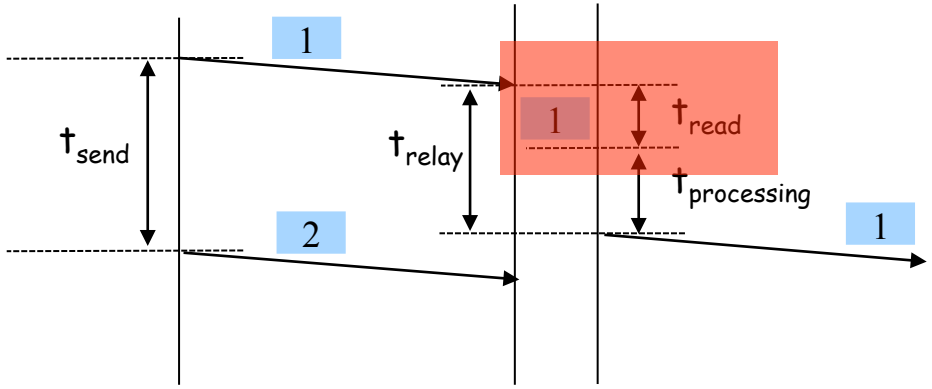
Maximum sending throughput





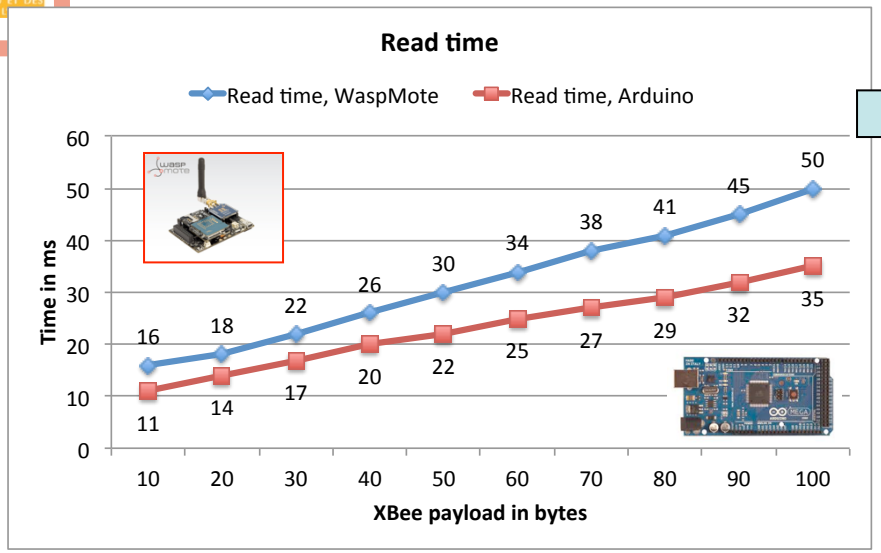


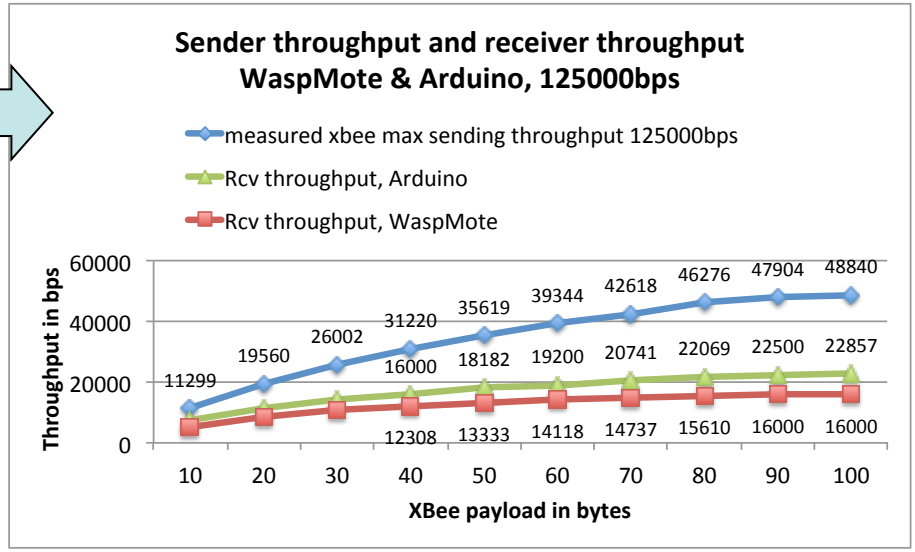
Receive performances

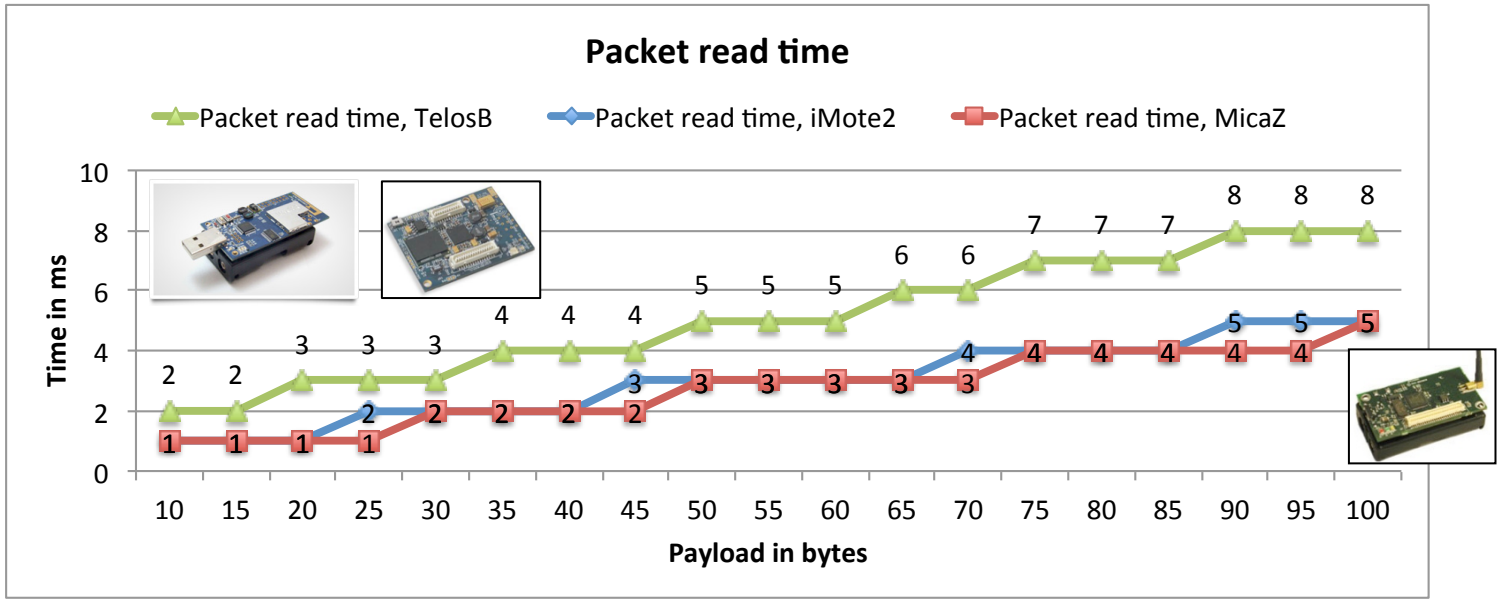


- At sender side, send as fast as possible
- At receiver side, determine T_{READ}
- … And also compute the maximum receive throughput per packet size

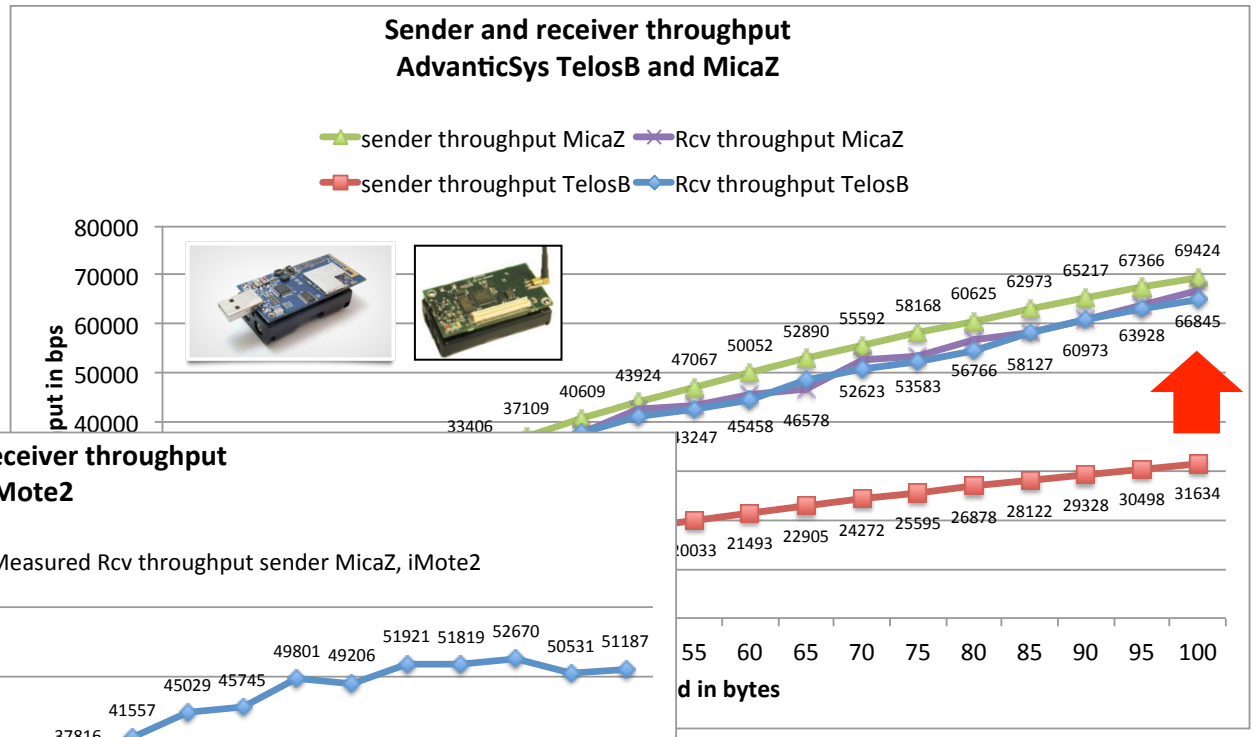
TREAD FOR VARIOUS MOTES

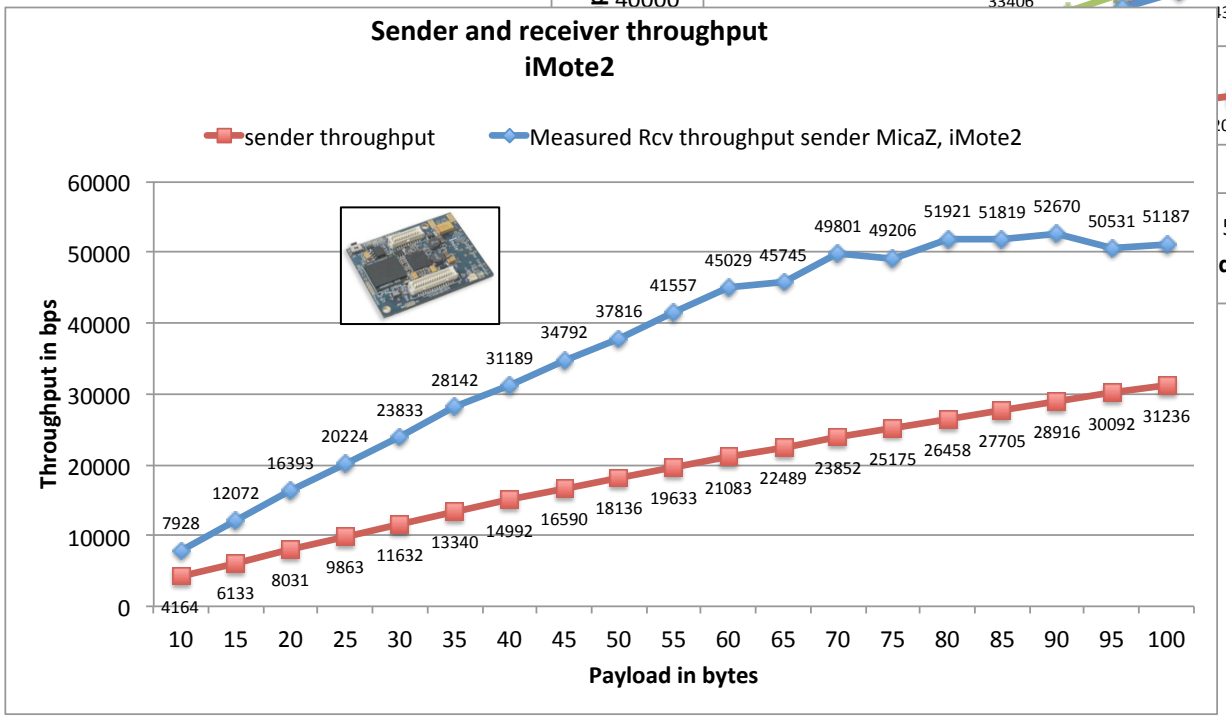




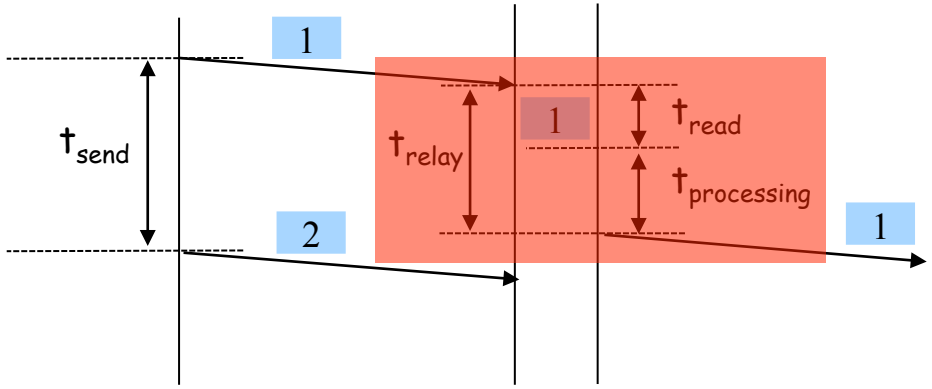


Receiver throughput



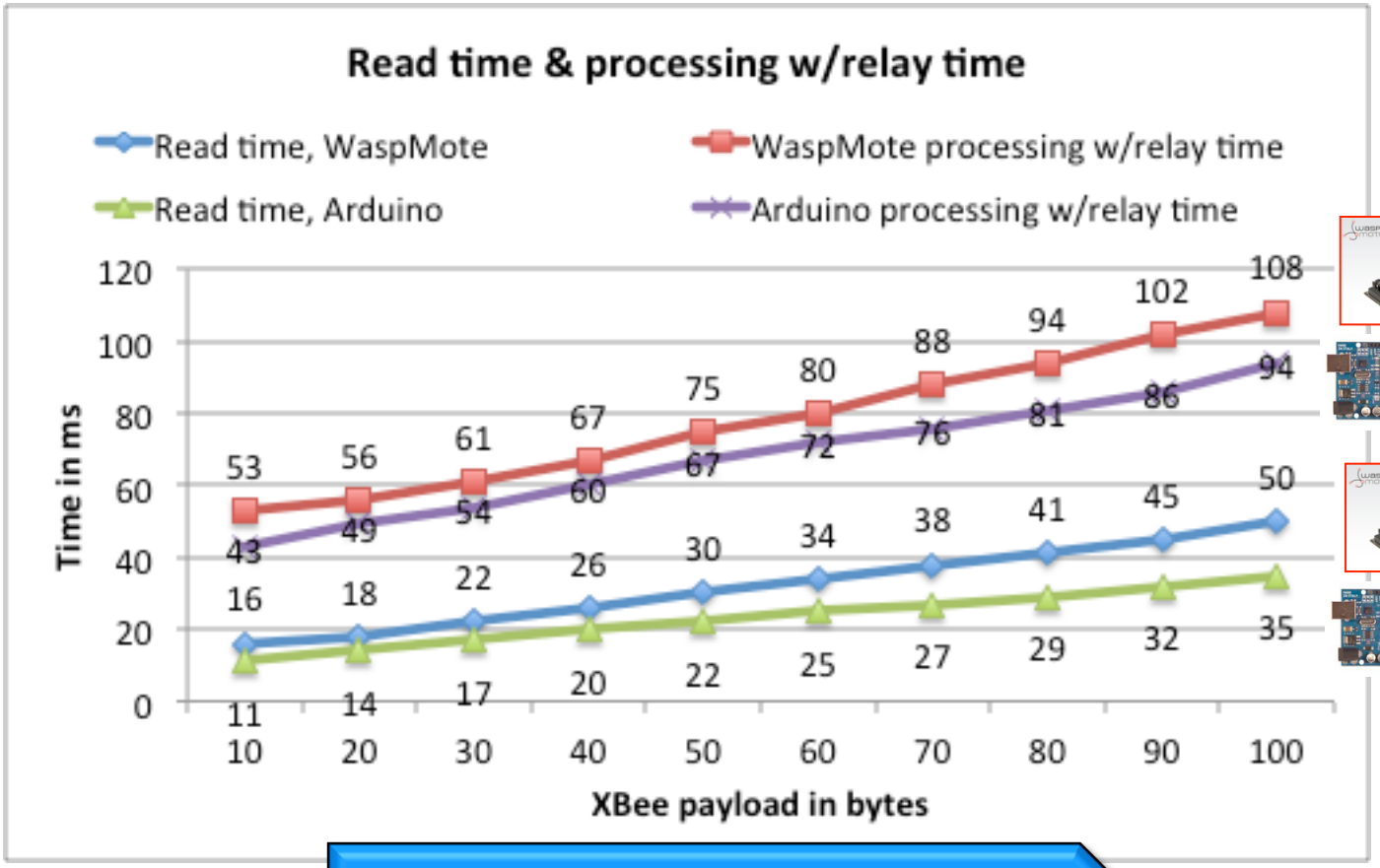


Relay performances



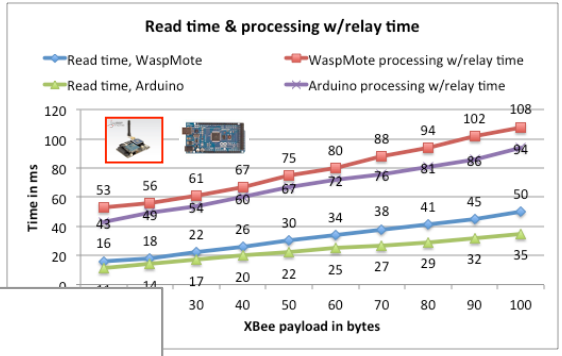
- Relaying are usually done at application-level (even OS level is considered app-level for the mote)
- Relaying means:
  - Read the packet in memory
  - Send the packet to next hop

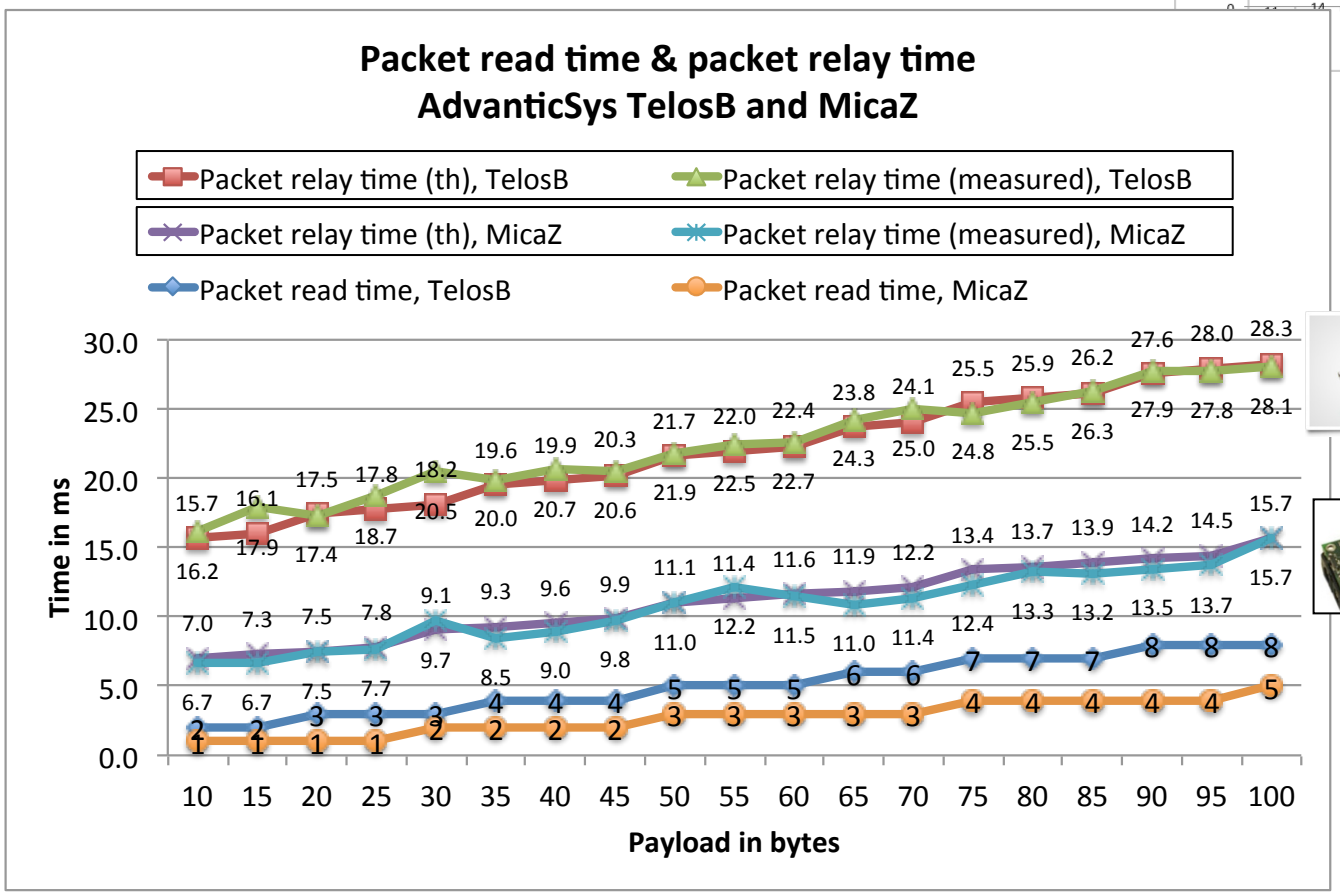
Read time and relay time



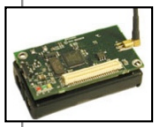
Read time is quite independant from the UART baud rate, but depends on microcontroller frequency

Read time and relay time

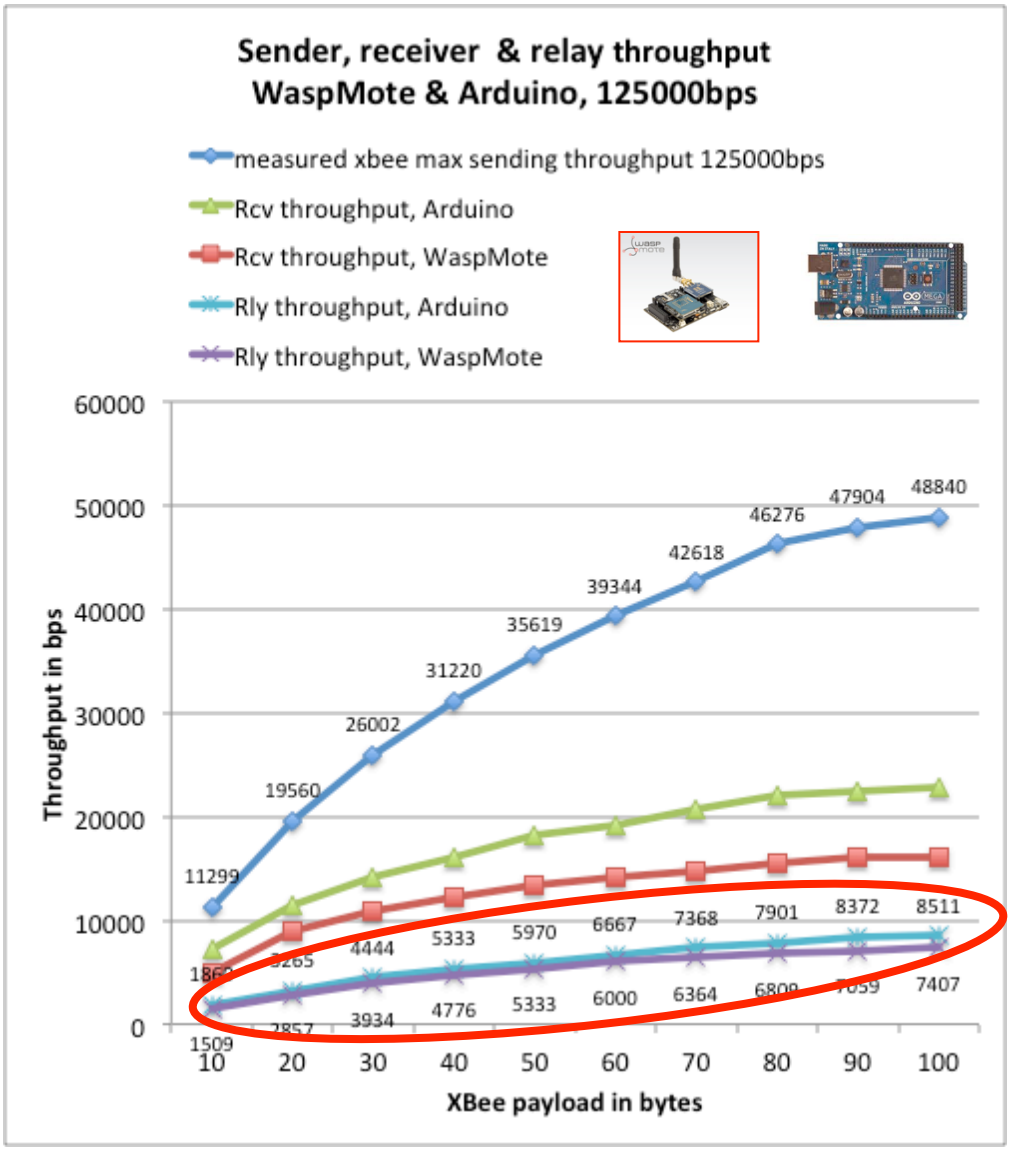




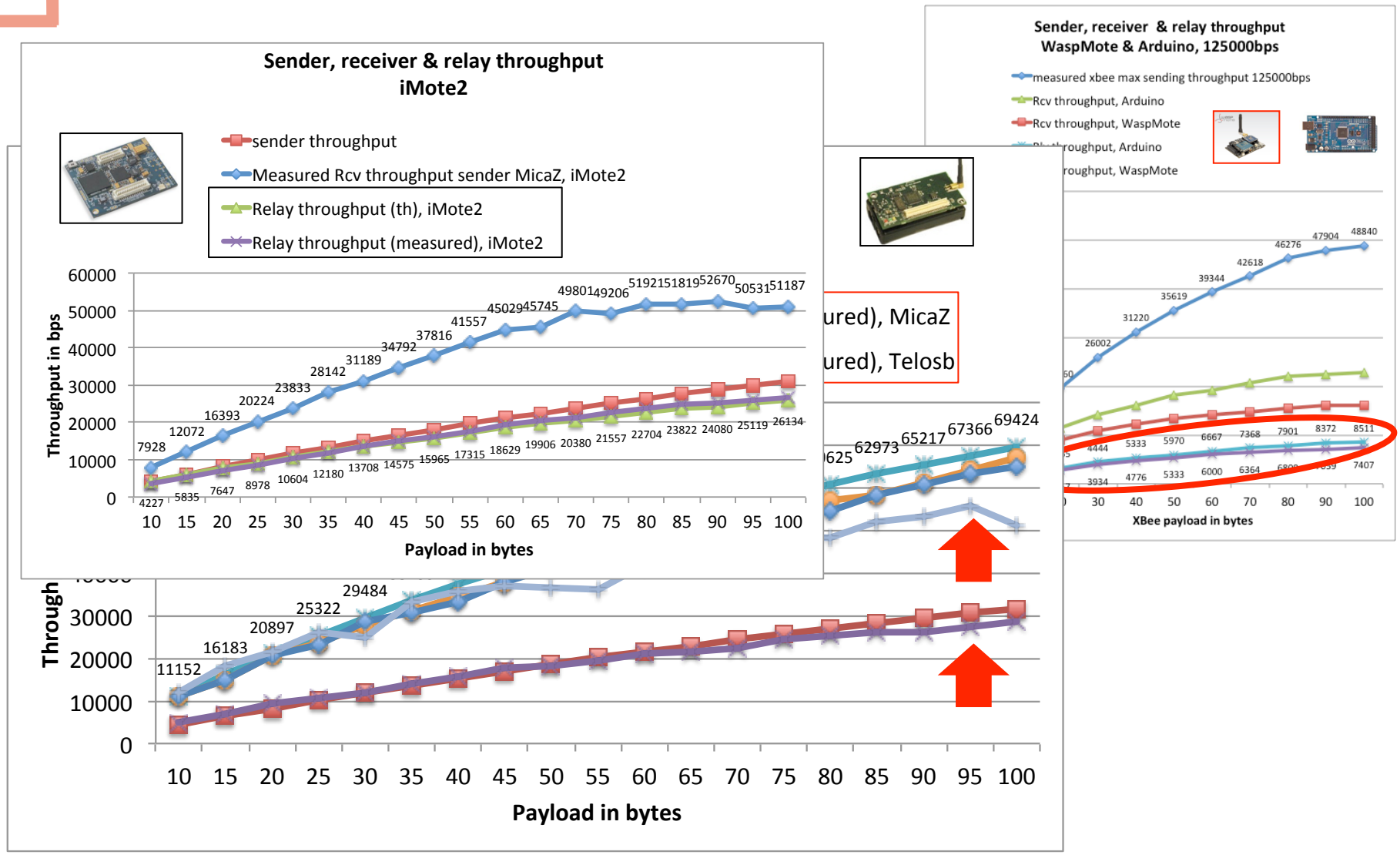




Maximum expected throughput in multi-hop



Maximum expected throughput in multi-hop



Example: Image transmission

C. Pham, V. Lecuire, J.-M. Moureaux, "Performances of Multi-Hops Image Transmissions on IEEE 802.15.4 Wireless Sensor Networks for Surveillance Applications", Proceedings of the 2013 IEEE WiMob, Lyon, October 7-9, 2013.

Robust image encoding

Original BMP 40000b



Original 200x200
256 gray levels,
adjustable
image quality: 6236b
(Q=20)

Max TX rate = 250 kps
(IEEE 802.15.4)

Minimum latency = 0.20s

Collaboration with CRAN laboratory, Nancy, France, for robust image encoding techniques for WSN.

Q=50 S=11045b 142pkts



PSNR=25.1661

Q=40 S=9701b 123pkts



PSNR=24.2231

Q=30 S=8100b 101pkts



PSNR=23.2264

Q=20 S=6236b 76pkts



PSNR=22.1293

Q=15 S=5188b 63pkts



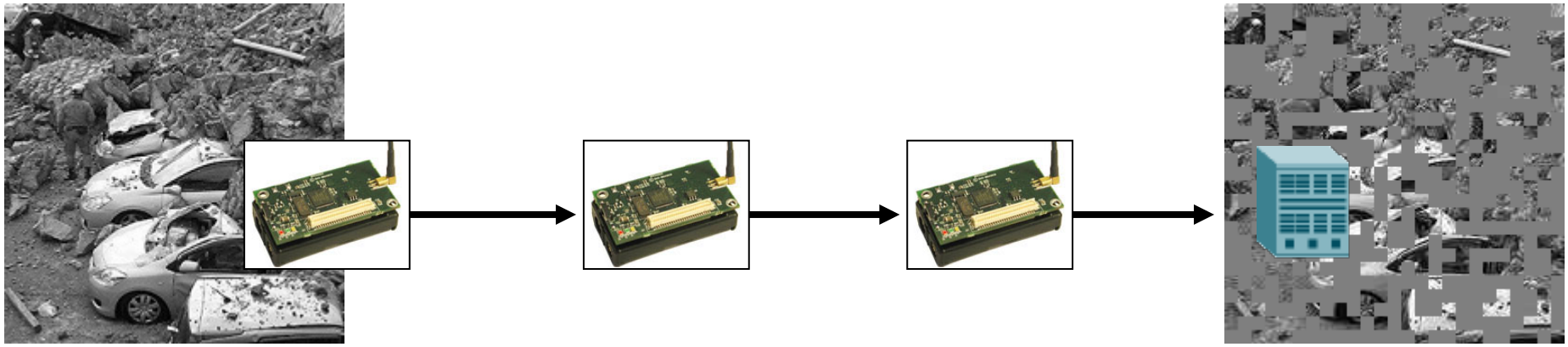
PSNR=21.4475

Q=10 S=3868b 47pkts



PSNR=20.5255

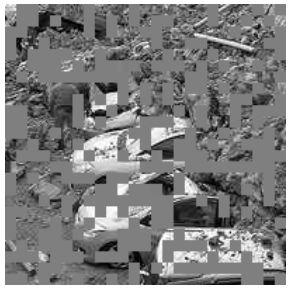
Robust to packet losses

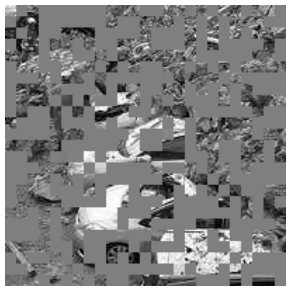


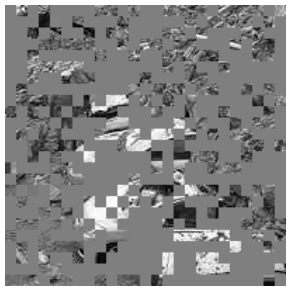

10%

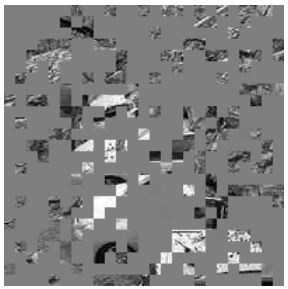

20%

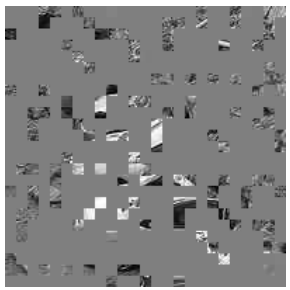

30%


40%


50%


60%


70%


80%

Transmission Time

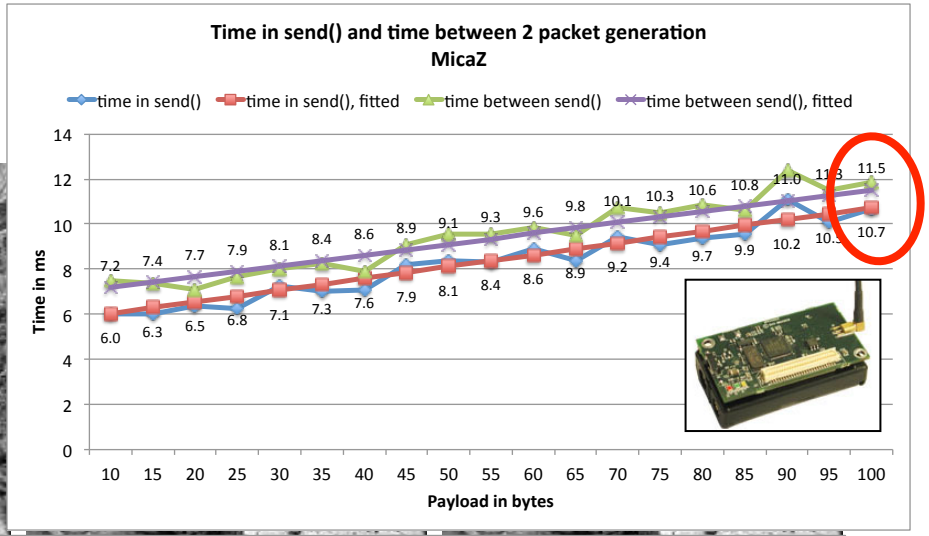
Original BMP 40000b



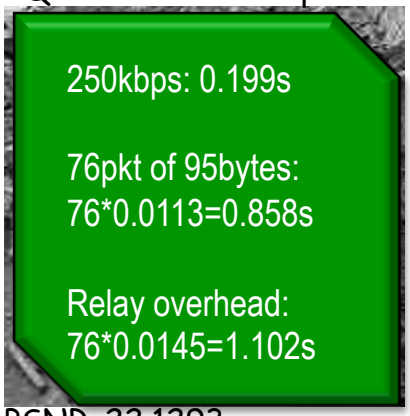
Q=50 S=11045b 142pkts



PSNR=25.1661



Q=20 S=6236b 76pkts

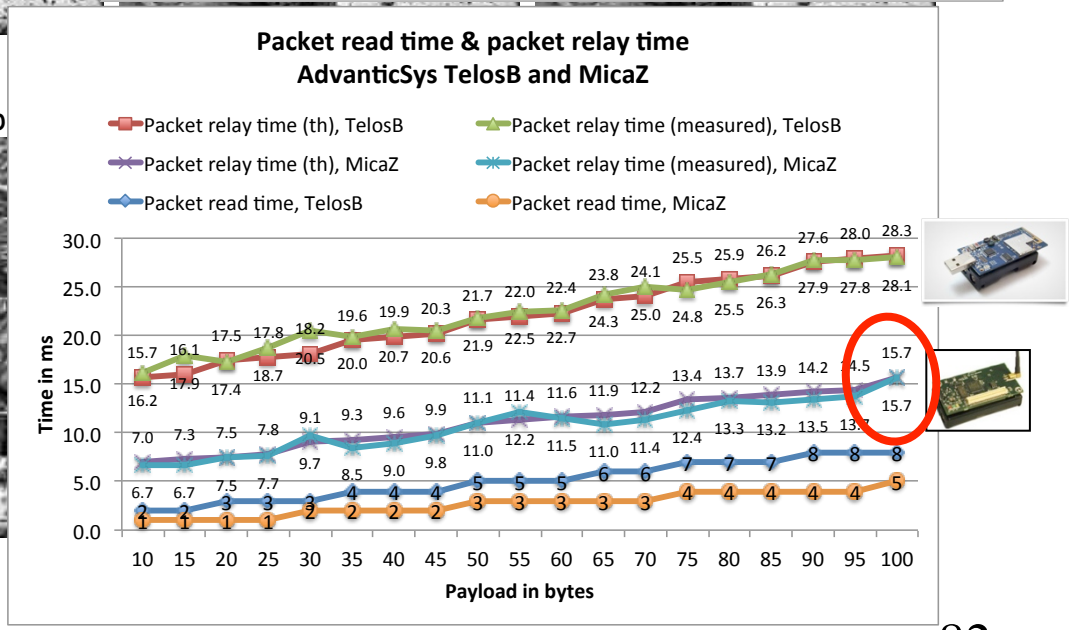


PSNR=22.1293

Q=15 S=5188b 63p



PSNR=21.4475

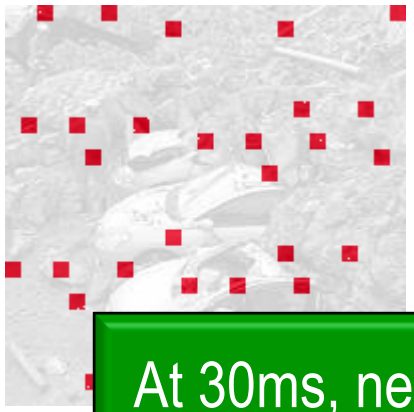


Experimental results Q=20, 76 pkts

TelosB relay node. Relay time T_R is 28ms-29ms (100B payload)



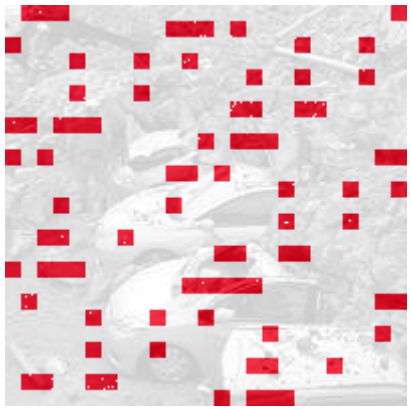
35ms



PS



30ms



PSNR=21.9901

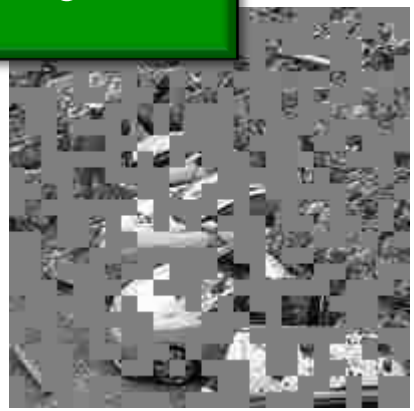
At 30ms, need 2.28s to send the image.



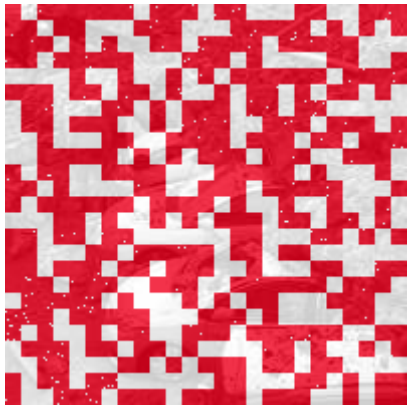
20ms



PSNR=17.265



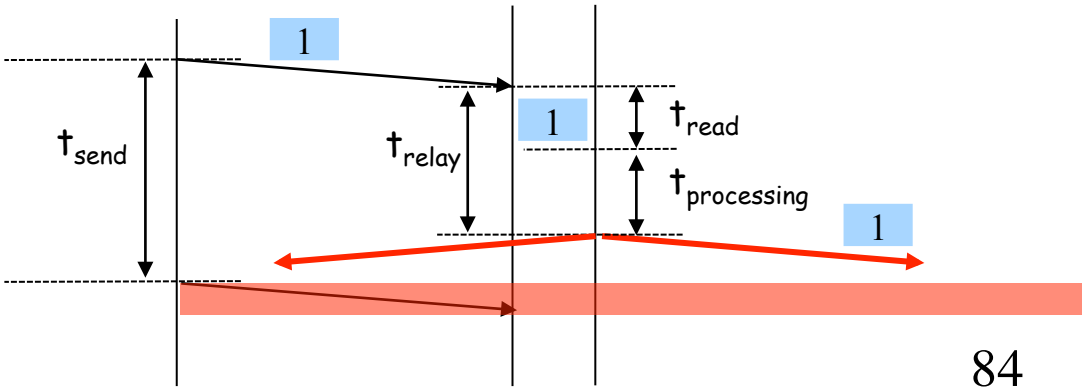
15ms



PSNR=14.2429

What impact on research?

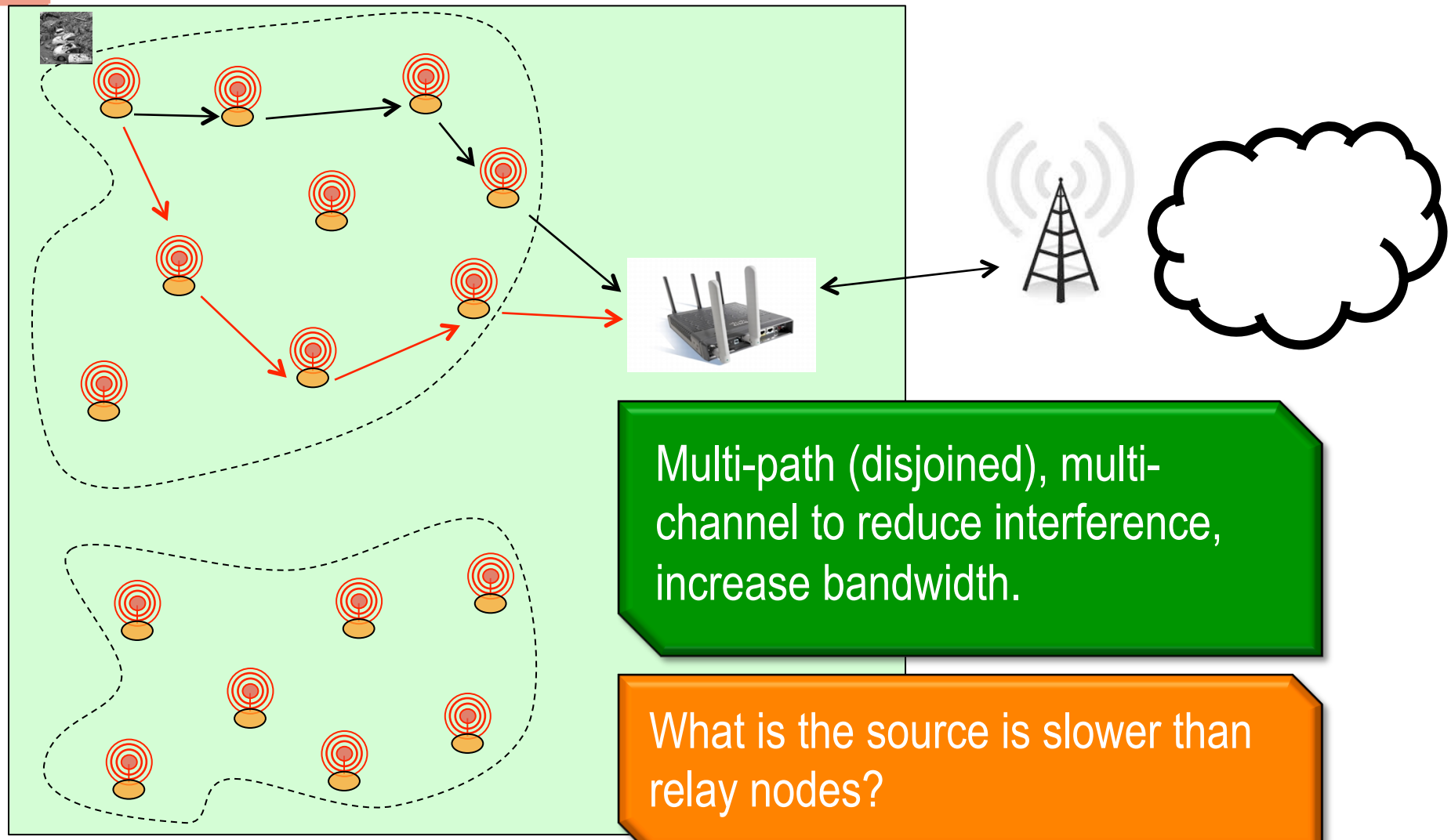
- Preparing image data and transmitting at the source can cost 20ms/pkt (or more!)
- Relaying can be reduced to about 15ms/pkt on some platforms
- Few interference from one node to another



What impact on research?

- Preparing image data and transmitting at the source can cost 20ms/pkt (or more!)
- Relaying can be reduced to about 15ms/pkt on some platforms
- Few interference from one node to another
- How efficient is multi-path/ multi-channel routing?

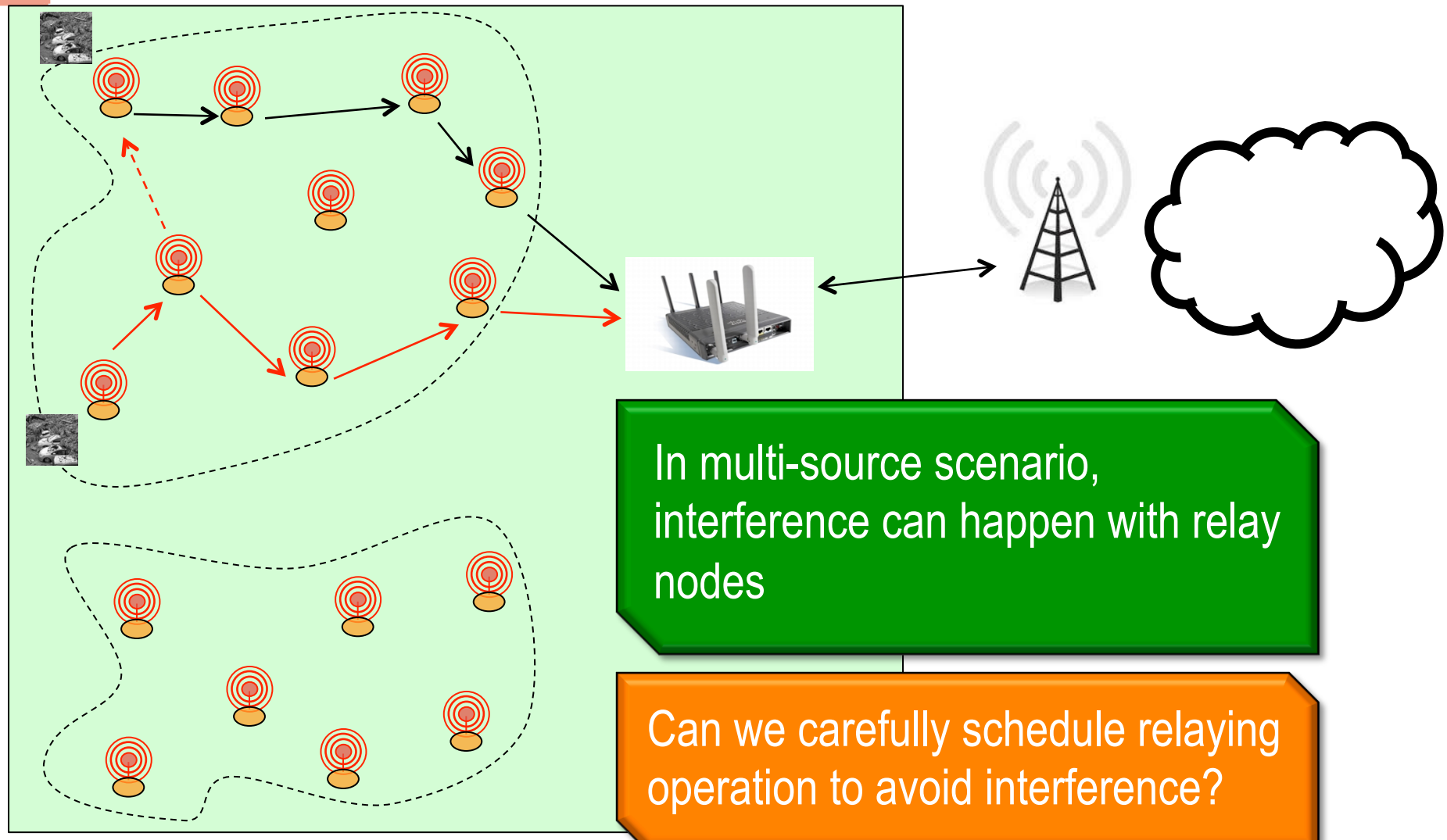
How efficient is multi-path/channel routing?



Multi-path (disjoined), multi-channel to reduce interference, increase bandwidth.

What is the source is slower than relay nodes?

Handle multi-source



In multi-source scenario, interference can happen with relay nodes

Can we carefully schedule relaying operation to avoid interference?

Example: Audio streaming

C. Pham, P. Cousin, A. Carer, "Real-time On-Demand Multi-Hop Audio Streaming with Low-Resource Sensor Motes", Proceedings of IEEE SenseApp, in conjunction with LCN 2014, Edmonton, Canada, September 2014.

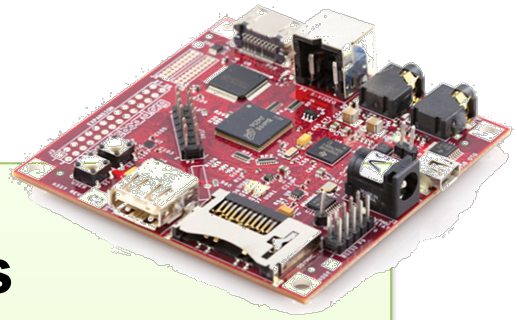
C. Pham and P. Cousin, "Streaming the Sound of Smart Cities: Experimentations on the SmartSantander test-bed", Proceeding of the 2013 IEEE International Conference on Internet of Things (iThings2013), Beijing, China, August 20-23, 2013.

the sounds of smart environments

Acoustic Sensing



www.ear-it.eu



Today's audio-ready IoT Technologies

- *Less Capable*
- *Low energy*
- *Cheaper to get*
- *Much deployed*

Today's Acoustic Sensing Technologies

- *Powerful*
- *Power greedy*
- *More costly*
- *Fewer available*

Combining the complementary Acoustic Sensing and Internet-of-Things technologies of today for value

From EAR-IT slides

EAR-IT test-beds

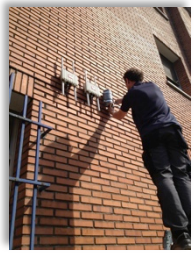


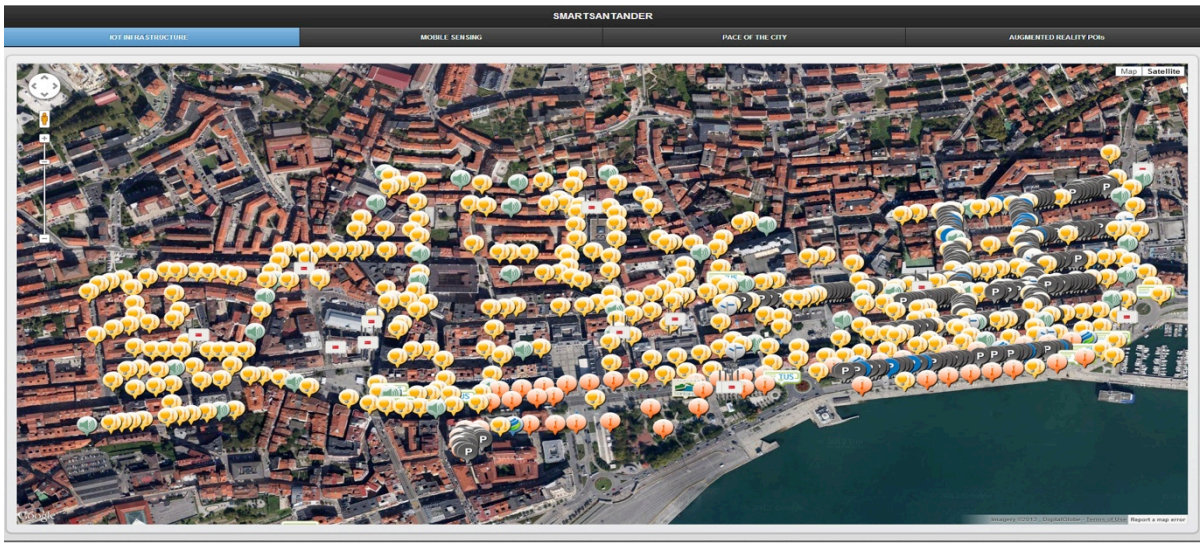
From EAR-IT slides

SmartSantander meets EAR-IT

Upon concrete noise pattern detected by the APU, legacy sensors collect data for several purposes ⇒ Two use cases as a starting point.











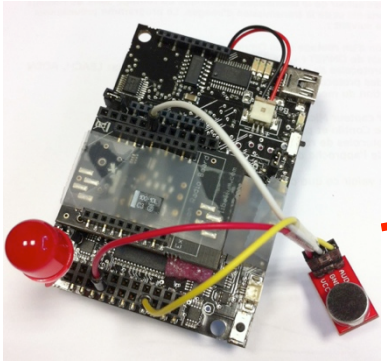


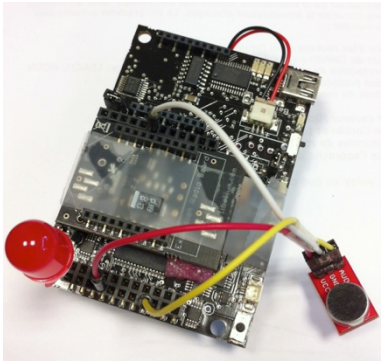




From EAR-IT slides

Use deployed low-resource IoT node to enhance acoustic services







To what extend digital audio traffic can be supported by low-resource IoT nodes?

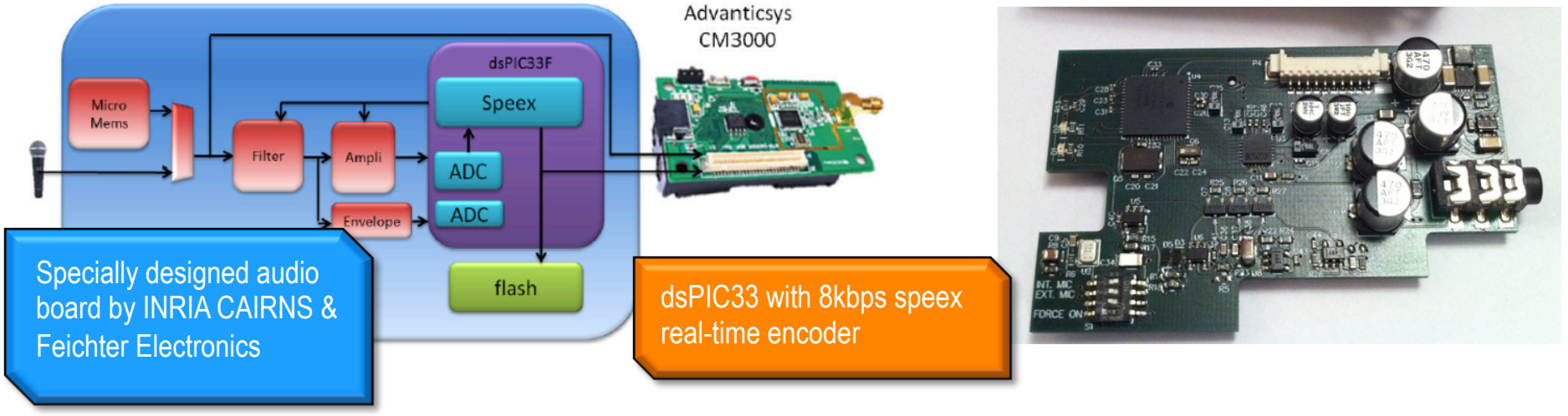
PLAY/STORE RECEIVED AUDIO DATA





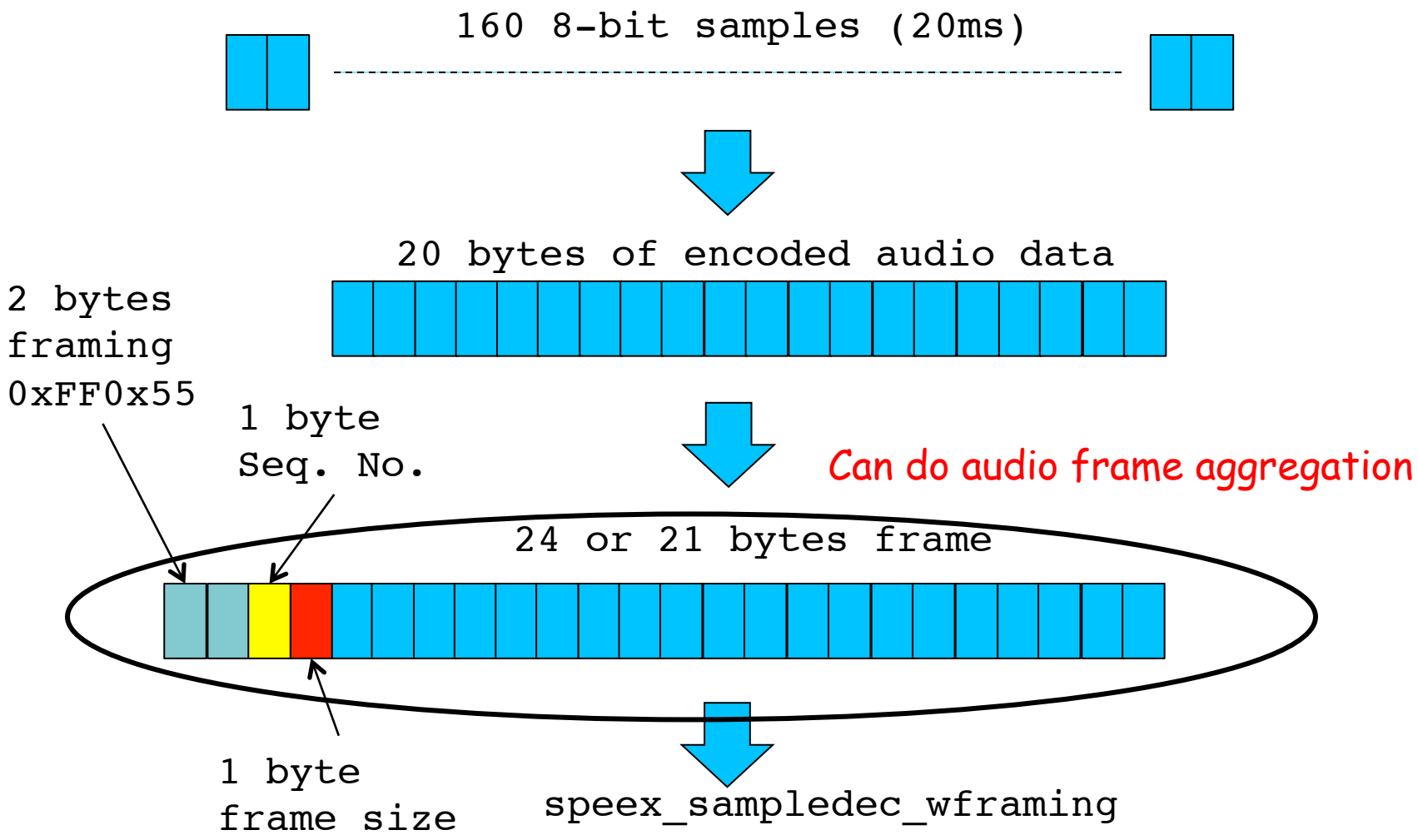
AUDIO BOARD

- USE DEDICATED AUDIO BOARD FOR SAMPLING/STORING/ENCODING AT 8KBPS



- ALLOWS FOR MULTI-HOP, ENCODED AUDIO STREAMING SCENARIOS

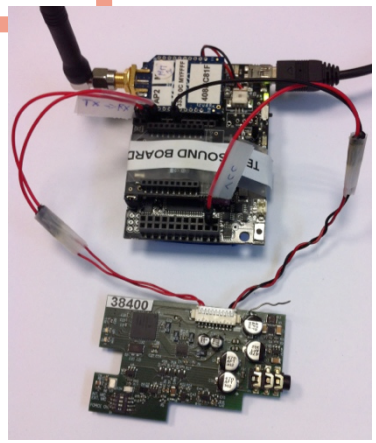
SPEEX AT 8KBPS



Summary of audio constraints

Codec	Minimum sending rate
Raw 4KHz 8KHz	 100 bytes every 25ms 100 bytes every 12.5ms
Speex 8000bps A1 A2 A3 A4	 24 bytes every 20ms 48 bytes every 40ms 72 bytes every 60ms 96 bytes every 80ms

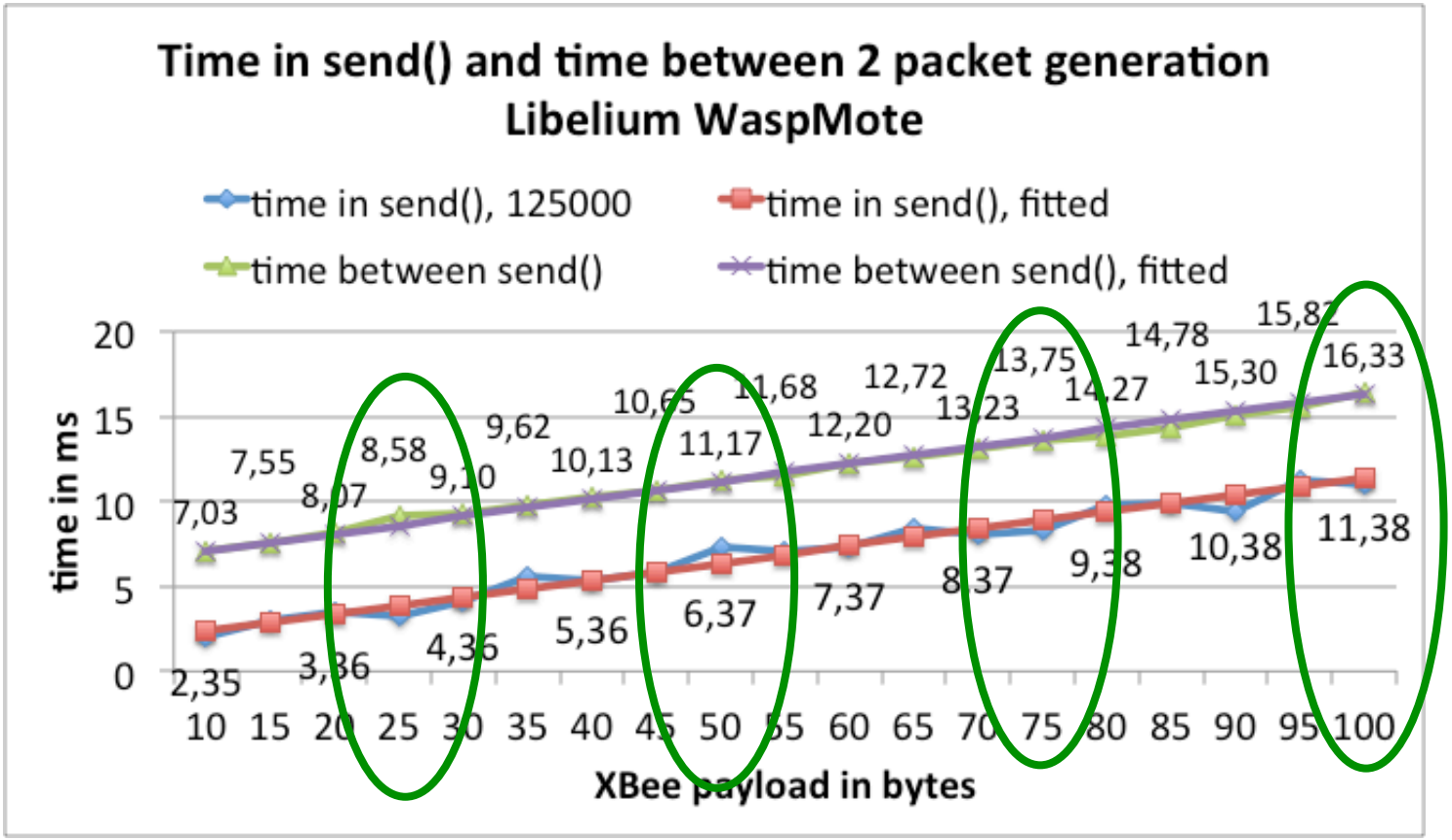
IoT node sending performance



Libelium WaspMote

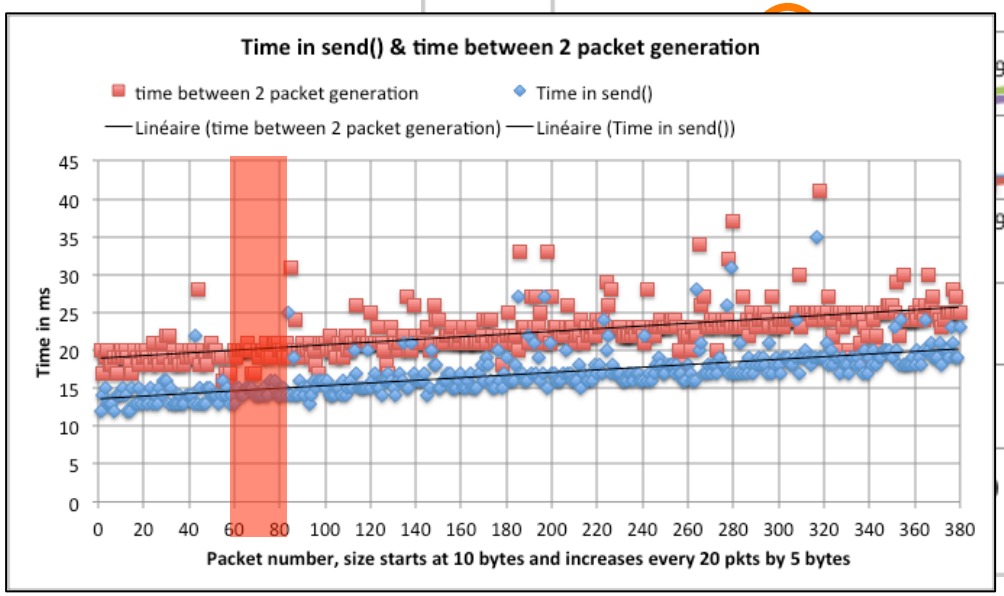
24 bytes every 20ms

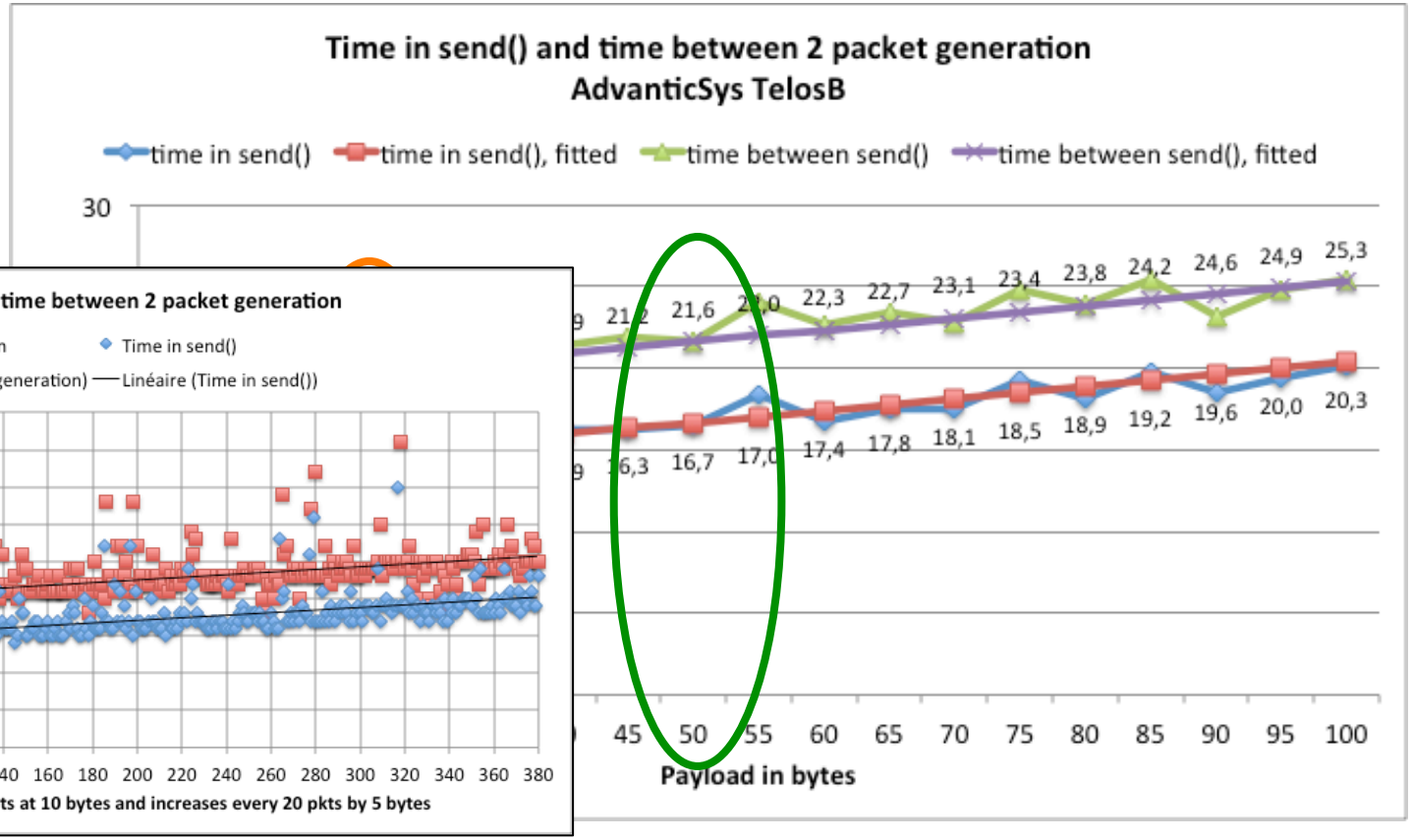




IoT NODE SENDING PERFORMANCE





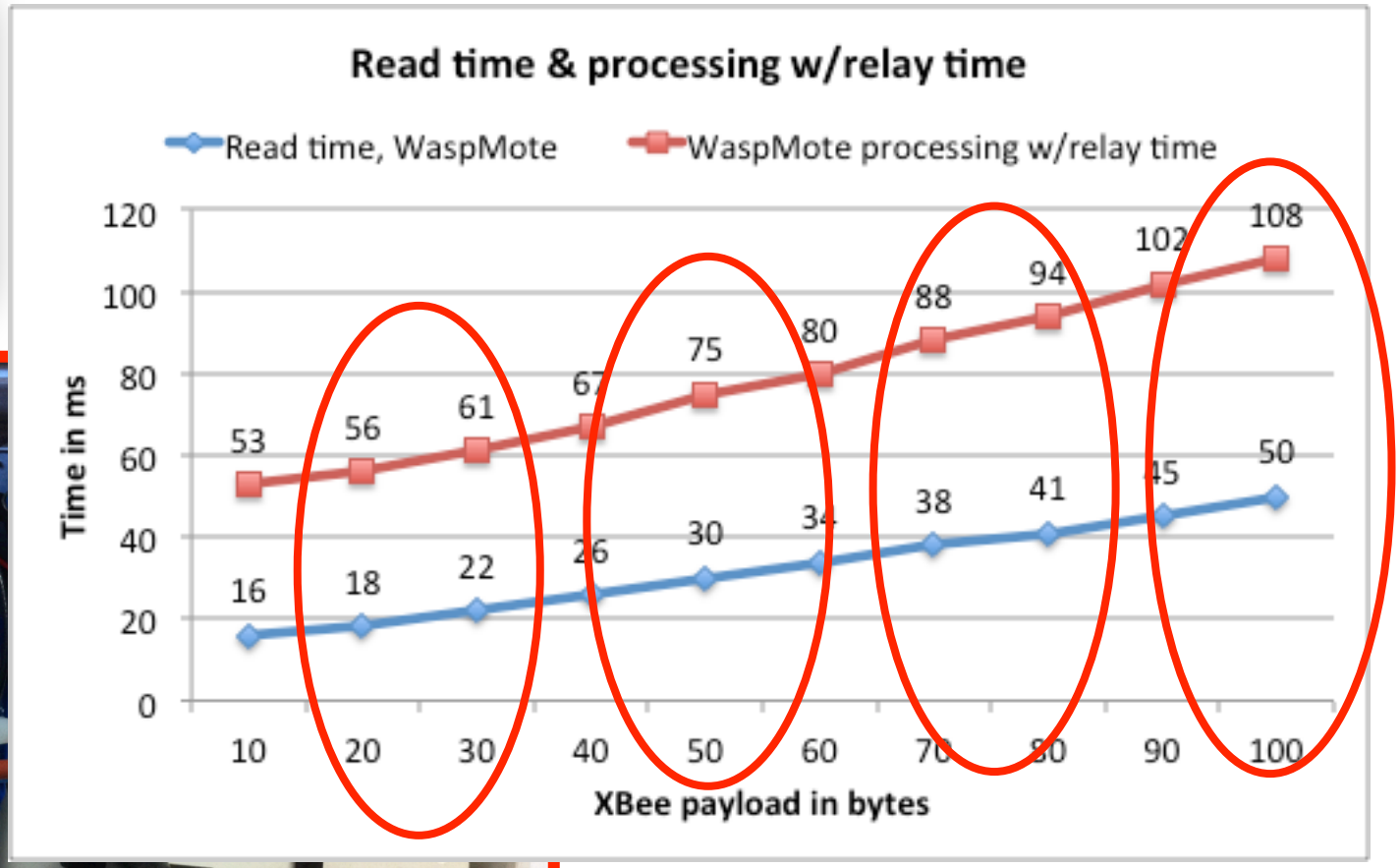


Better with A2 agregation

Santander's limitations



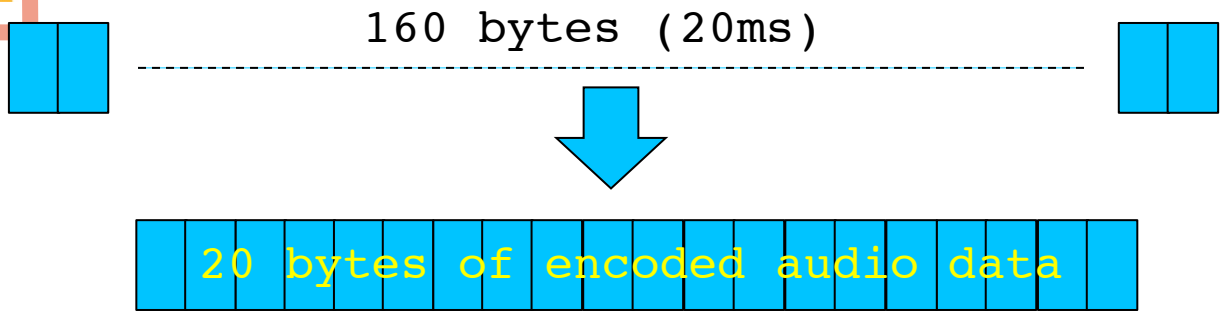




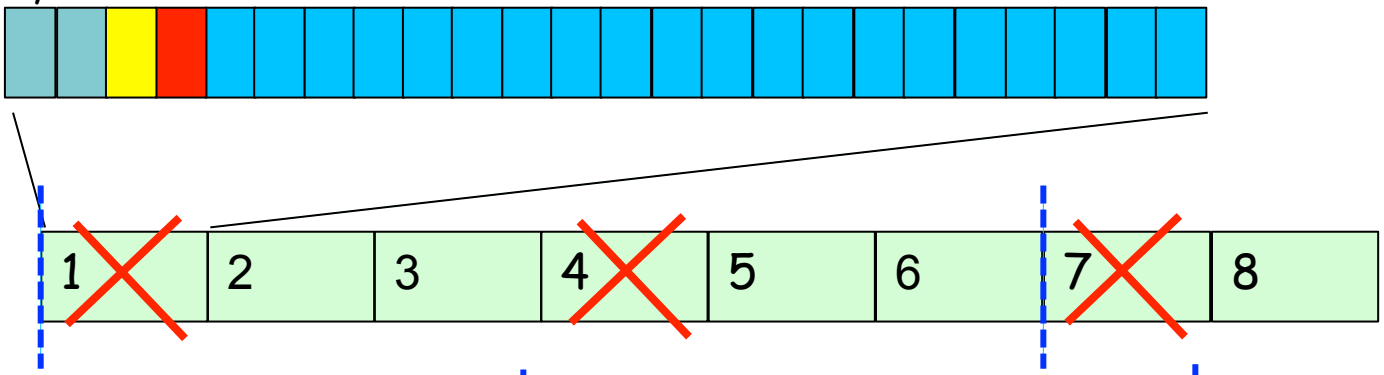
SmartSantander's IoT node uses 38400 baud rate for communication between XBee radio and host ucontroller

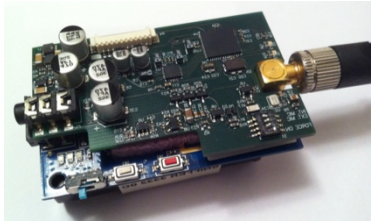
Needs to discard audio frame at the source to increase the time window

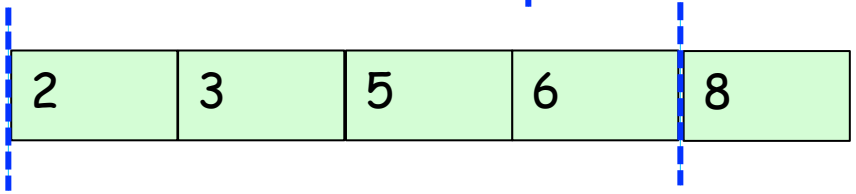
SPEEX AT 8KBPS ON SLOW RELAY NODES



Add framing bytes







A6 aggregate audio frames

Capture 6 audio frames (120ms) but only send 4

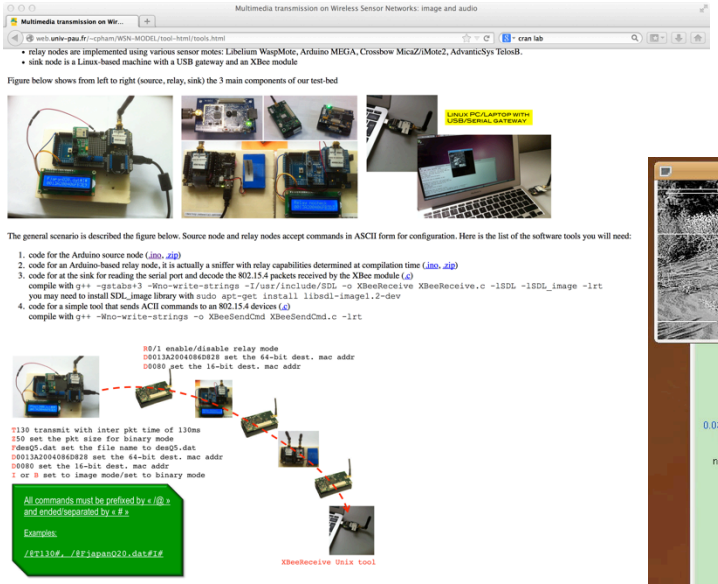
Need to be able to relay 96-byte pkt every 120ms

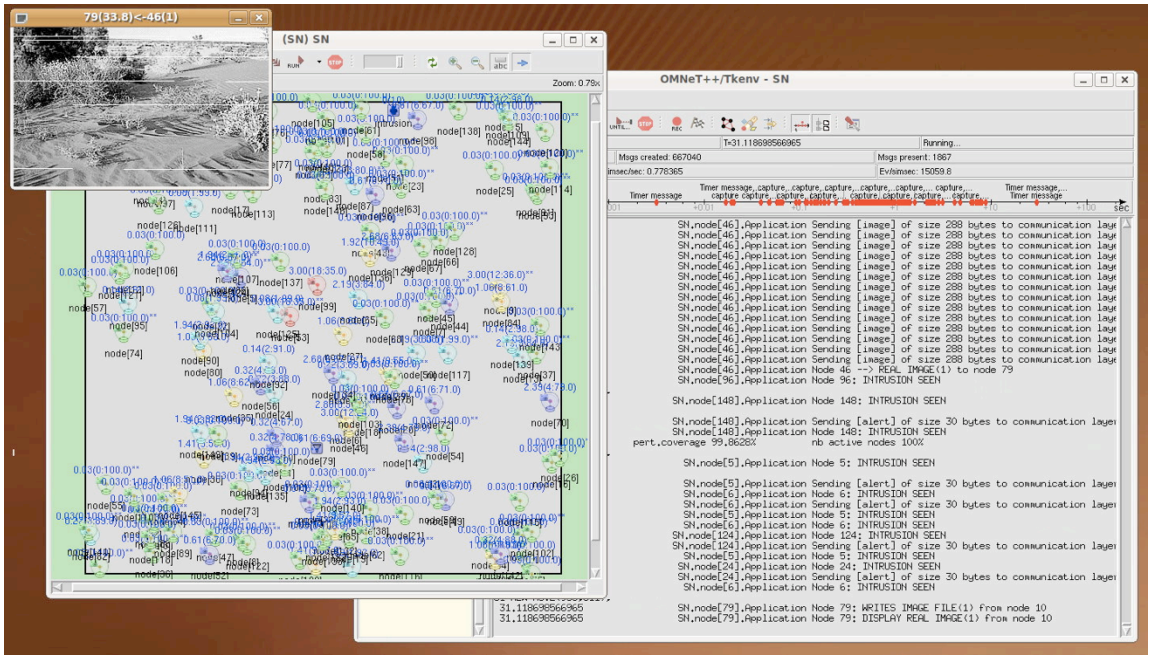
Conclusions

- Need to move to more « real » experiments
- Sensor hardware are becoming cheap and easy to buy
- Take realistic performance values
  - Avoid unrealistic propositions/ studies
  - Knowing real constraints leads to more adapted control mechanisms

Some links

http://web.univ-pau.fr/~cpham/WSN-MODEL/tool-html/tools.html





http://web.univ-pau.fr/~cpham/WSN-MODEL/wvsn-castalia.html