Wireless Sensor Network: from theory to practice

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December, 10th, 2013

Oran, Algérie



Prof. Congduc Pham

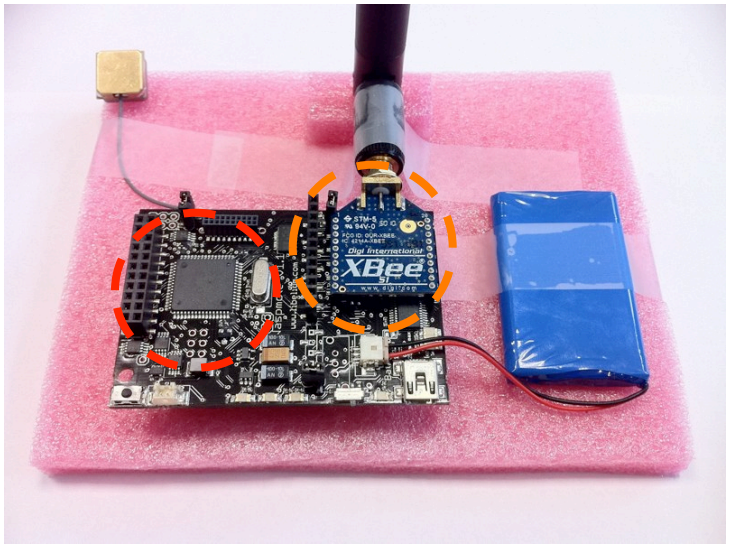
http://www.univ-pau.fr/~cpham

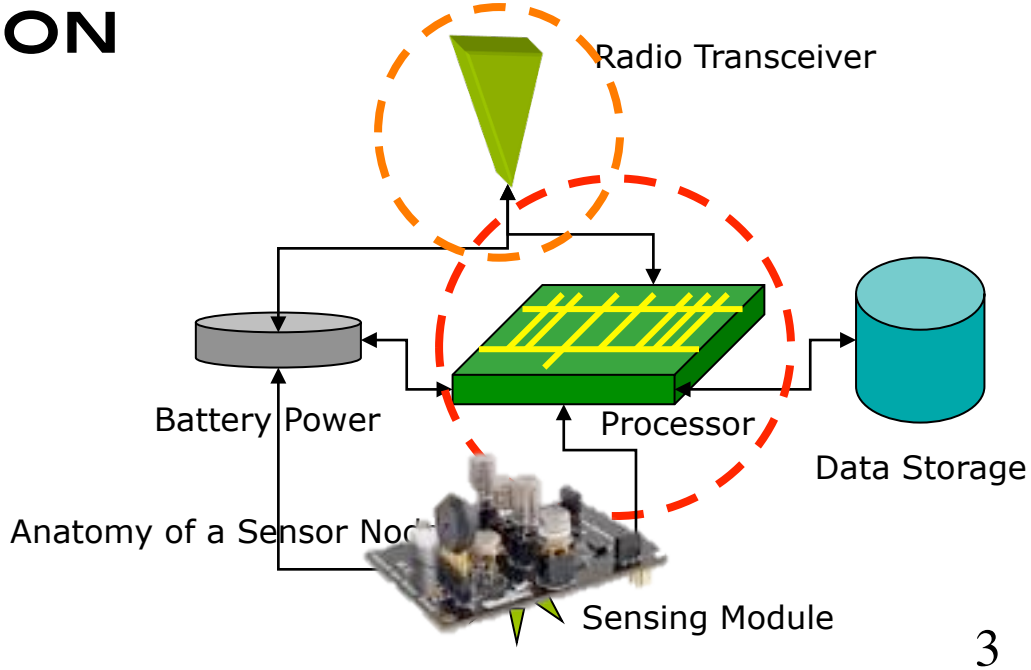
Université de Pau, France



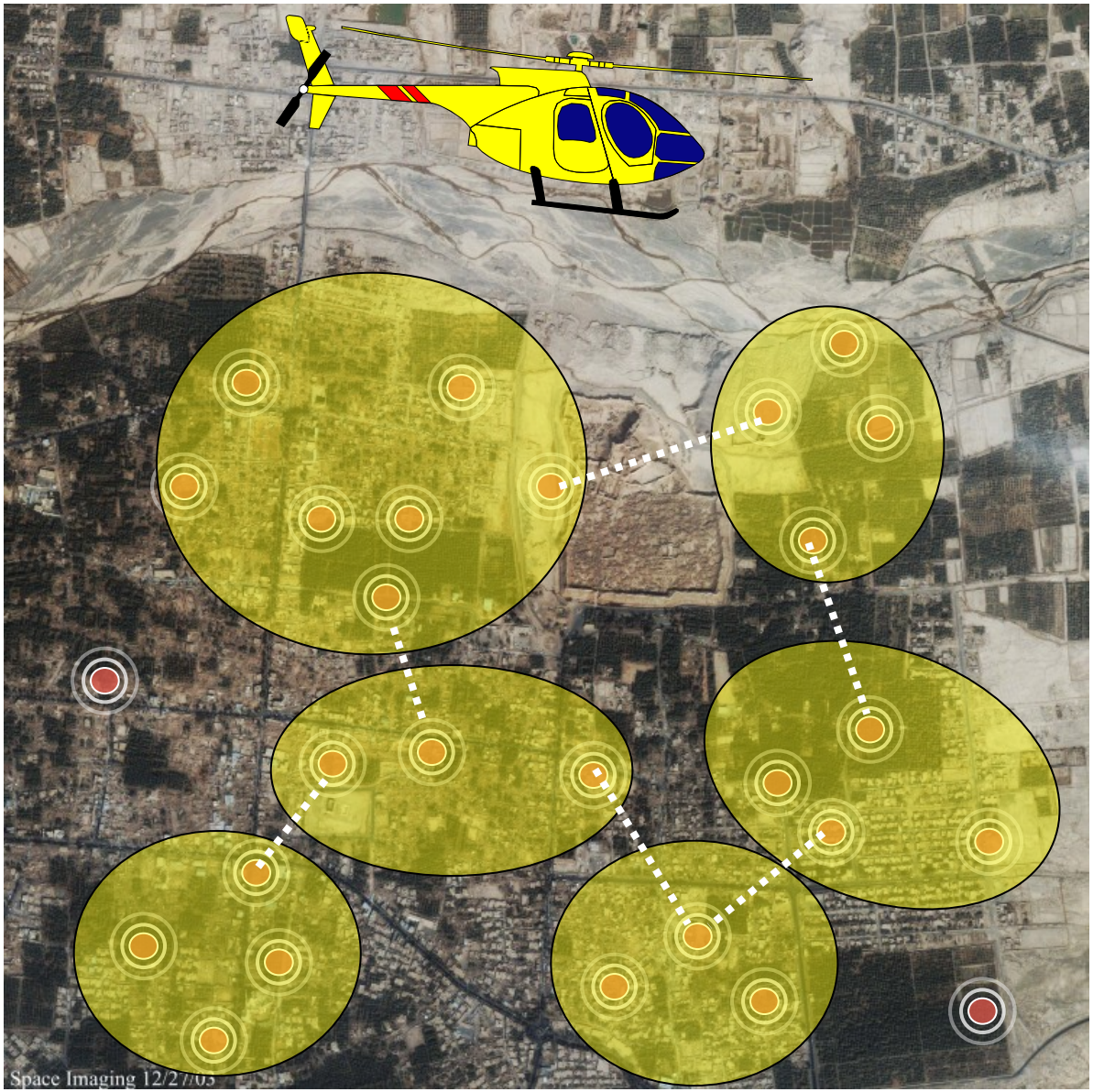
Wireless autonomous sensor

- In general: low cost, low power (the battery may not be replaceable), small size, prone to failure, possibly disposable
- Role: sensing, data processing, communication

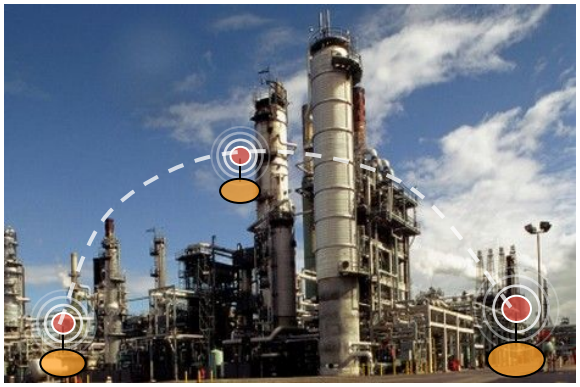




LARGE SCALE DEPLOYMENT



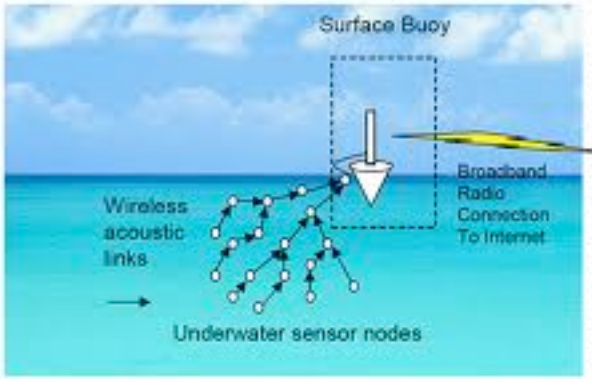
« Naturally » well suited for Monitoring/Surveillance









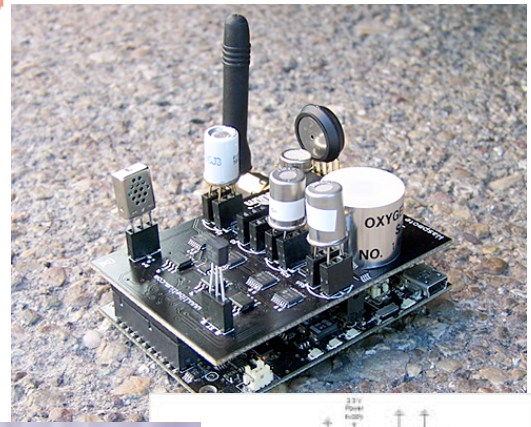








Energy consideration





18720 Joules

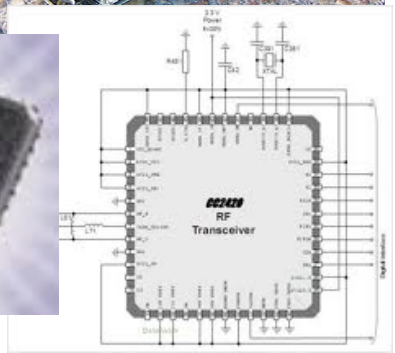
TX power 0dbm: 17.4mA

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

MIDDLEWARE/APP. ISSUES

ENERGY CONSIDERATIONS

NETWORK

SIGNAL IMAGE/VIDEO PROCESSING

OS MIDDLEWARE SOFT. ENG.

DATA MNGT SECURITY MOBILITY

HARDWARE RADIO

SENSOR'S OS

SUPERVISION PLATFORM

APPLICATIONS

CBSE for SENSOR NODE DYNAMIC RECONFIGURATION

SERVICE-ORIENTED SERVICE REPOSITORY

ADAPTIVE APPLICATION

QOS

NETWORK ISSUES

ENERGY CONSIDERATIONS

NETWORK

SIGNAL IMAGE/VIDEO PROCESSING

OS MIDDLEWARE SOFT. ENG.

DATA MNGT SECURITY MOBILITY

HARDWARE RADIO

ORGANIZATION OVERLAYS SCHEDULING

- IMAGE COVERAGE SELECTION &
- WAKE-UP MECHANISM
- CRITICALITY-BASED SCHEDULING

TRANSPORT

- LOAD-REPARTITION
- CONGESTION CONTROL

ROUTING

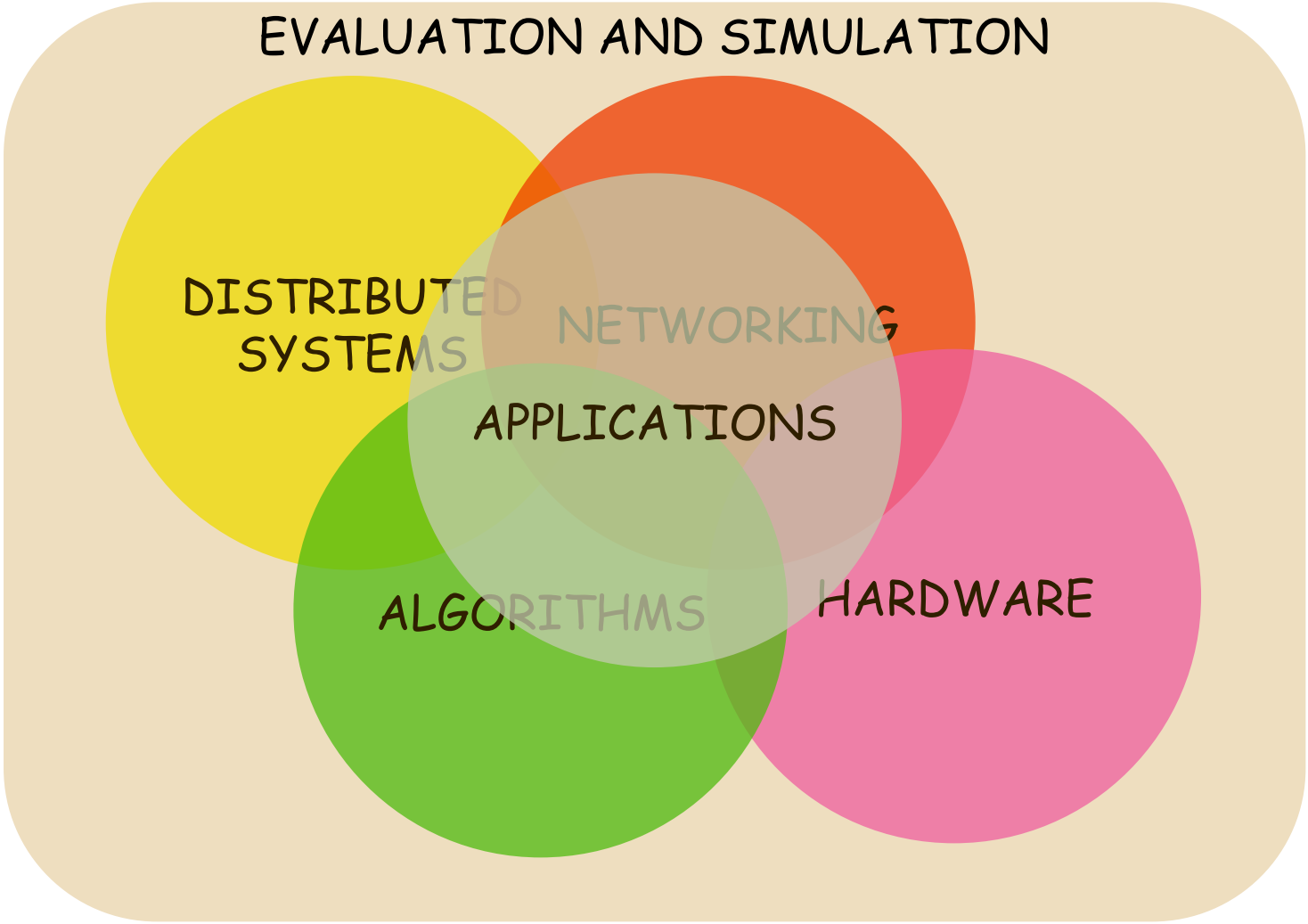
- 2-HOP INFORMATION
- GEOGRAPHIC ROUTING
- MULTI-PATHS ROUTING

MAC RESOURCES ALLOCATION

- DUTY-CYCLED MAC
- CRITICALITY-ADAPTIVE MAC

QOS

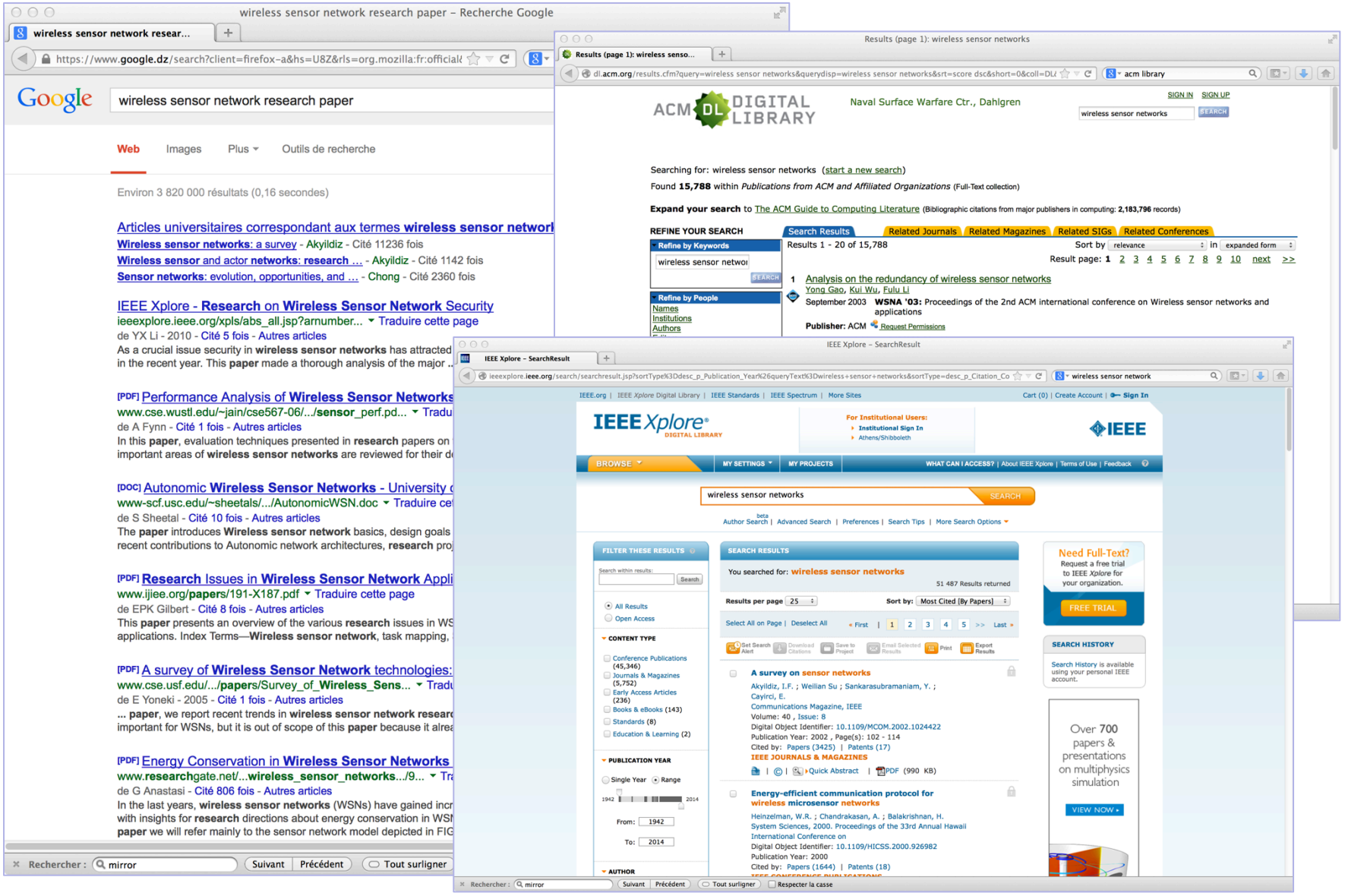
MULTIDISCIPLINARY RESEARCH



RESSACS 2010, 2011, 2012, 2013. RSAC 2011. Brest 2012. Béjaia 2013. Oran 2013...

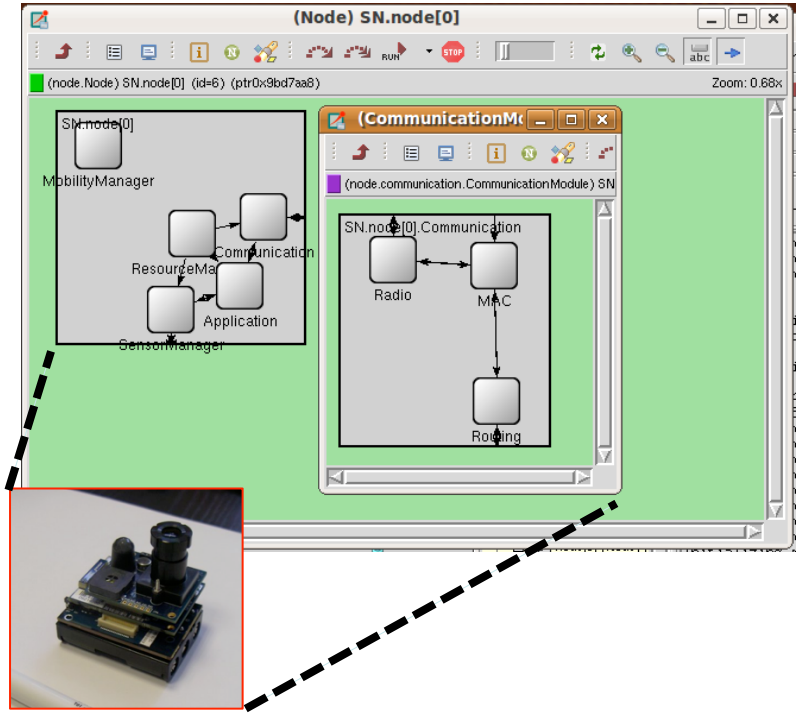


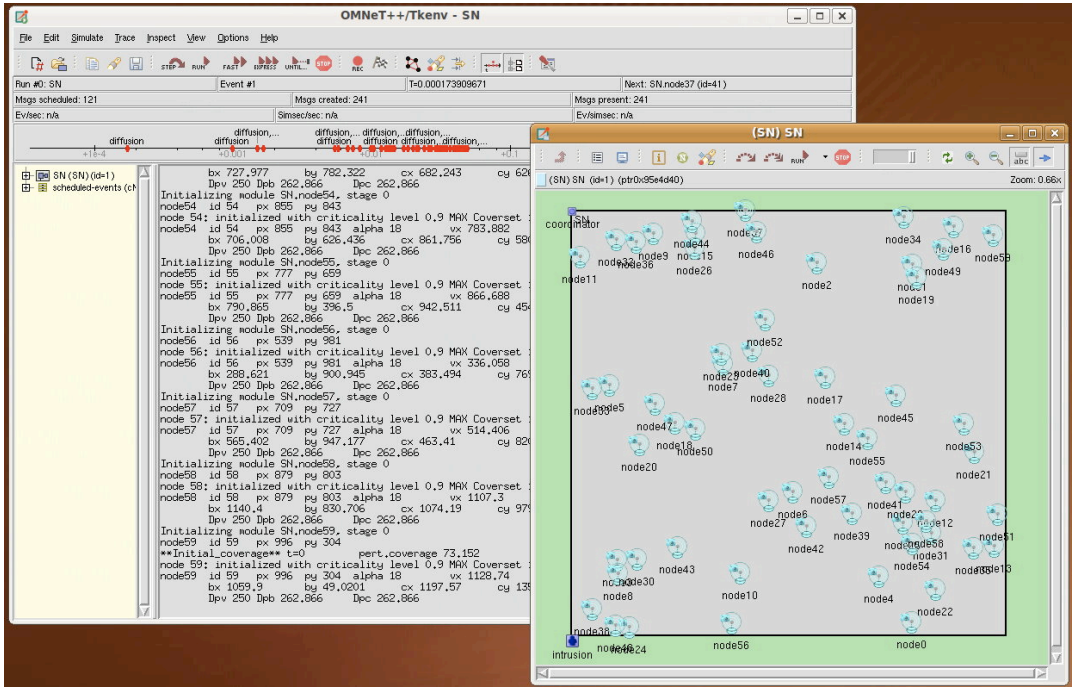
Huge amount of contributions...



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

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

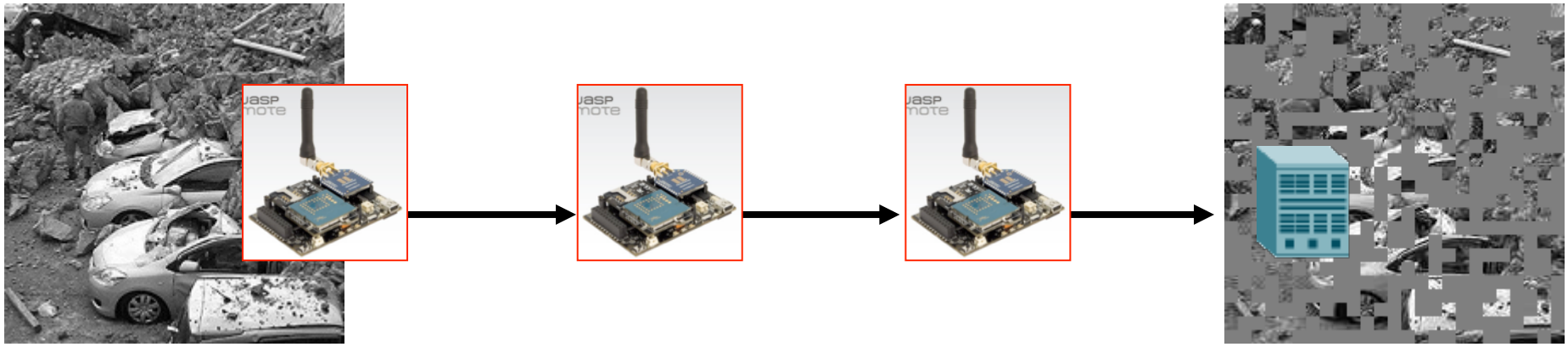


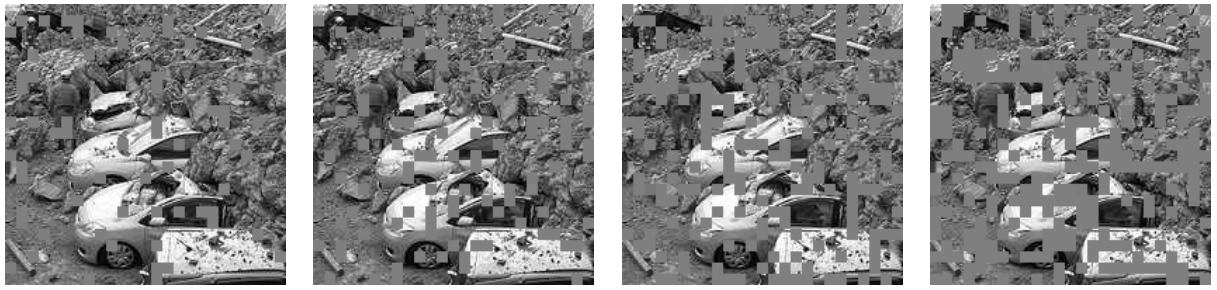


Search & Rescue, Situation awareness

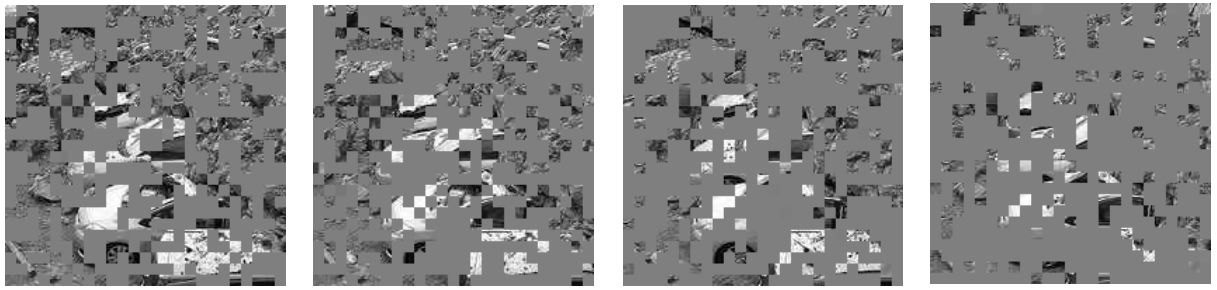


Image quality, delivery latencies,...



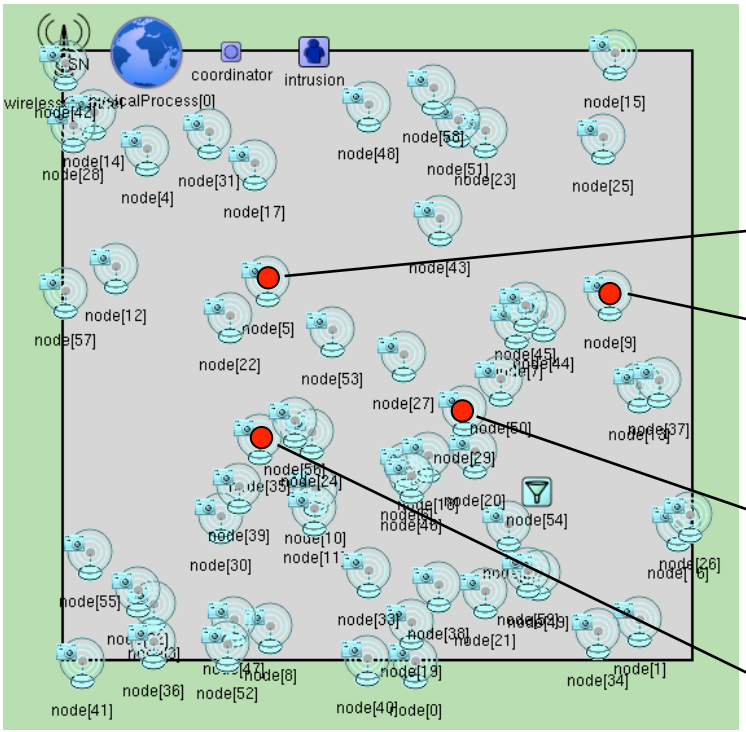


10% 20% 30% 40%



50% 60% 70% 80%

Some images displayed by the sink



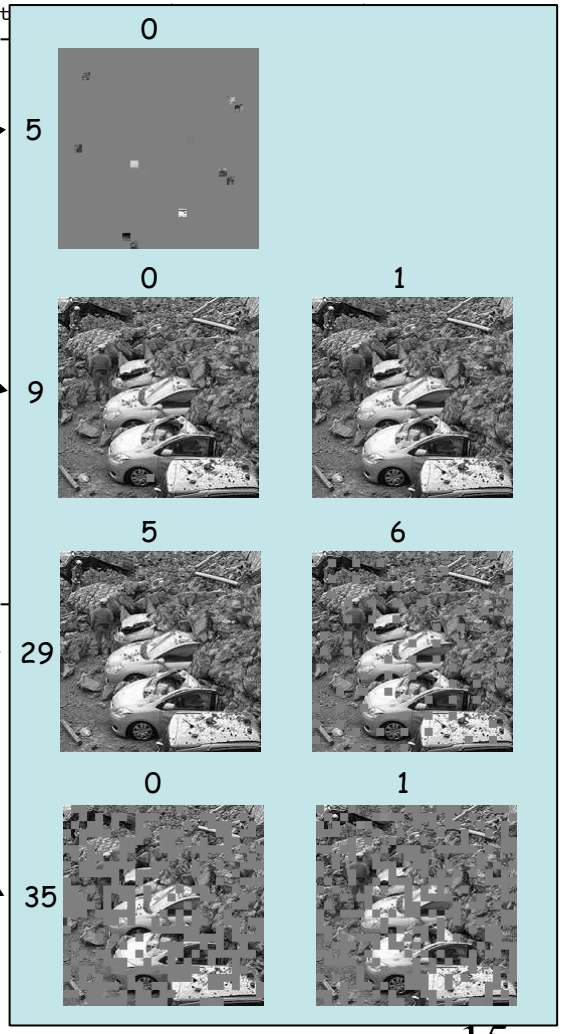
60 image sensor nodes
75mx75m
1 sink (node 54)

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

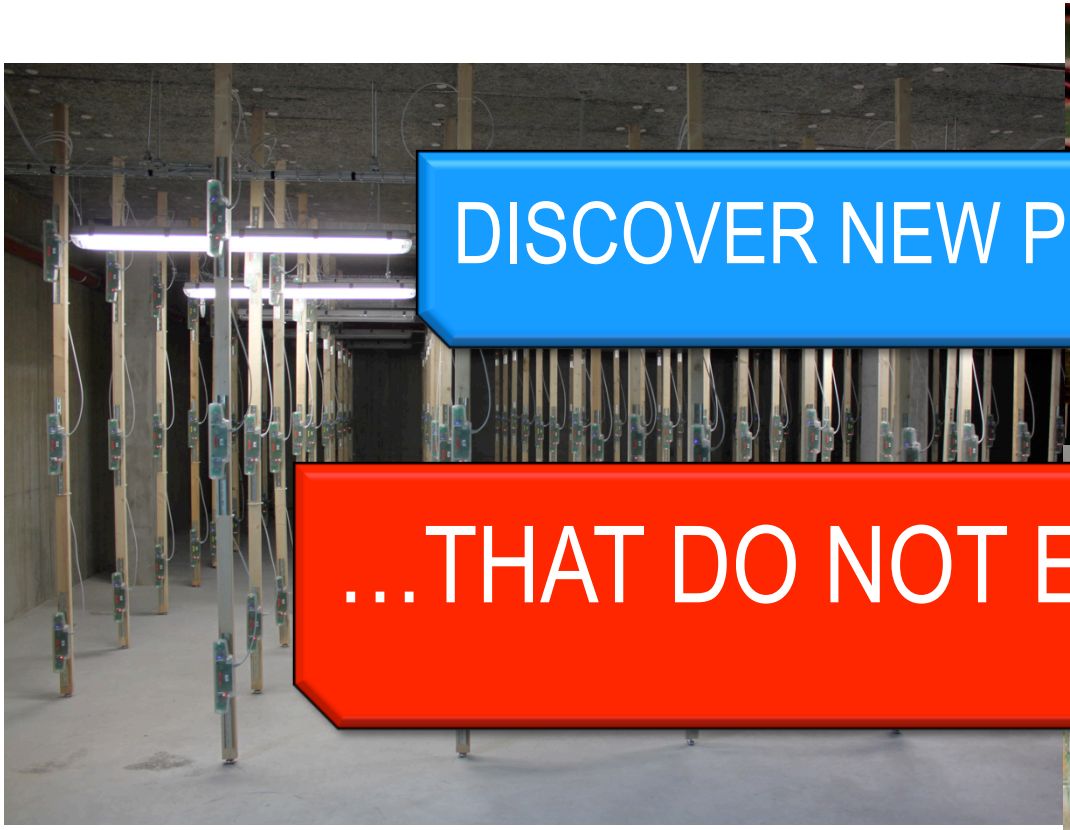


Test-beds ?









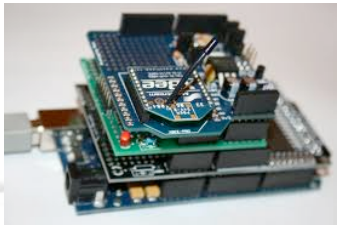


DISCOVER NEW PROBLEMS…

…THAT DO NOT EVEN EXISTS?

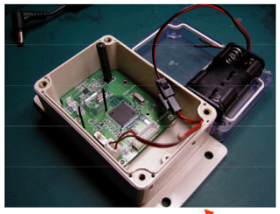
Academic vs Industrial

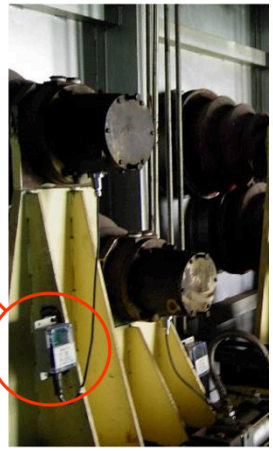
Millions of sensors, self-organizing, self-configuring, with QoS-based multi-path routing, mobility, and …





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

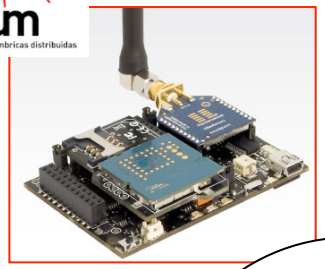
Towards WSN mass-market

NOW



2000-2007

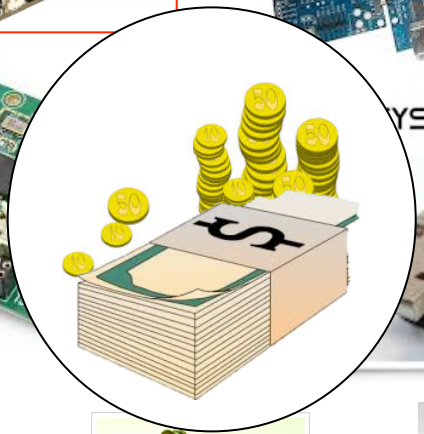
libelium
comunicaciones inalámbricas distribuidas



ARDUINO









TST







MICROCHIP

Genet
Generation Next
Technology Laboratories

Jennic
TECHNOLOGY FOR A CHANGING WORLD

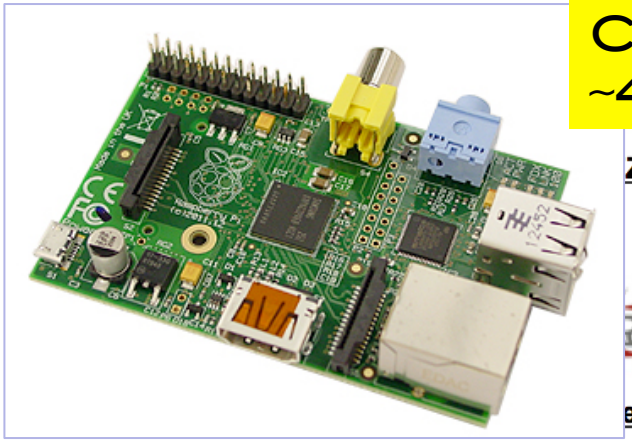
...AND CHEAP POWERFULL EMBEDDED SYSTEMS

Arduino™

CUBLOC

Beagleboard

Raspberry Pi

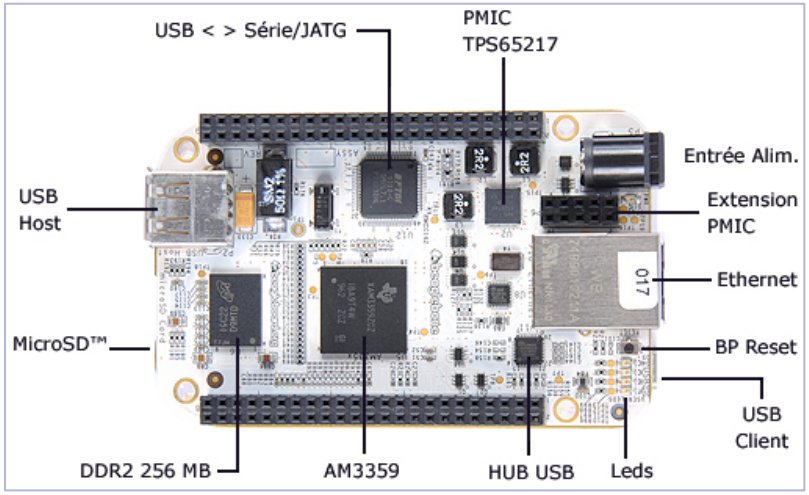


Cost: ~40€

Z/Gadgeteer

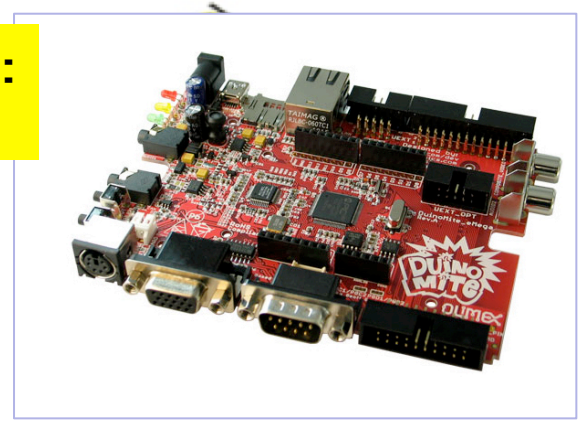
edded Artists

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!



Real test-bed? Not so difficult!



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!

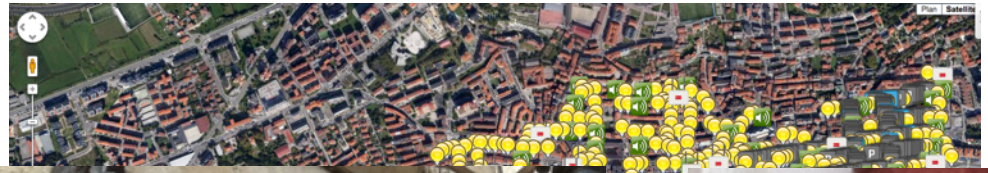


SmartSantander

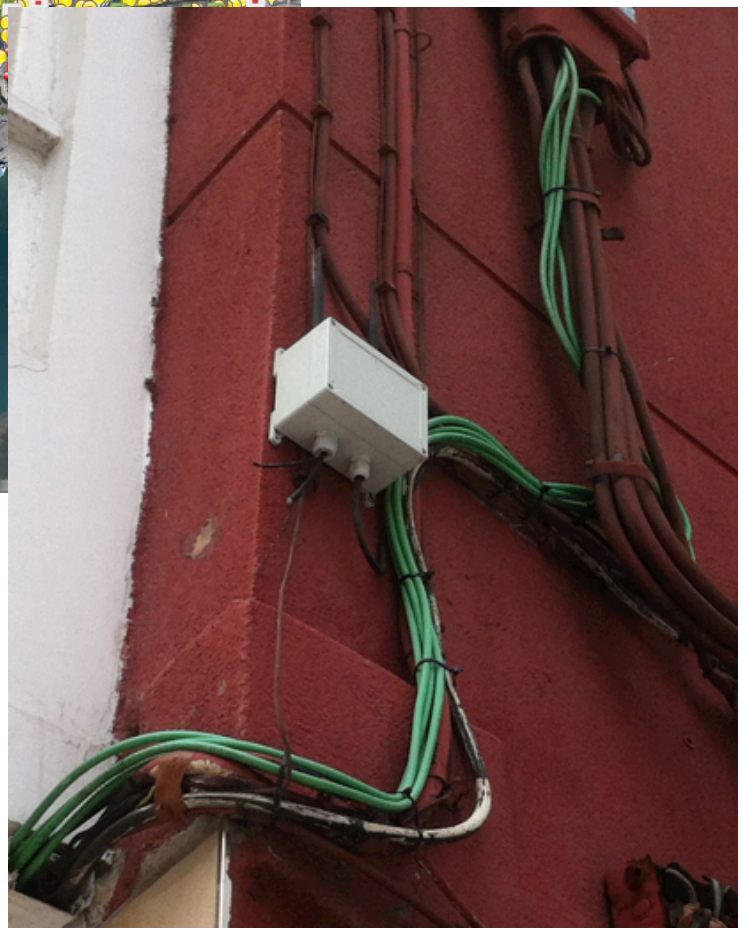
www.smartsantander.eu



SmartSantander nodes



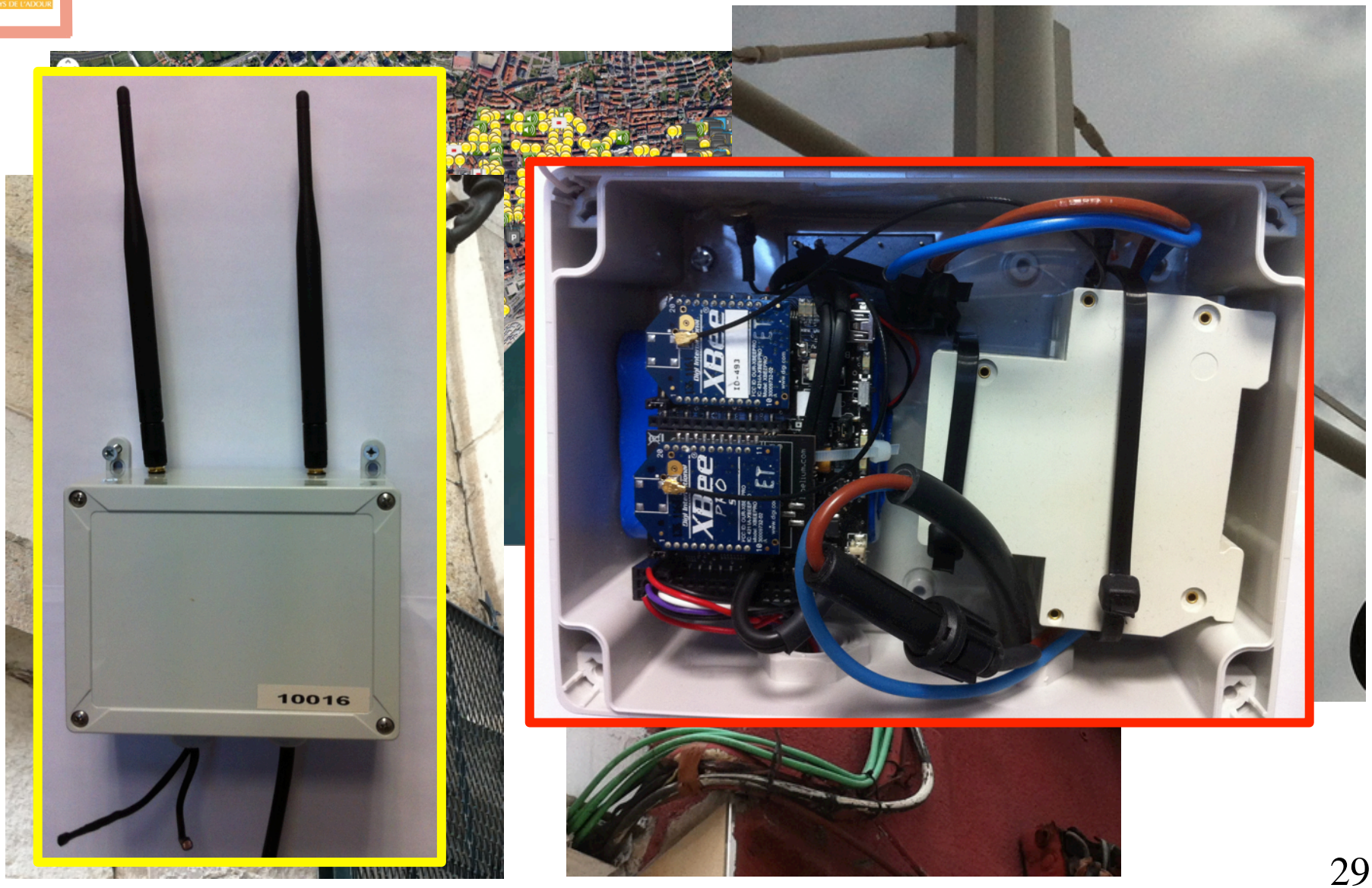




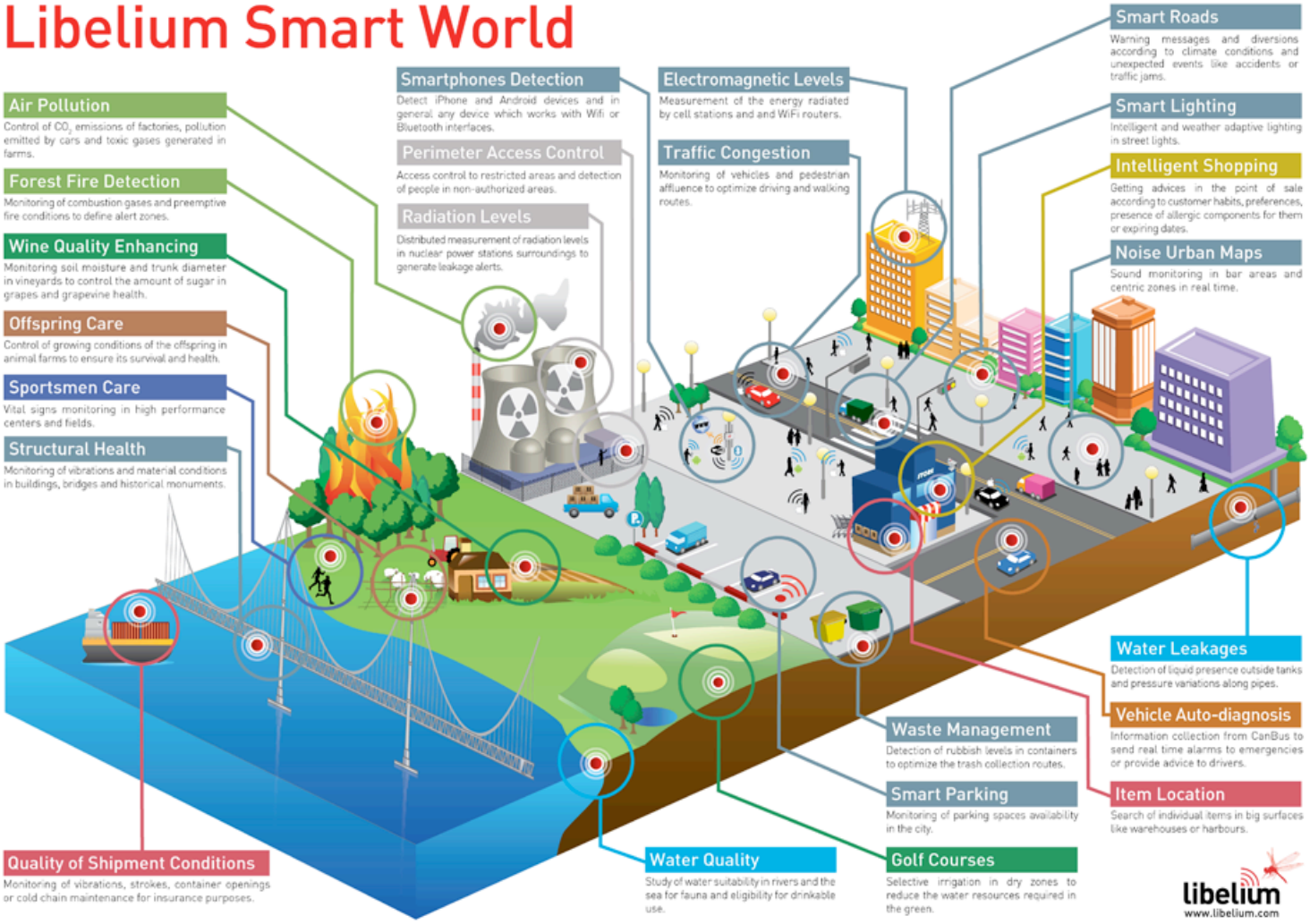
SmartSantander nodes



SmartSantander nodes



Smart Cities



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

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

















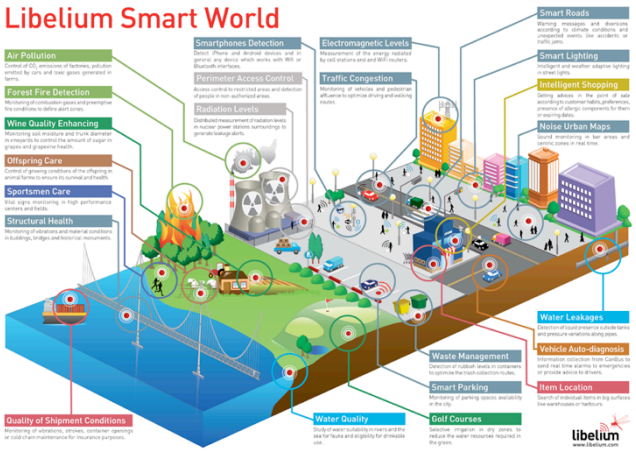
- Passive communication







A BUSINESS MODEL IN SMARTCITIES





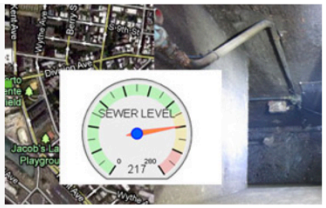
KEEP STREETS CLEAN

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



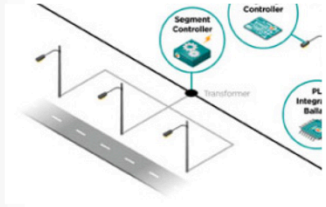
RECEIVE POLLUTION WARNINGS

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/

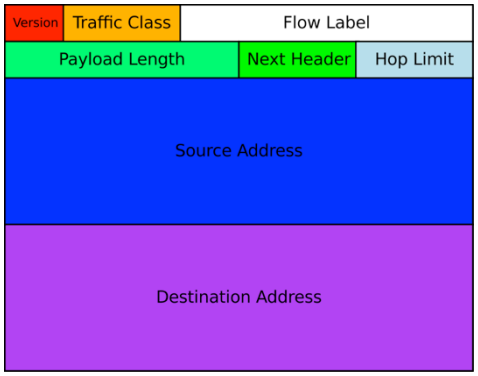
From « ad-hoc » protocols to « standards »



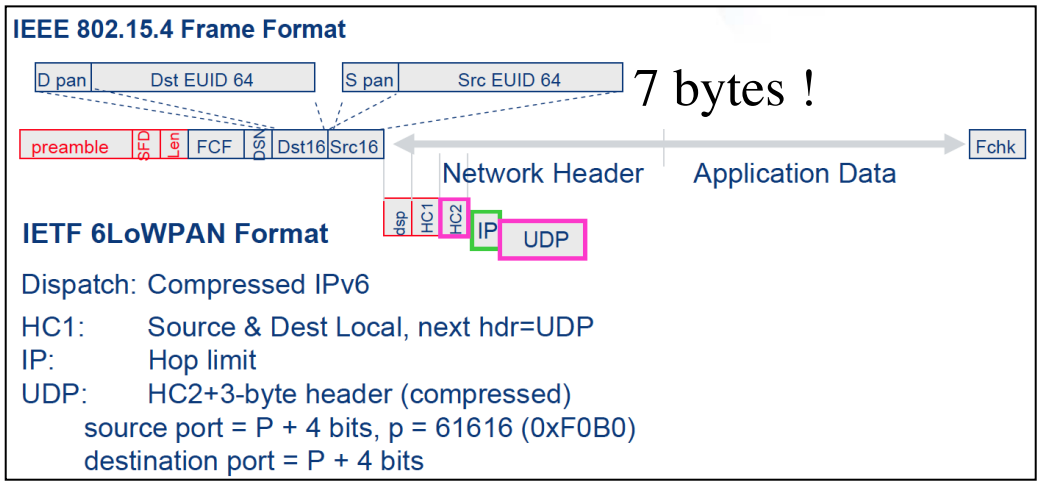


Internet of Things: IoT

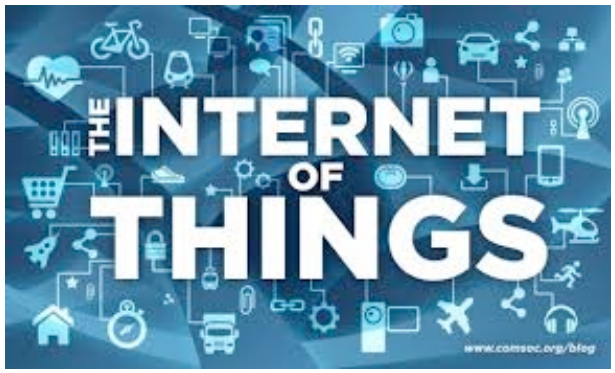
- IPv4 has no more addresses!
- IPv6 gives plenty of addresses
  - 128bit address=16bytes!
- 6LowPAN adapts IPv6 to resource-constrained devices
  - Compressed IPv6 header



40 bytes



6LowPan protocol suite



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"

CoAP
Constrained Application Protocol

RPL
Routing Protocol for LLN
LLN: Low power & Lossy Networks

6LowPan
802.15.4

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

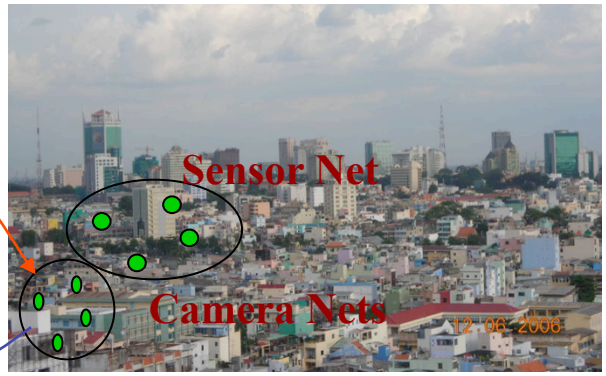
WHO IS CONCERNED?



Global Sensing Scenario



Activating



Intelligent Agent

Sending

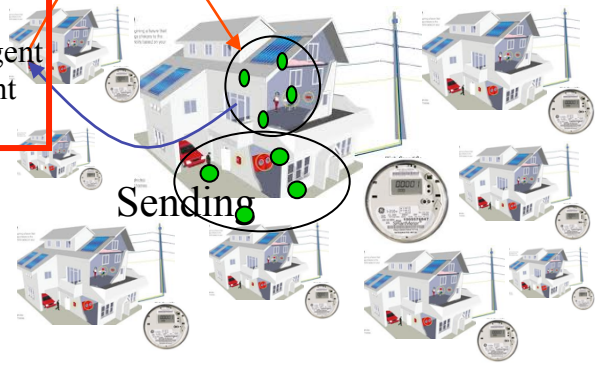




Activating

Intelligent Agent

Sending



Activating



Intelligent Agent

Sensor Net

Sending

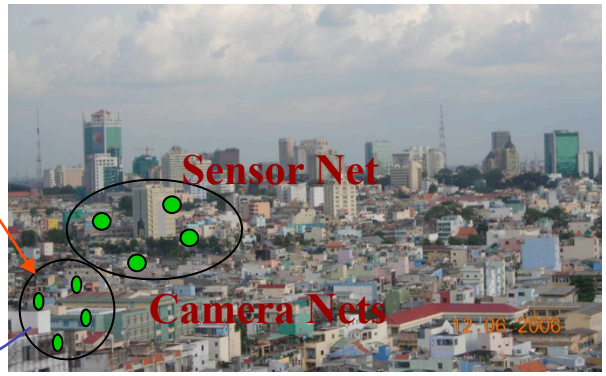


From network issues to big data issues!



Activating

Intelligent Agent





IBM

DELL

iCloud

amazon web services™

Dropbox

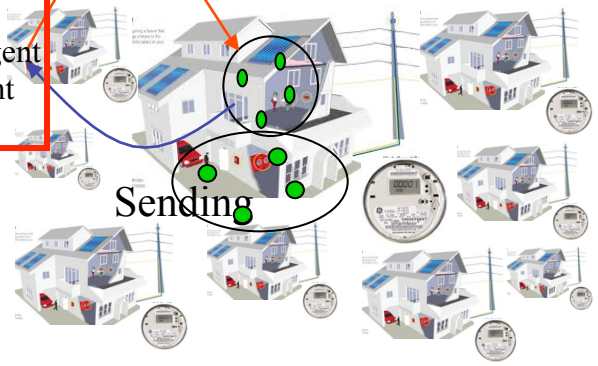
Google

mobile me

Windows Azure

Activating

Intelligent Agent



Sending



Activating

Intelligent Agent

Sensor Net

Sending



Control, optimize & Instrument









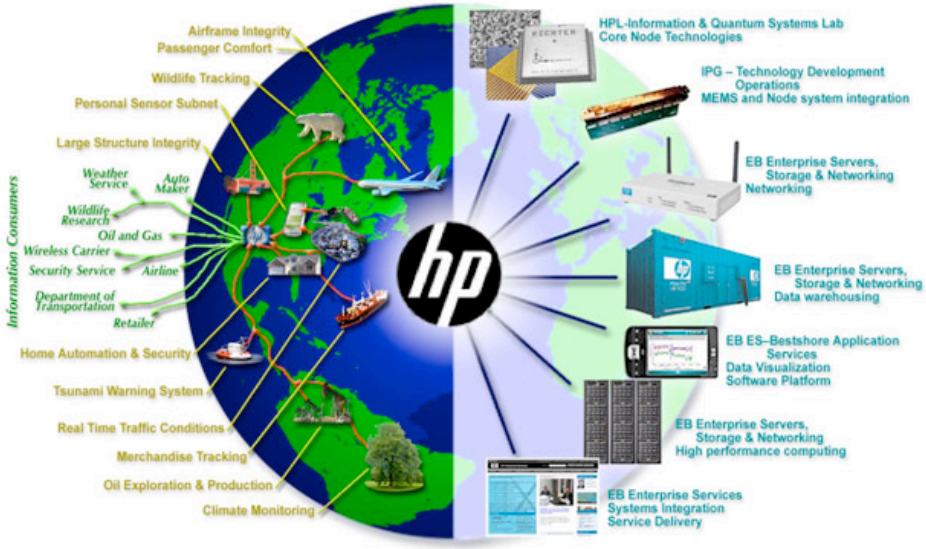
Pervasive Systems

Sensing

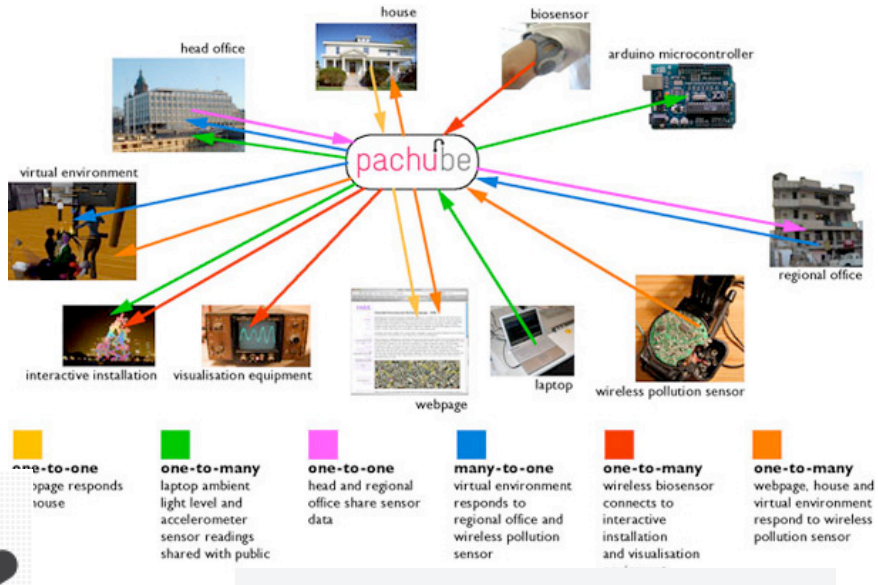
PEOPLES, INFRASTRUCTURES, BUILDINGS, VEHICULES

Big actors for big data

HP CeNSE



Pachube/Cosm



IBM Smarter Planet



cosm™ BETA
Connect to your world

http://readwrite.com/2010/12/15/top_10_internet_of_things_developments_of_2010

Opportunities for Telco operators & more...

Transmission rate

Roving Networks, a leading provider of wireless solutions announced the RN-XVee, its new ultra-low power, through hole 802.11 b/g module that is drop in compatible with existing 802.15.4 modules. 2011



UMTS, HDPA, LTE, LTE-A

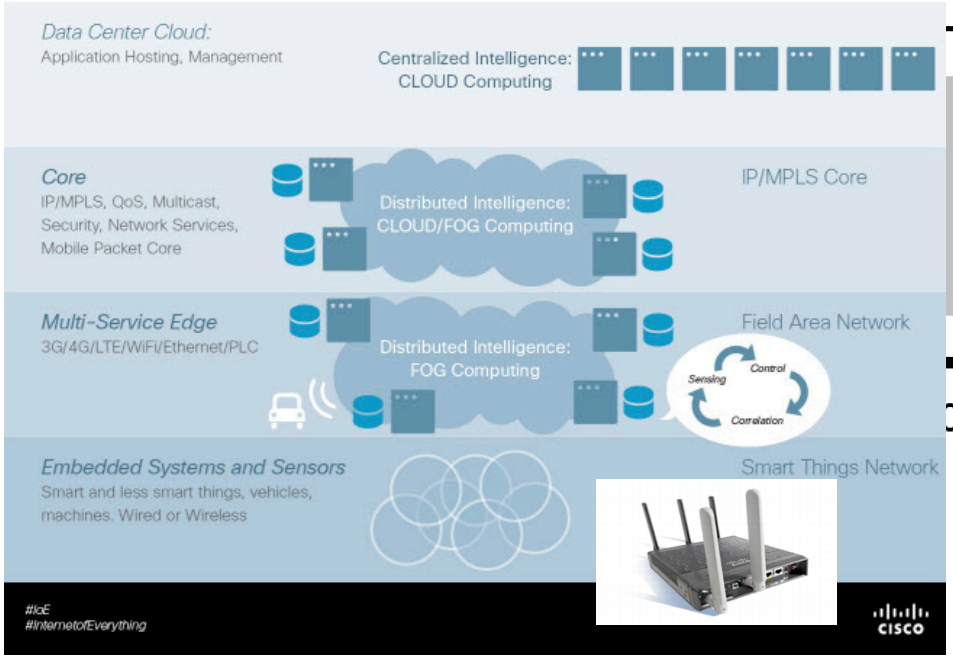


Opportunity for M2M

00 m 1 Km 10 Km

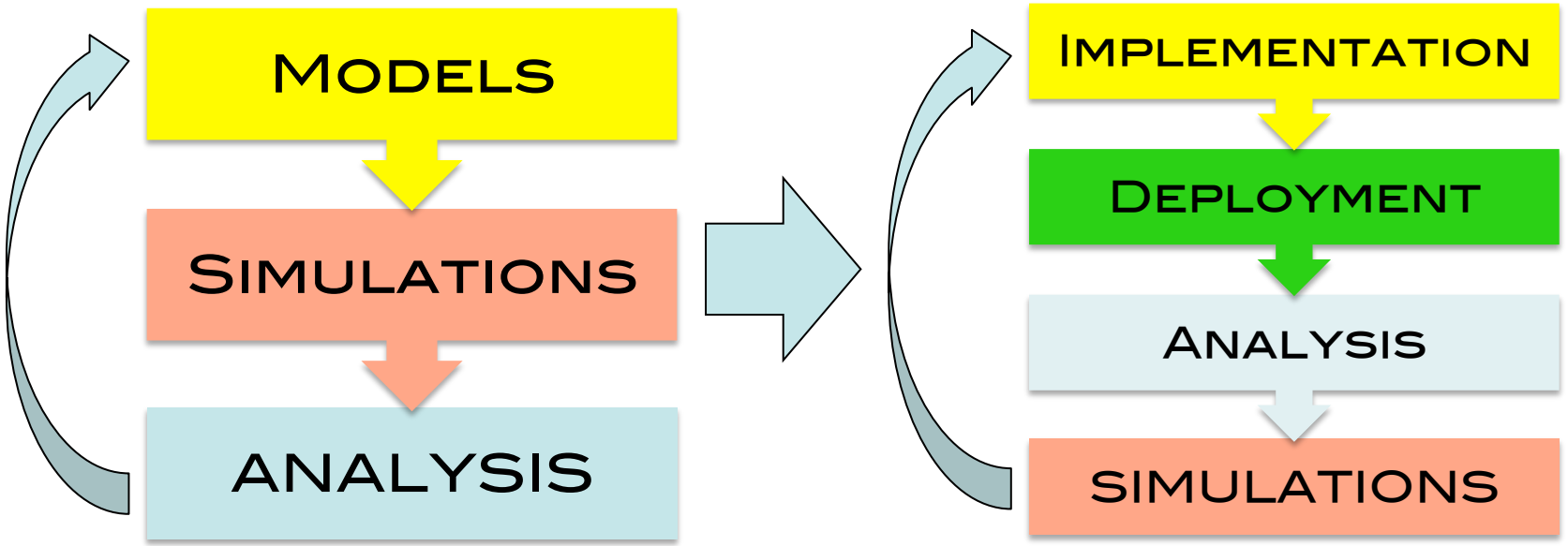
in SmartCities"

The "Common" Cisco IoT Platform Architecture General Functionality



Summary

- More than a decade of Wireless Sensor Networks
- Lot's of needs, lot's of expectations
- SmartCities are one of the economically viable app, more to come!

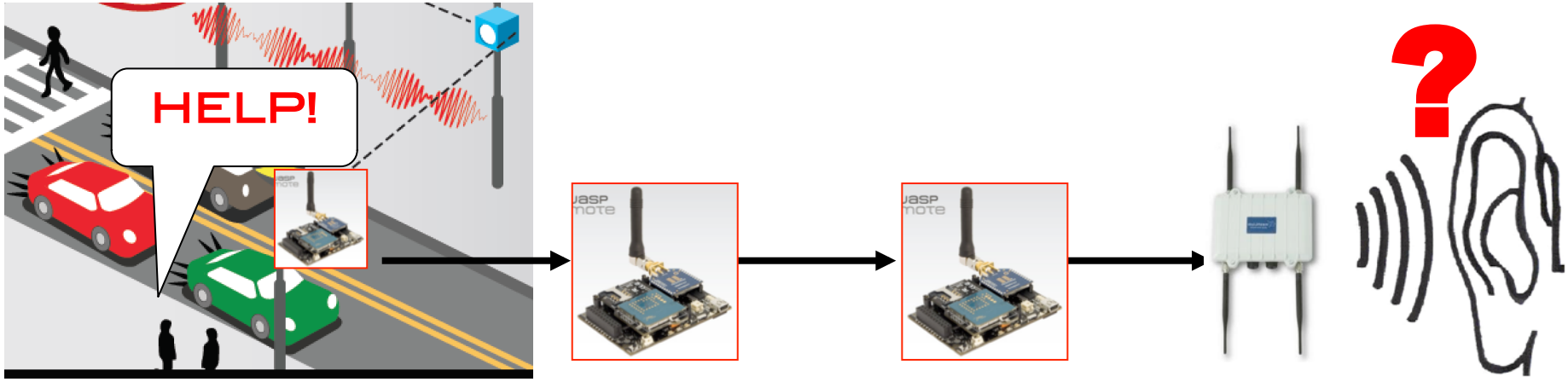


Some contributions « from theory to practice »

Search & Rescue, Situation awareness



EAR-IT: audio surveillance in SmartCities and SmartBuildings



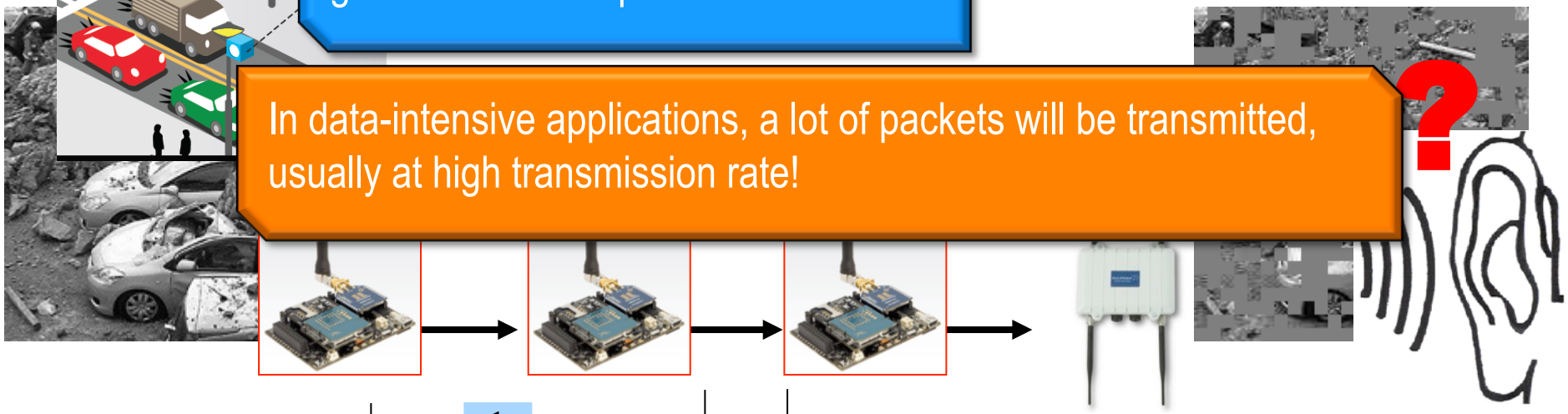


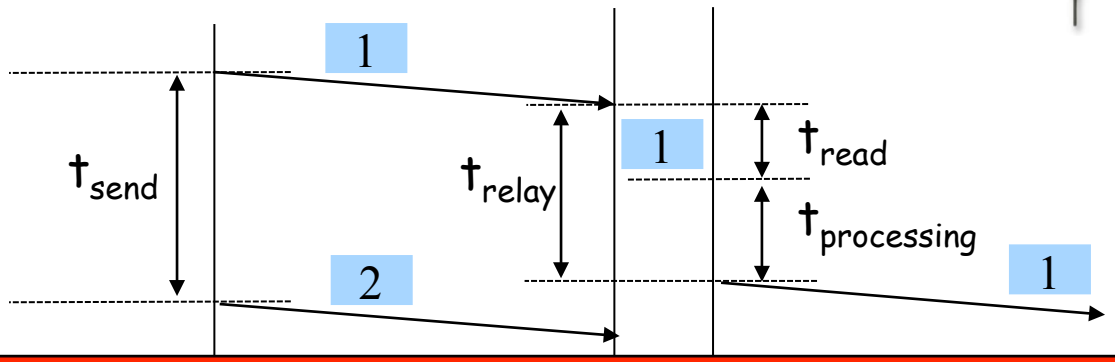
See http://www.ear-it.eu

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!





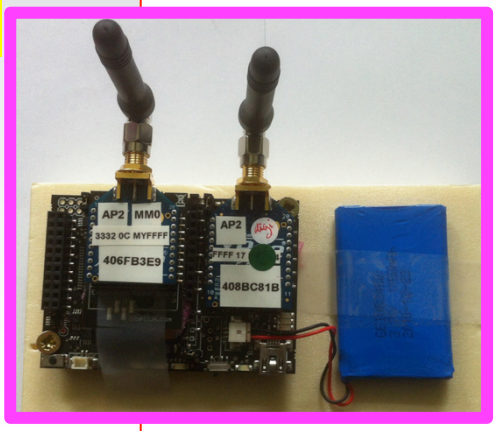
What level of performances can we expect?

Mass-market sensors

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

Cost:
~100€





Libelium WaspMote

Cost:
~80€



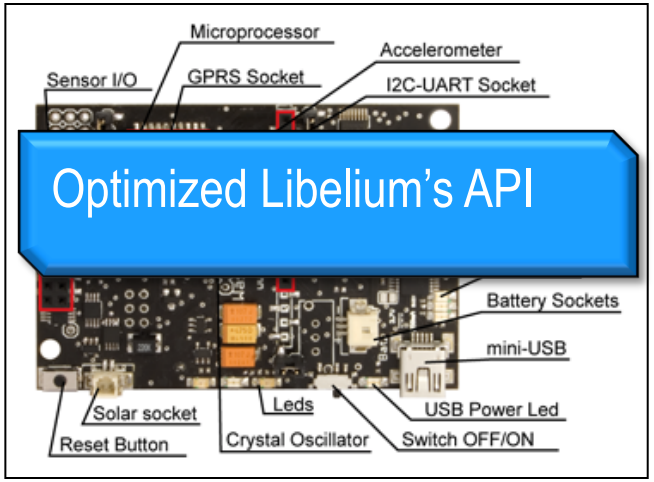
Arduino Mega2560

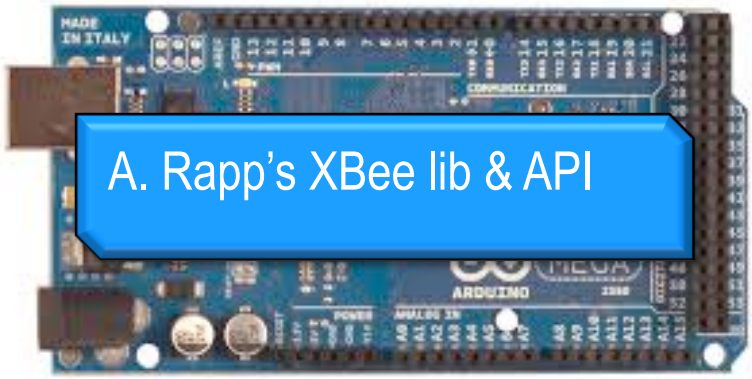
16MHz Atmega1281
8kB SRAM, 128kB Flash
Xbee radio



Sensor's HW&SW

Libelium WaspMote



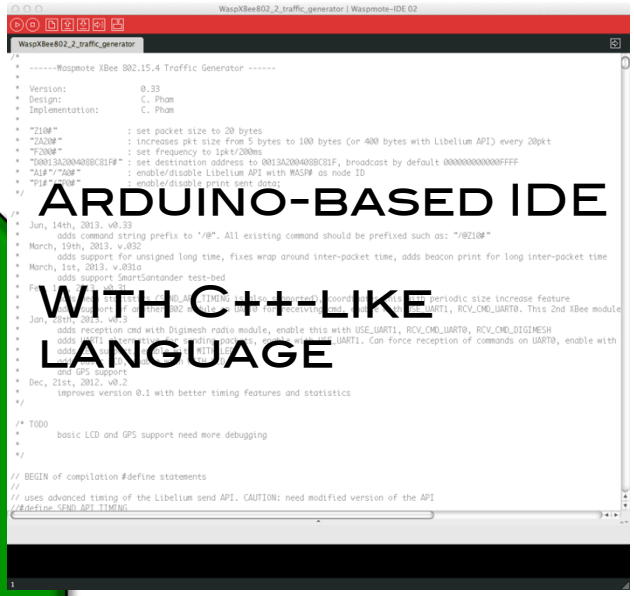


Arduino Mega2560

UART-based connection to micro-controller

Default speed is usually 38400 bauds

Higher baud rate are possible but…

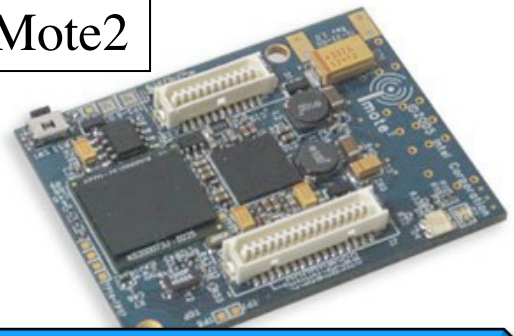




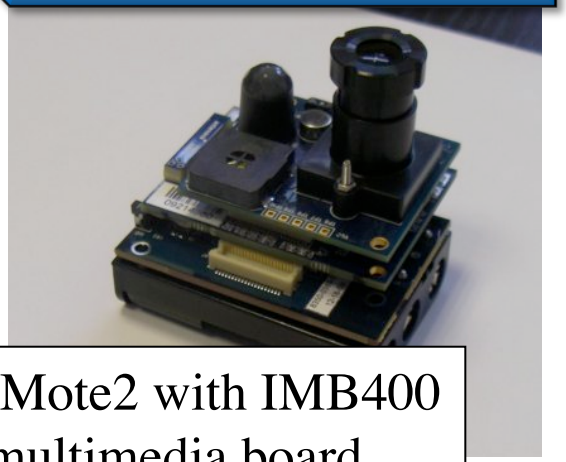
XBee 802.15.4

« Academic » sensors

iMote2



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



iMote2 with IMB400
multimedia board



MICAz

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



AdvanticSys CM5000 & CM3000
TelosB-like mote

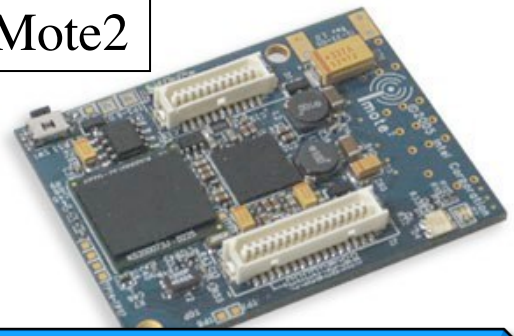


TelosB

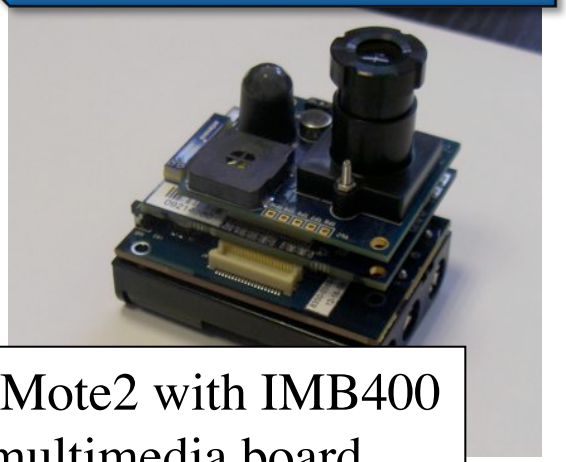
8Mhz MSP430F1611
10K SRAM, 48K flash
CC2420 radio

« Academic » sensors

iMote2



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



iMote2 with IMB400
multimedia board



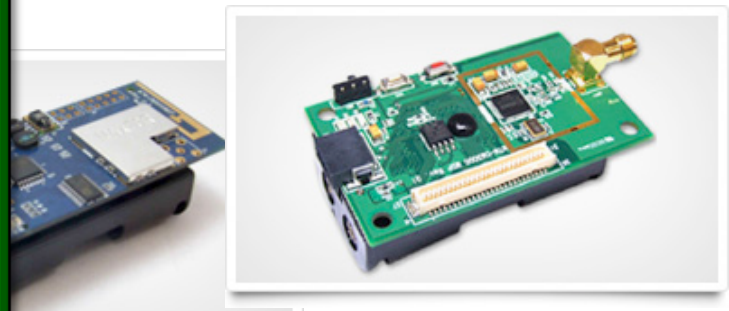
8MHz Atmega128L
4kB SRAM, 128kB Flash
CC2420 radio

Radio module
CC2420 is
connected
through SPI bus

SPI speed is in
the order of
several
hundredth kbps



TelosB

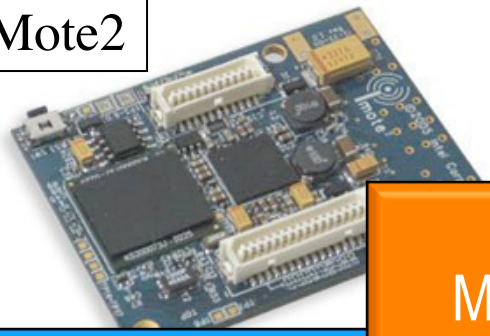


AdvanticSys CM5000 & CM3000
TelosB-like mote

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

« Academic » sensors

iMote2



8MHz Atmega128L
4kB SRAM, 128kB Flash
[illegible]420 radio

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

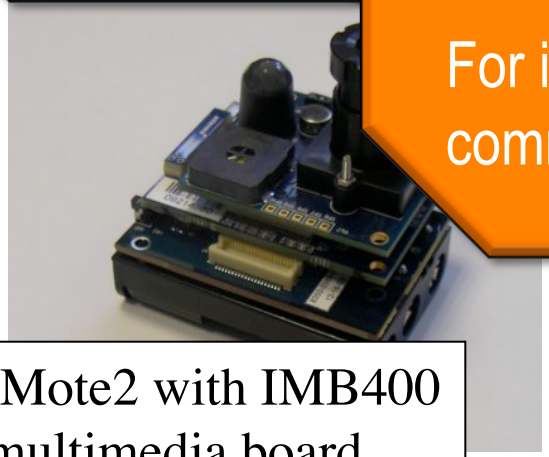
Motes are programmed under the TinyOS operating system & lib

For MicaZ and TelosB we use TKN154 communication stack

For iMote2 we use IEEE154 communication stack



s CM5000 & CM3000
mote



iMote2 with IMB400
multimedia board



TelosB

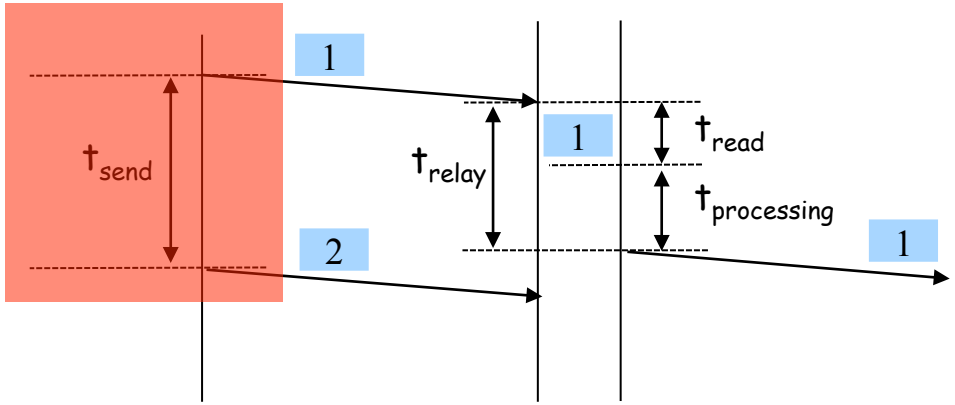
8Mhz MSP430F1611
10K SRAM, 48K flash
CC2420 radio

Communication performances

- Application level performances depends on OS, API, hardware architecture
- Usually much lower than radio performances
- What are minimum 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.

Sending performances



Traffic Generator

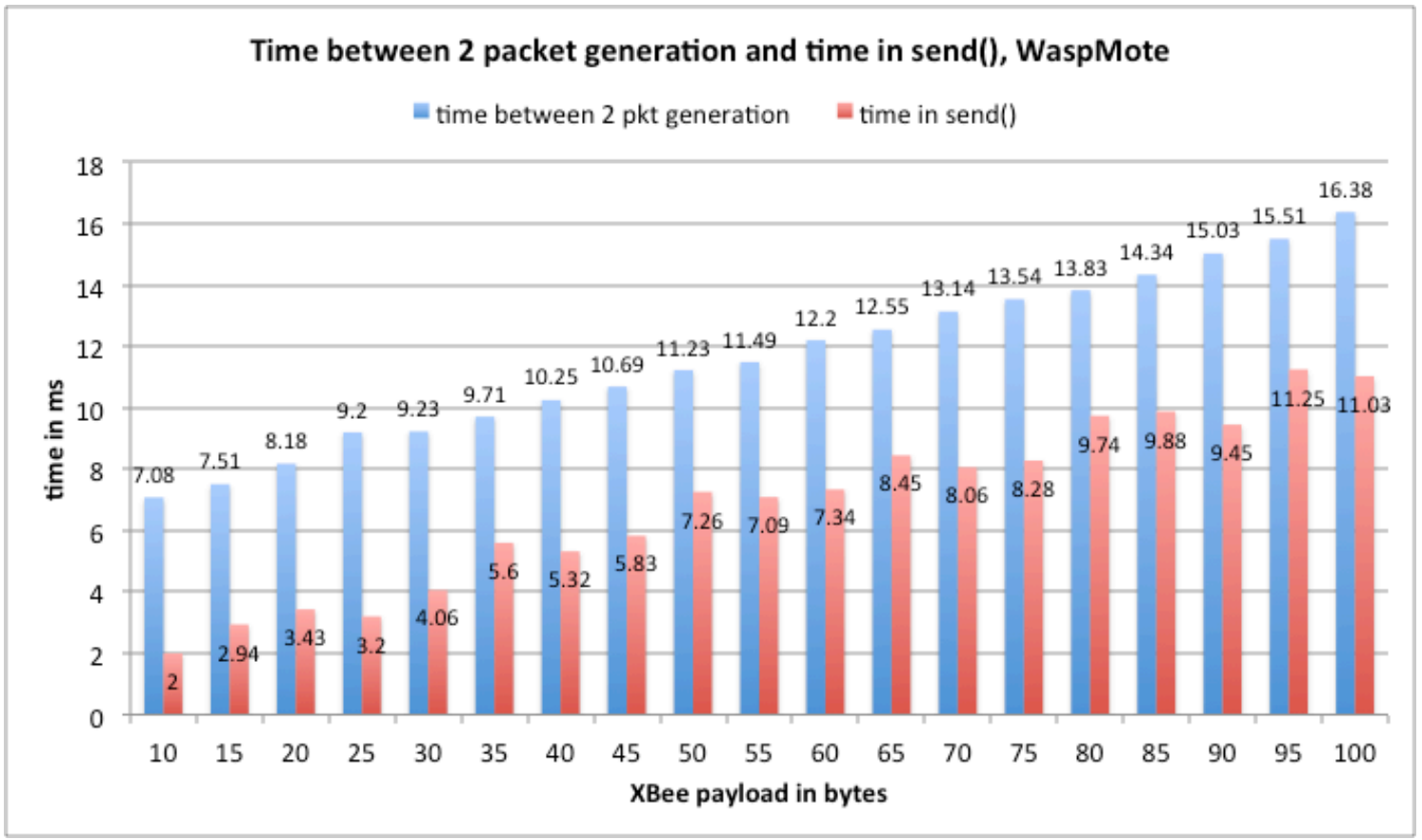
```
void loop() {
        T0;
        L0=T0;
        ...
        T1;
        send(buf);
        T2;
        ...
}
```

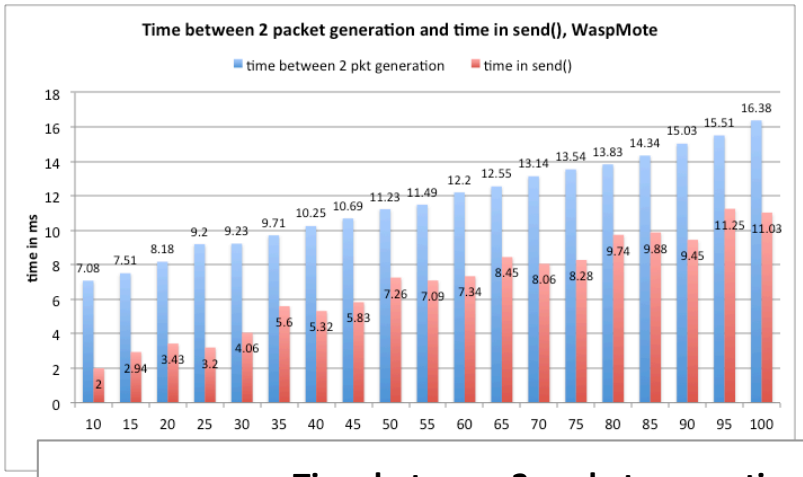
« Time in send() » is T2-T1
« Time between 2 pkt generation » is T0-L0
Time resolution is millisecond
Minimum data manipulation

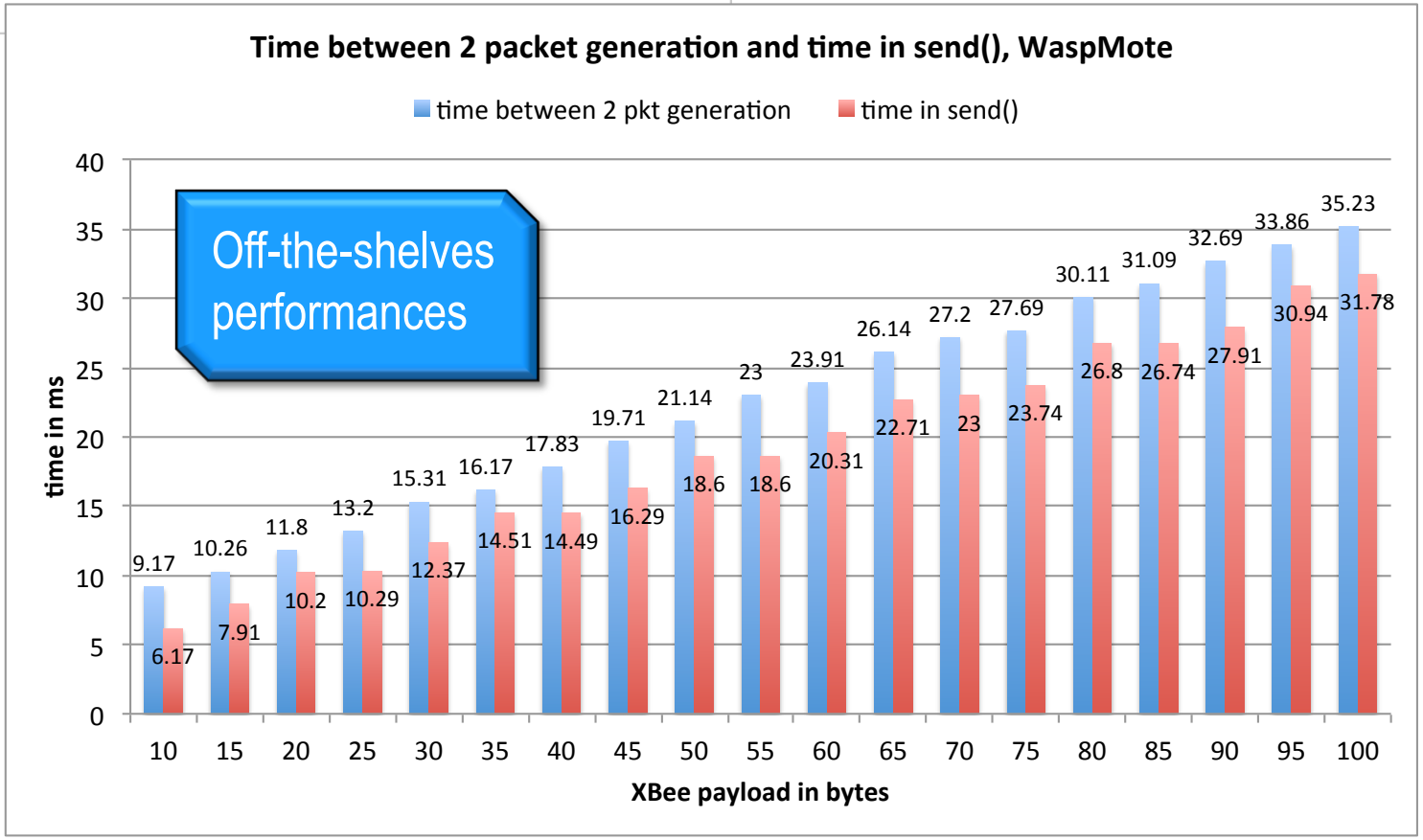
Measure the time in various part of API `send()` when possible.

Sending performances

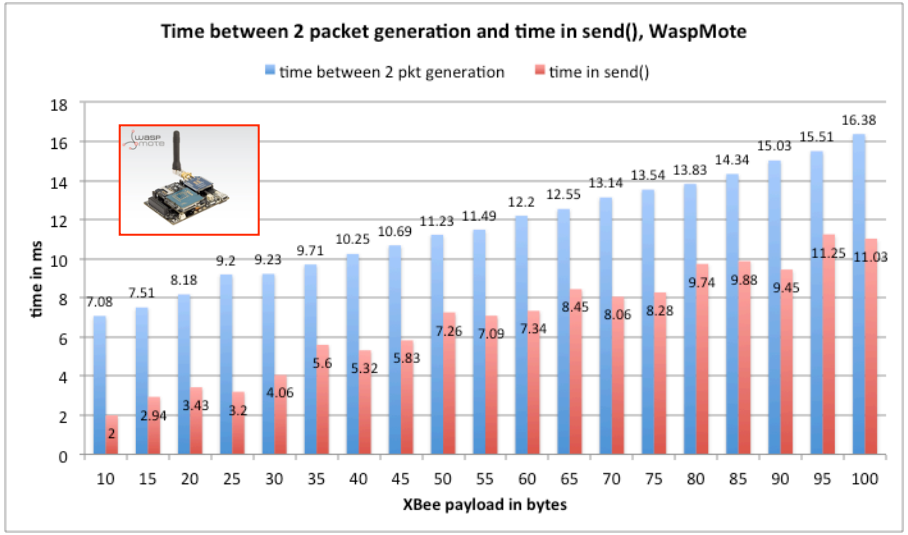


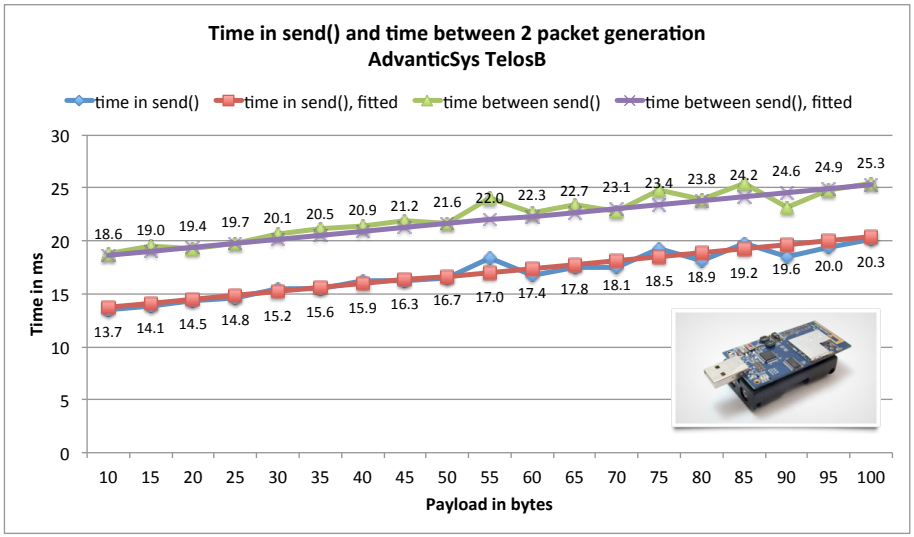


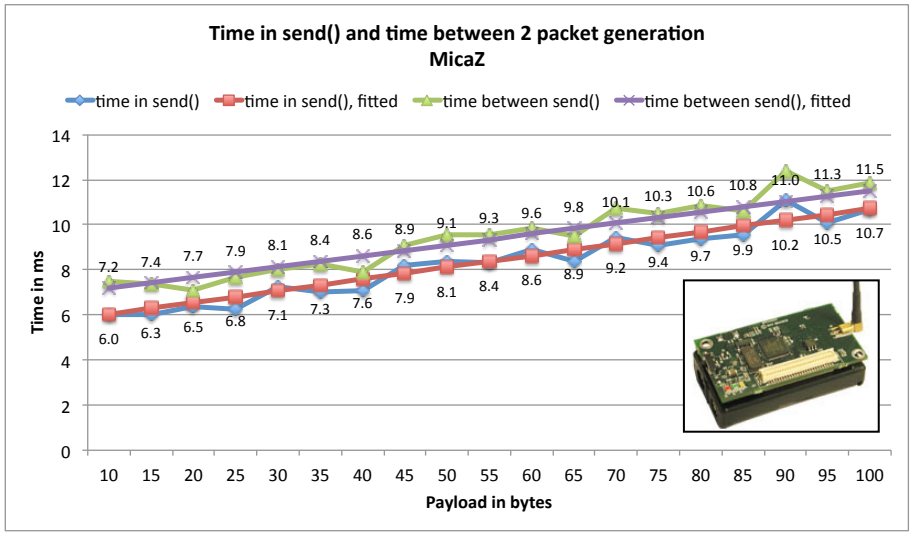

Time between 2 packet generation and time in send(), WaspMote
time between 2 pkt generation
time in send()
time in ms
7.08 2
7.51 2.94
8.18 3.43
9.2 3.2
9.23 4.06
9.71 5.6
10.25 5.32
10.69 5.83
11.23 7.26
11.49 7.09
12.2 7.34
12.55 8.45
13.14 8.06
13.54 8.28
13.83 9.74
14.34 9.88
15.03 9.45
15.51 11.25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

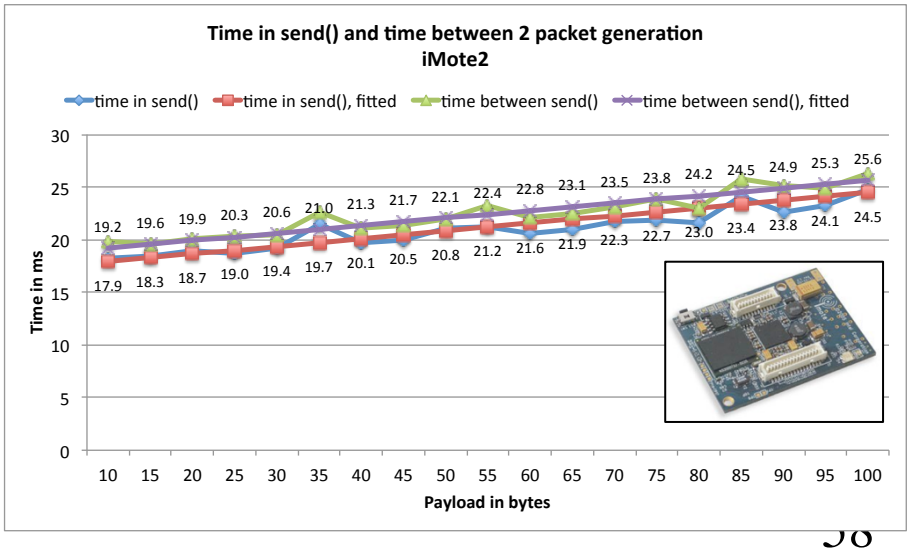

Time between 2 packet generation and time in send(), WaspMote
time between 2 pkt generation
time in send()
Off-the-shelves performances
time in ms
9.17 6.17
10.26 7.91
11.8 10.2
13.2 10.29
15.31 12.37
16.17 14.51
17.83 14.49
19.71 16.29
21.14 18.6
23 18.6
23.91 20.31
26.14 22.71
27.2 23
27.69 23.74
30.11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

Sending performances: comparison

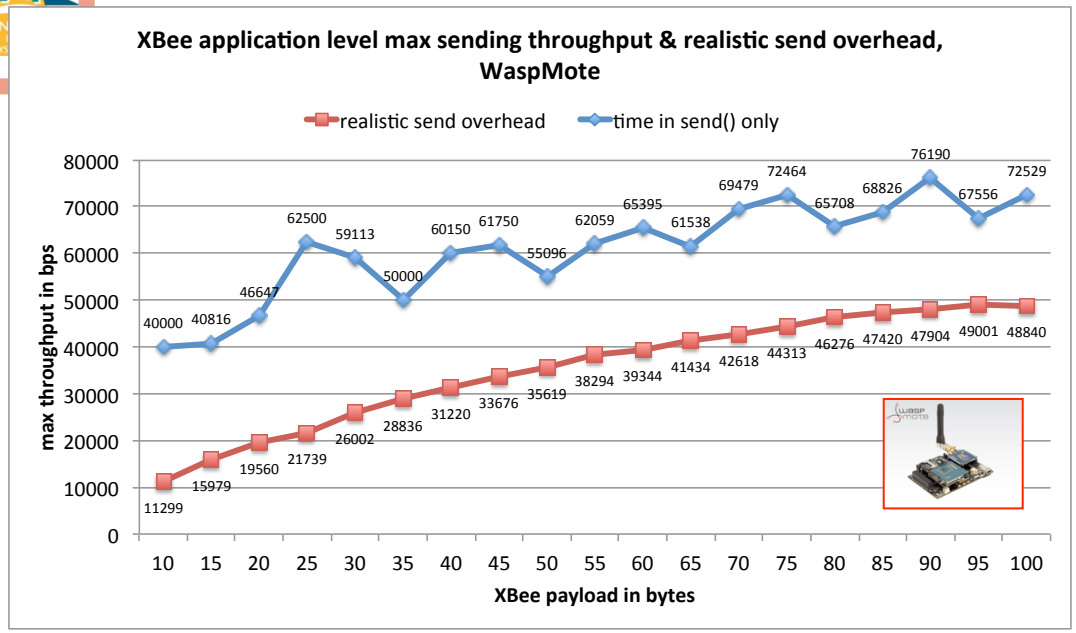




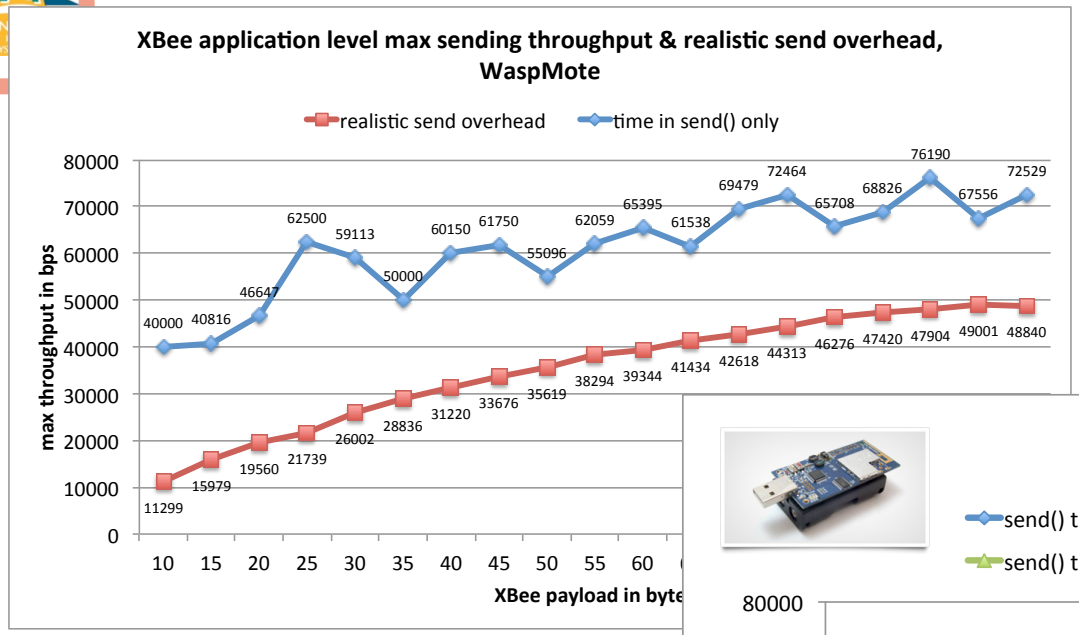


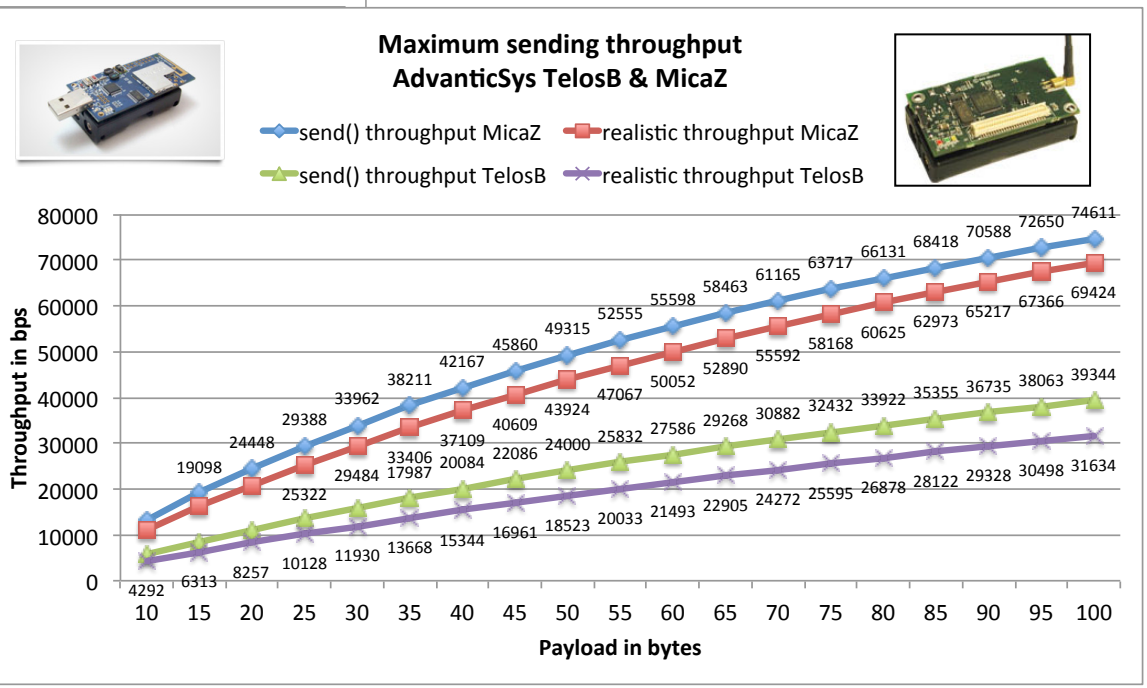


Maximum sending throughput

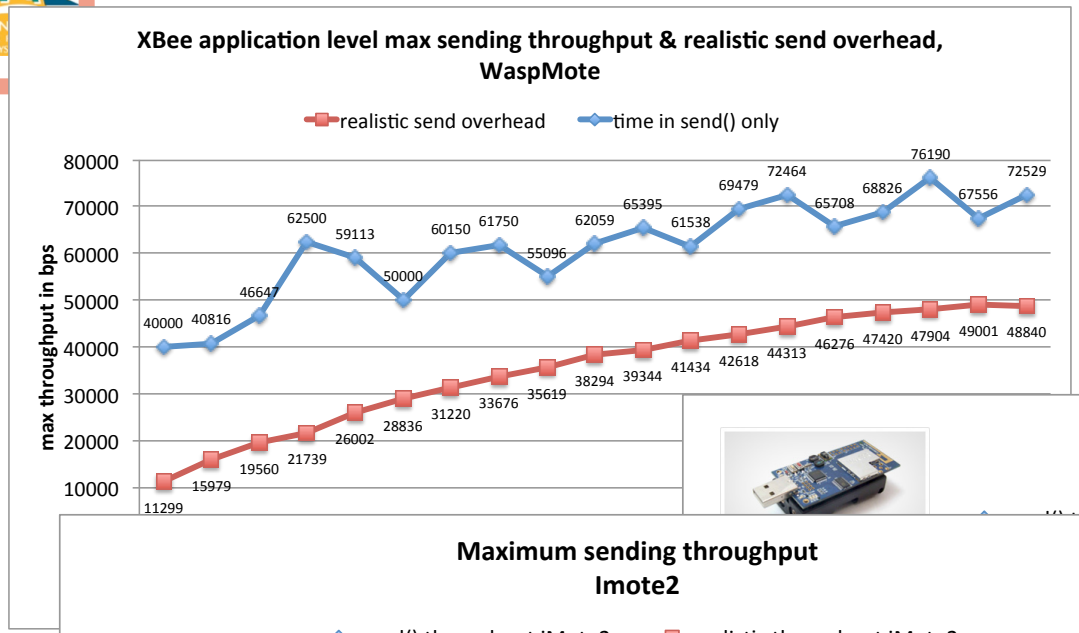


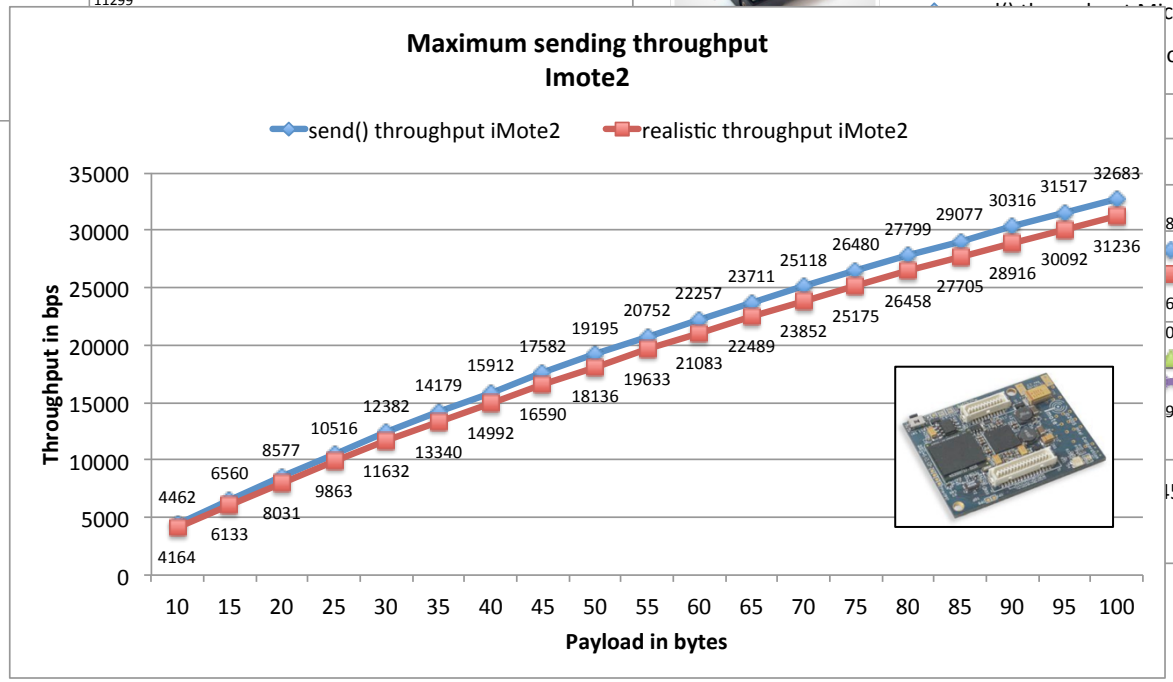
Maximum sending throughput

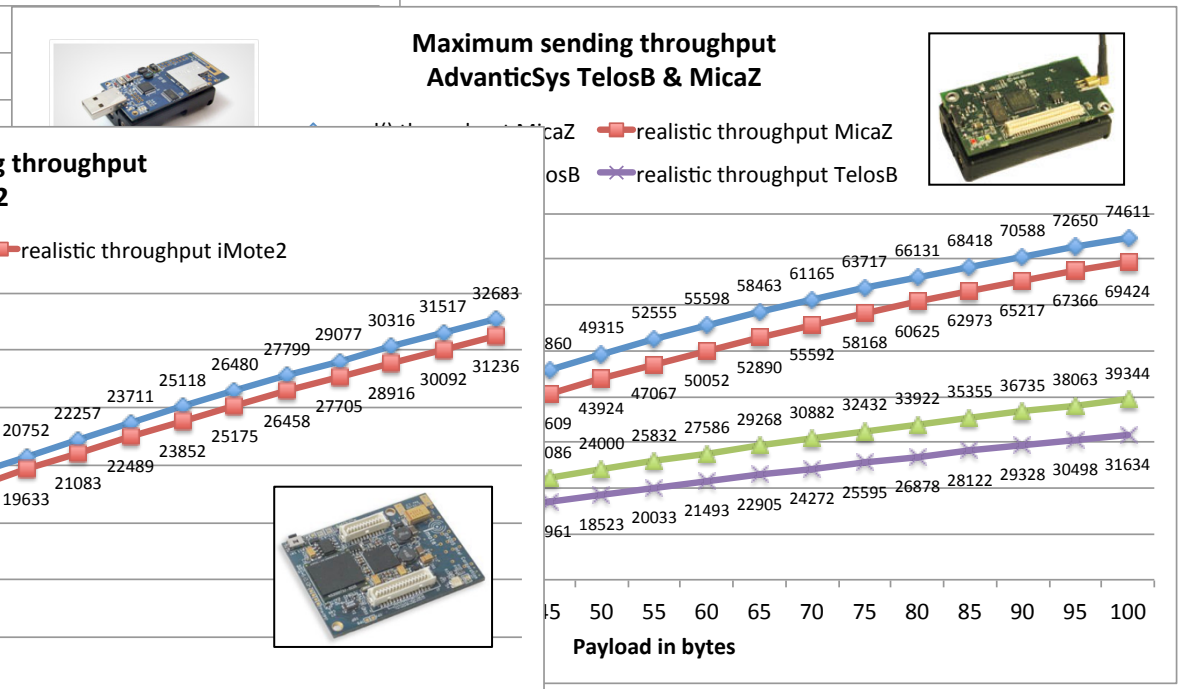




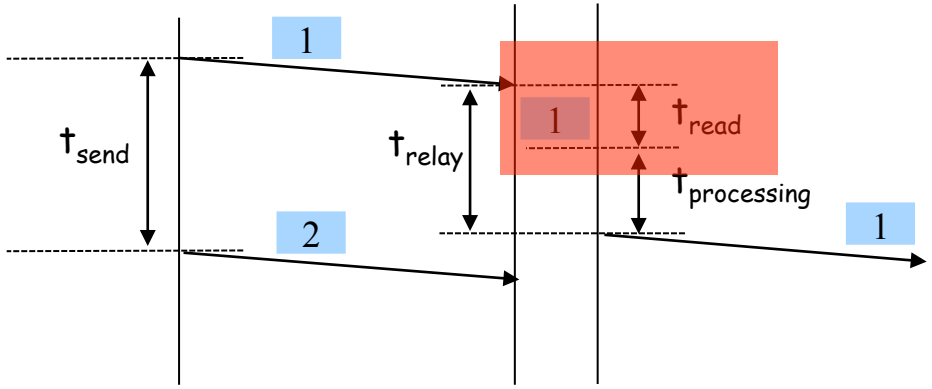
Maximum sending throughput





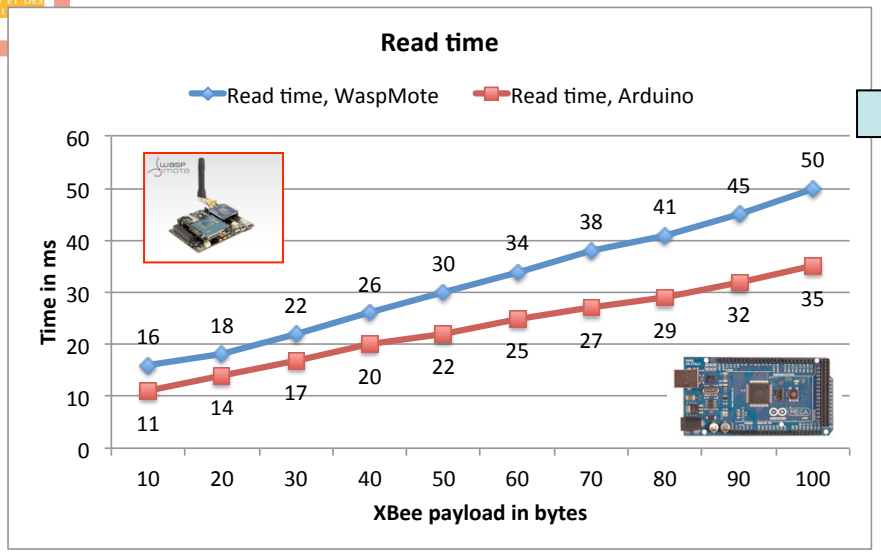


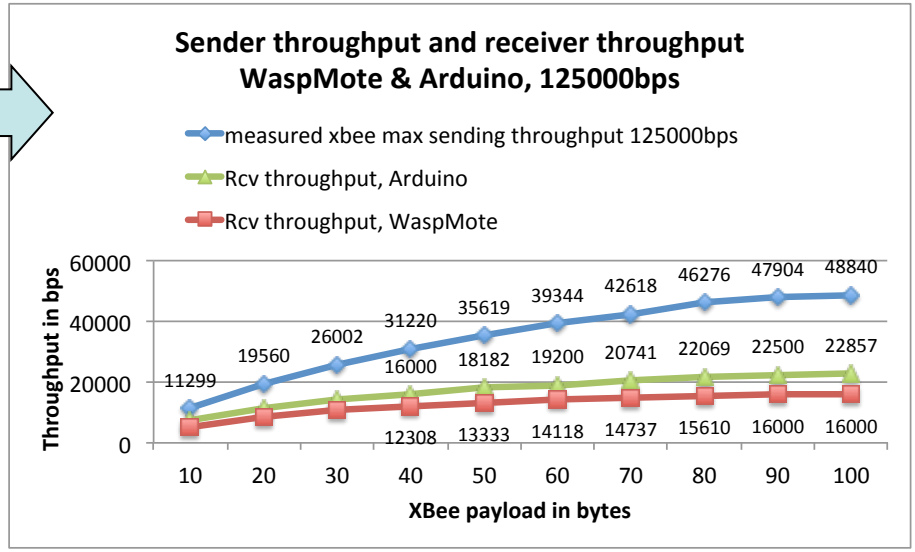
Receive performances

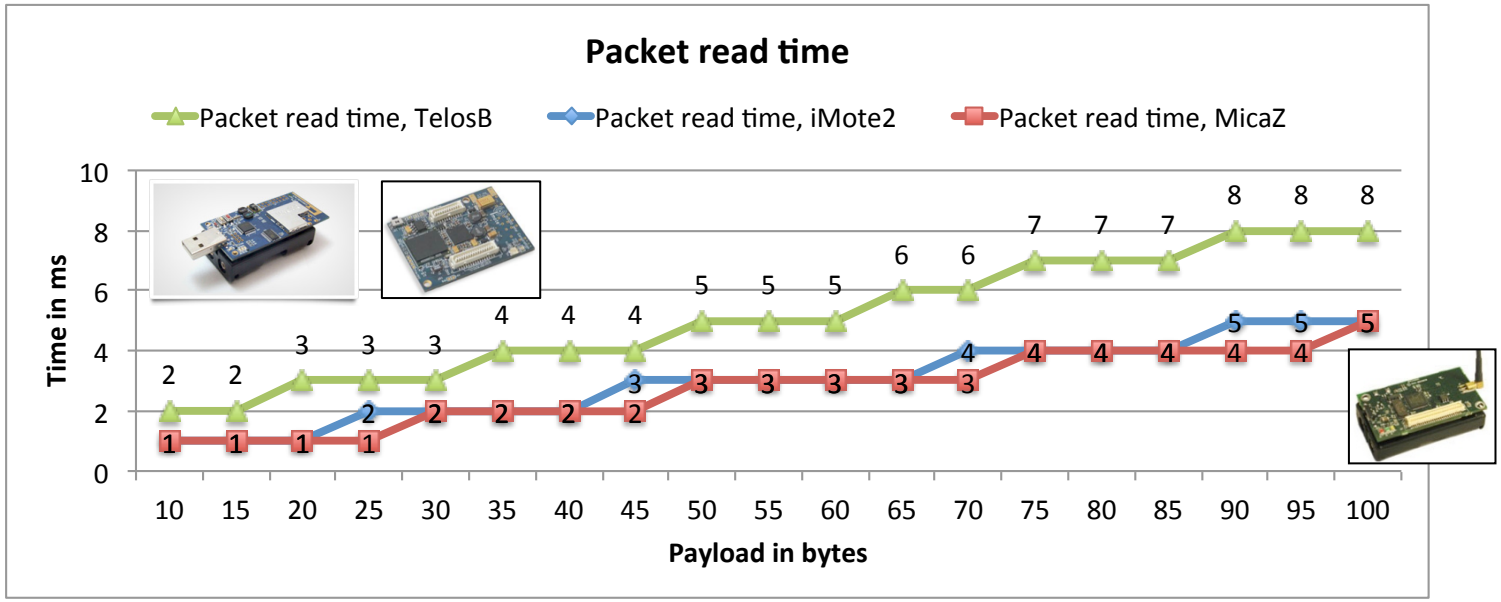


- At sender side, send as fast as possible
- At receiver side, determine T_{READ}
- … And also compute the maximum receive throughput per packet size

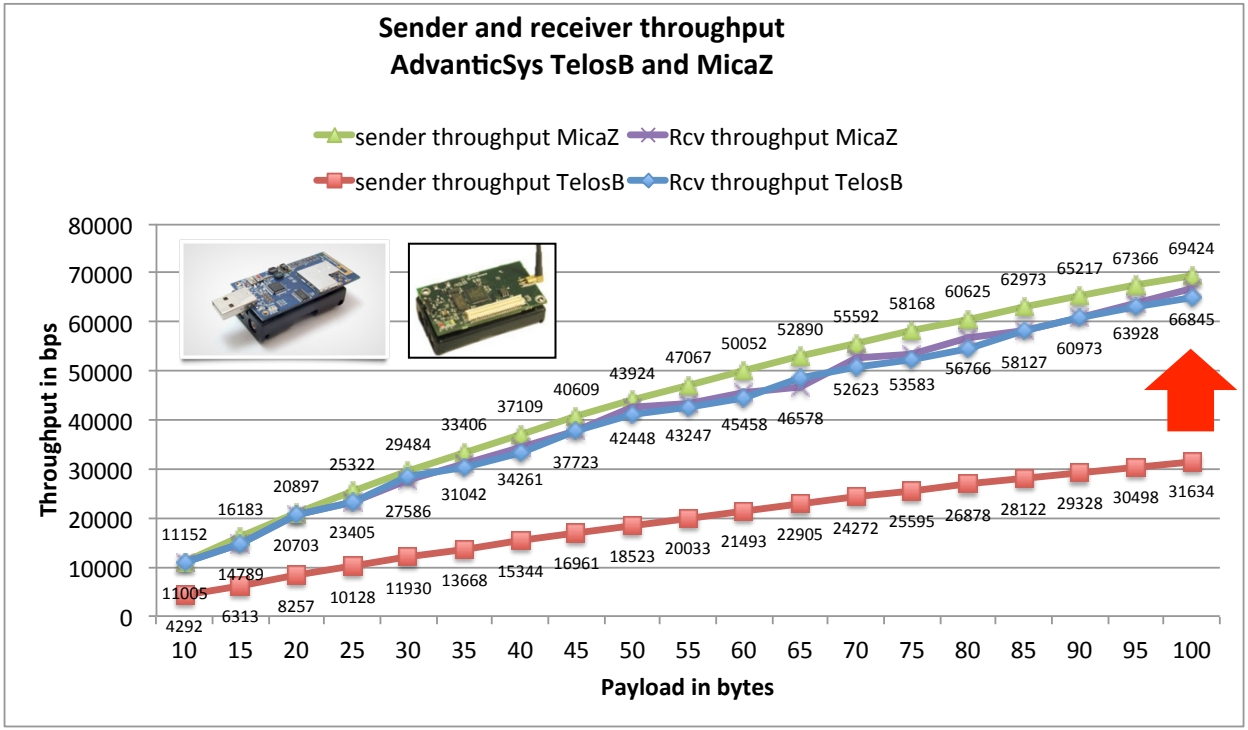
TREAD FOR VARIOUS MOTES



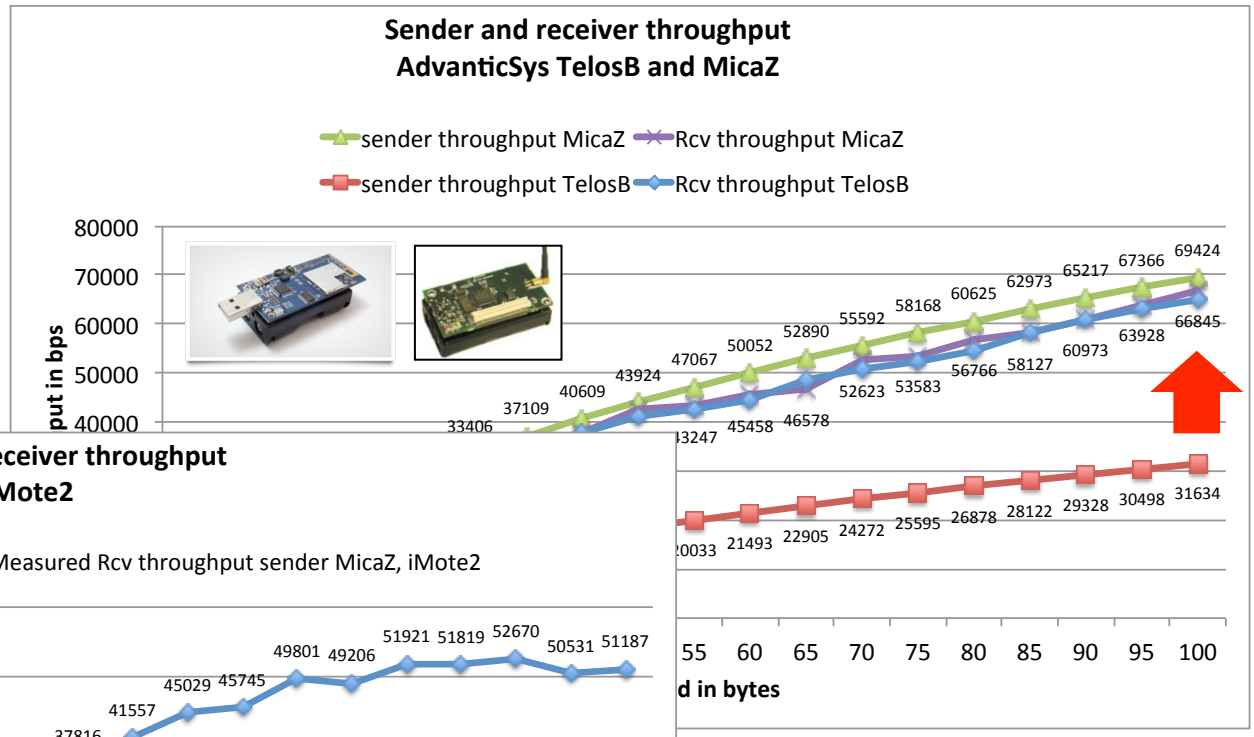


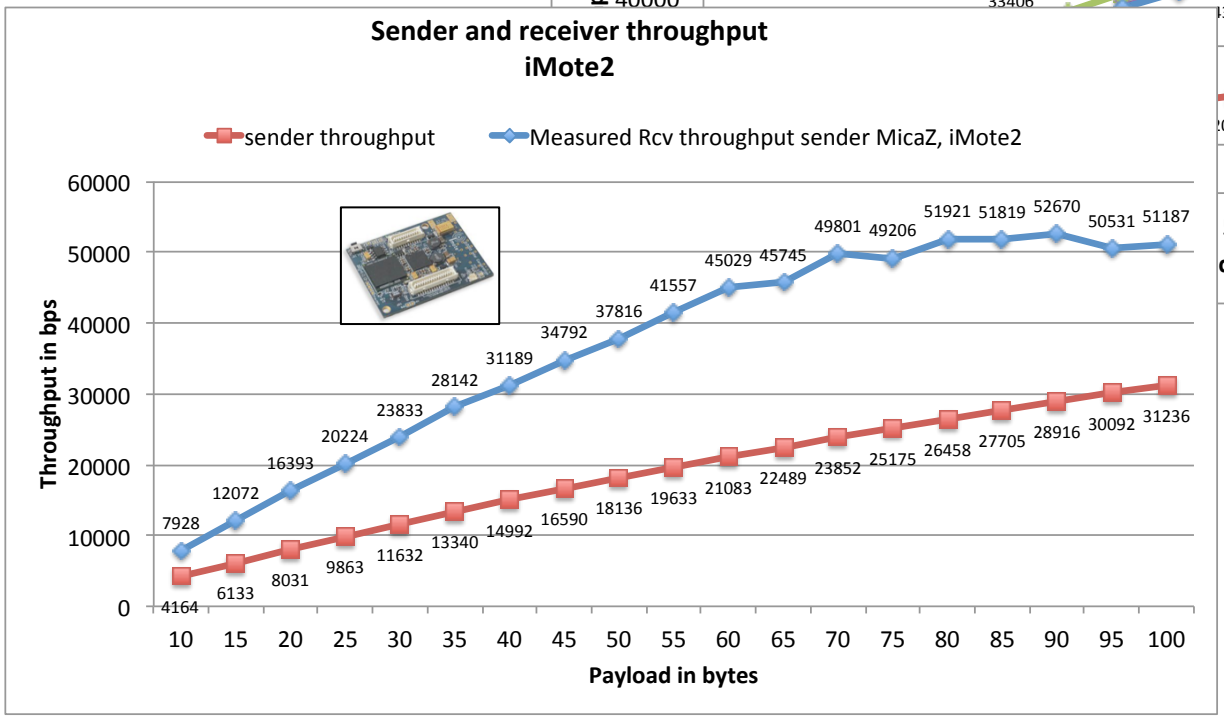


Receiver throughput

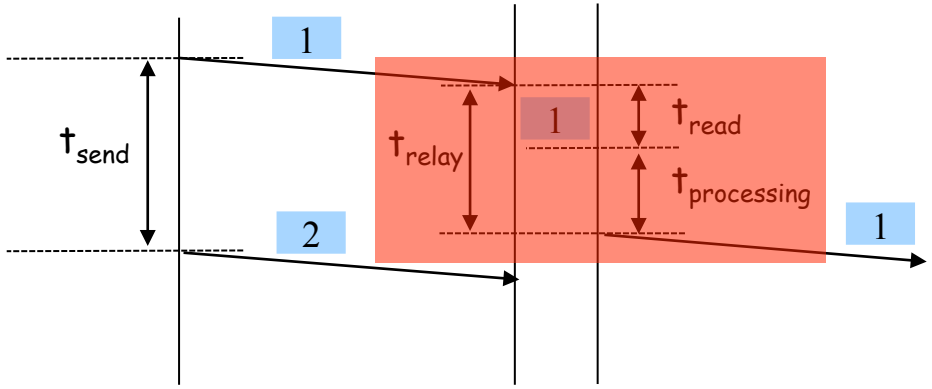


Receiver throughput



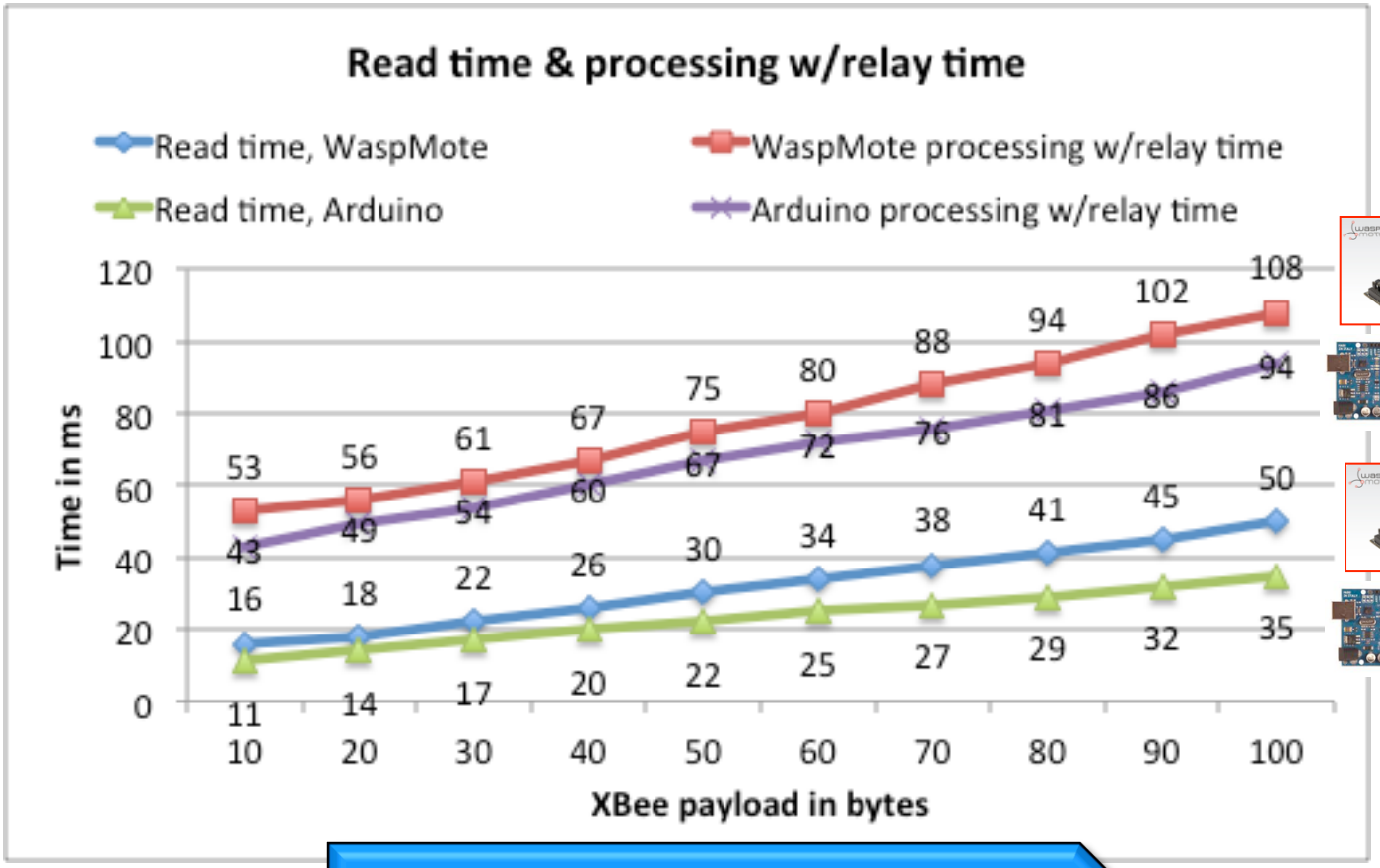


Relay performances



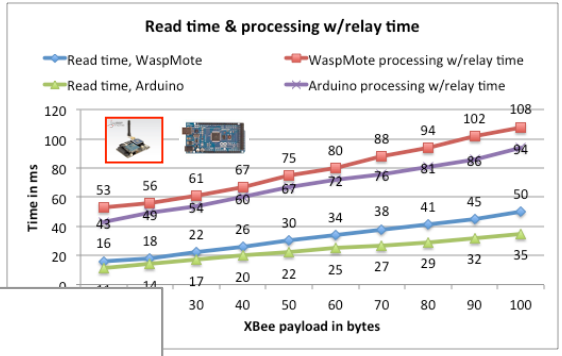
- Relaying are usually done at application-level (even OS level is considered app-level for the mote)
- Relaying means:
  - Read the packet in memory
  - Send the packet to next hop

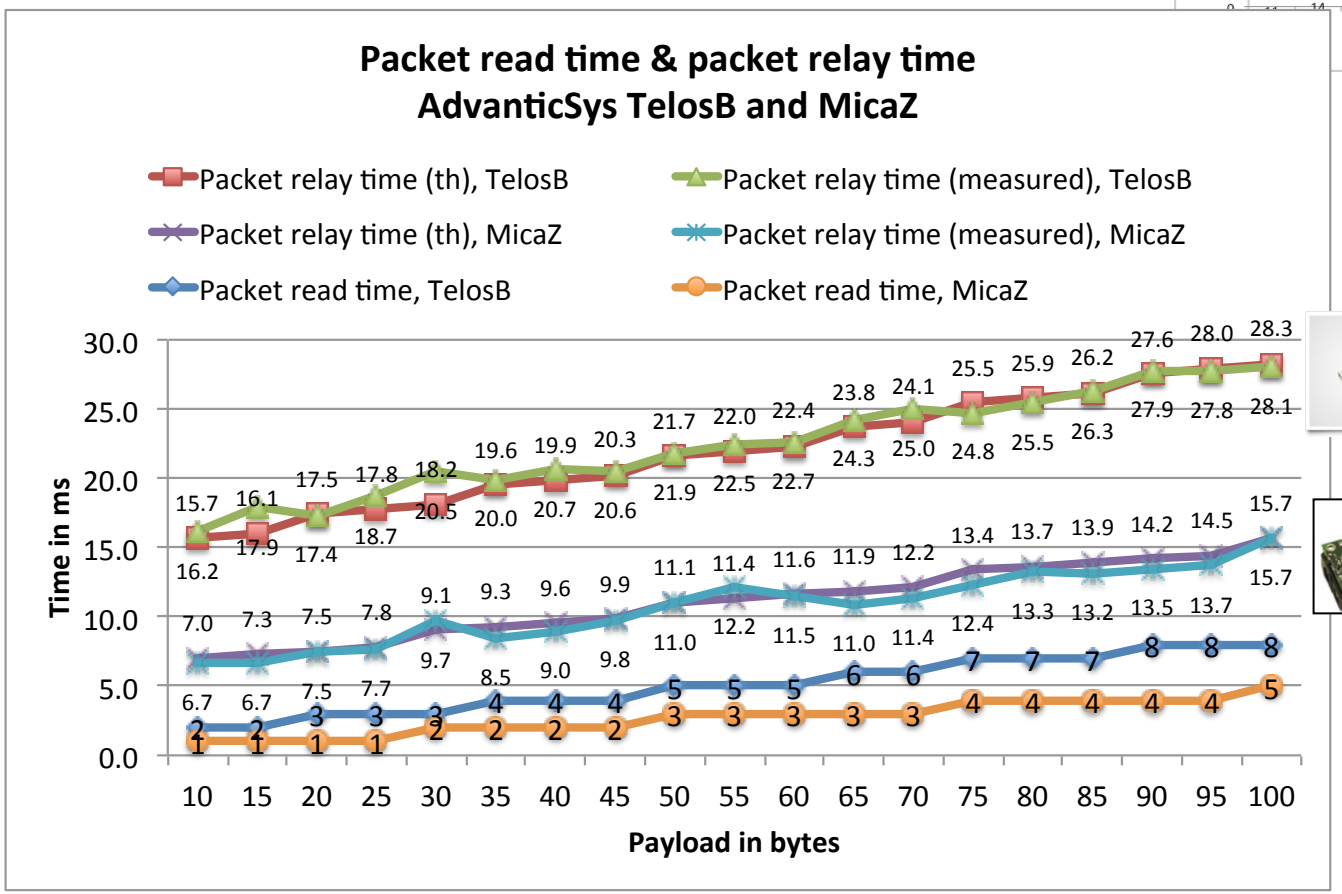
Read time and relay time



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

Read time and relay time

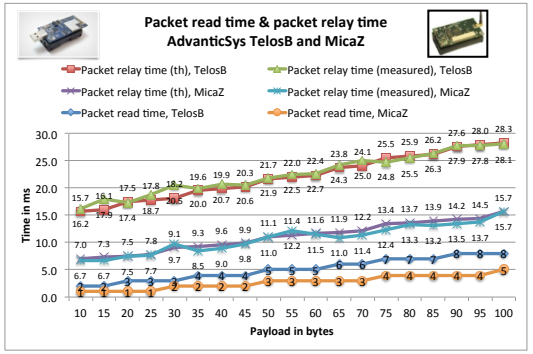


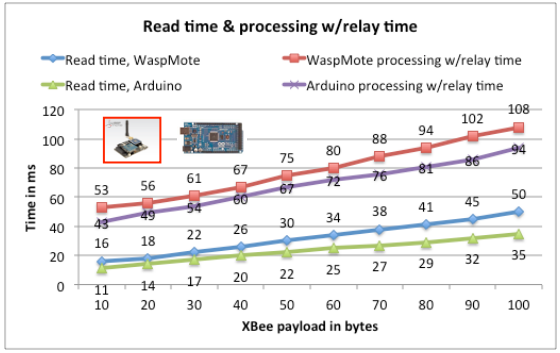


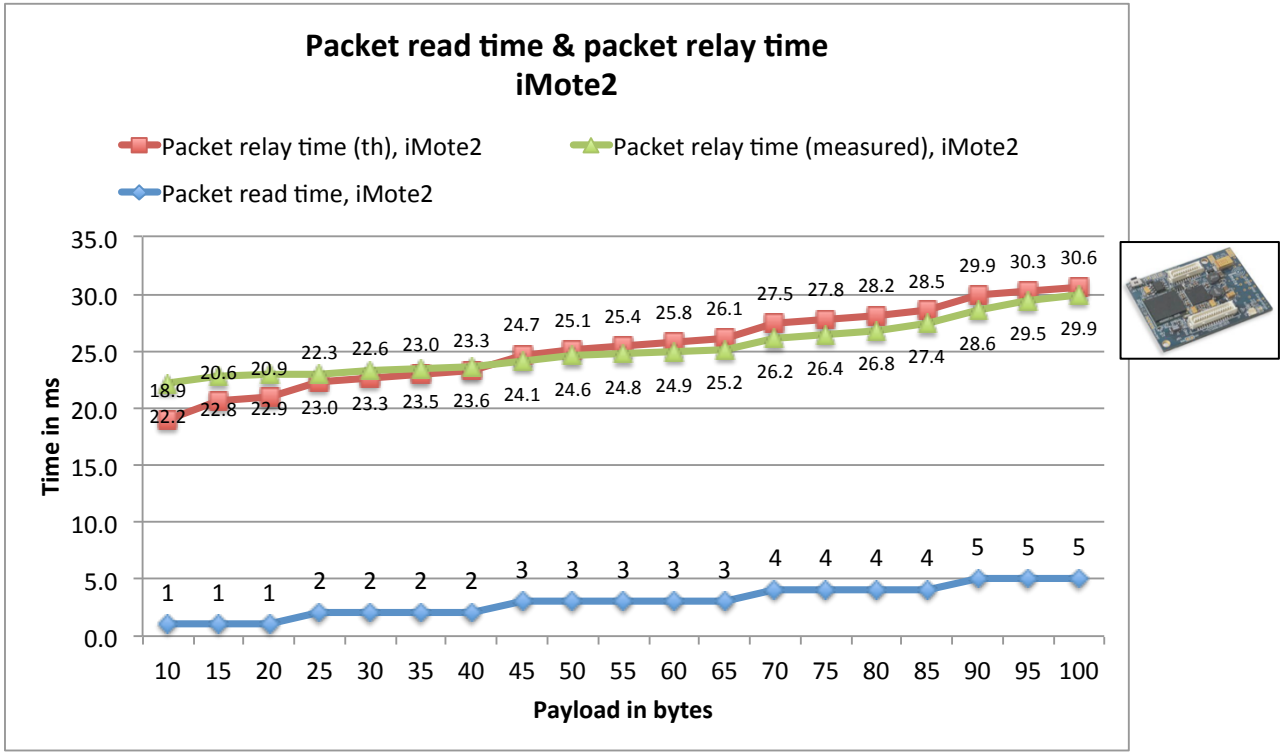




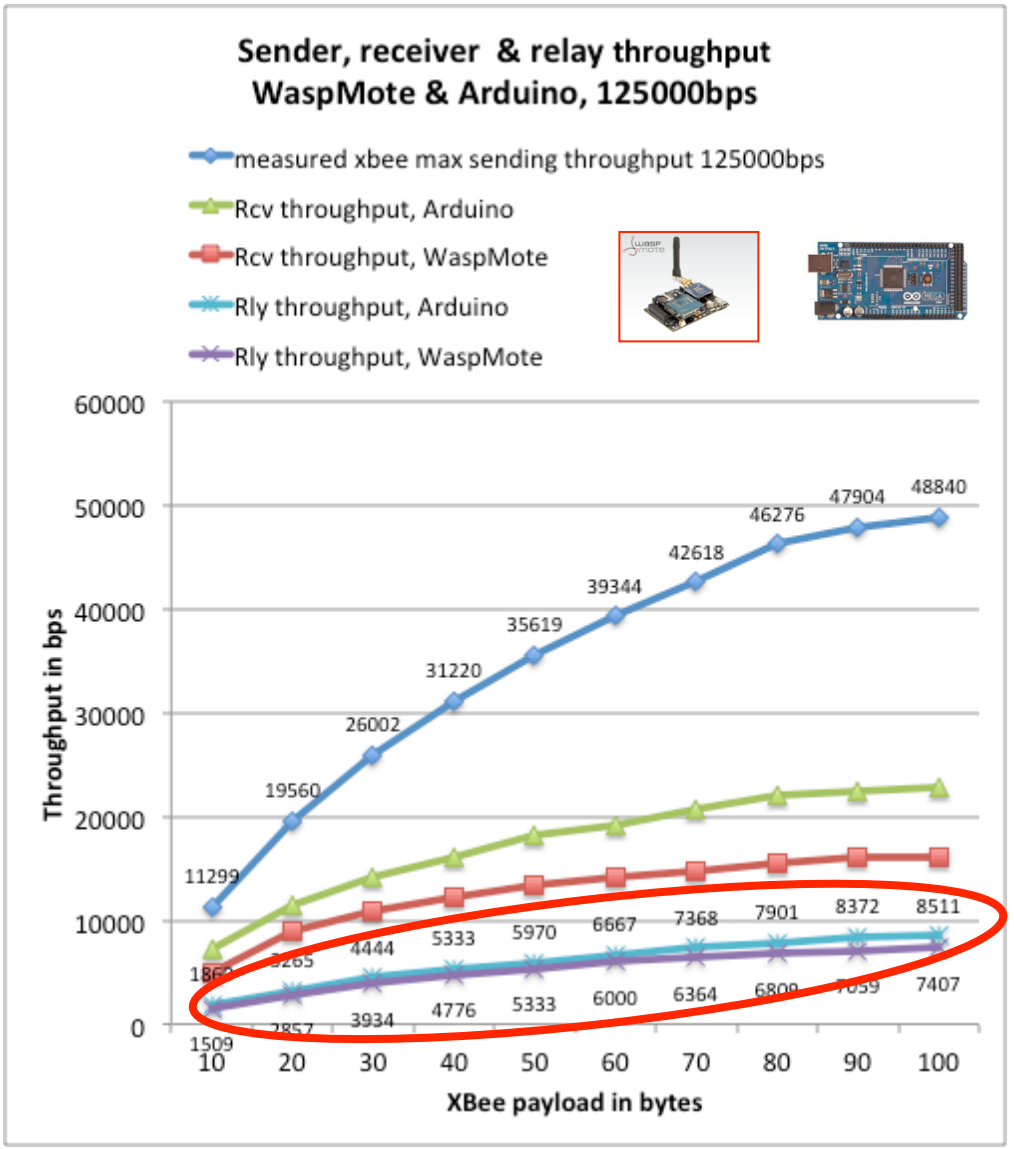
Read time and relay time



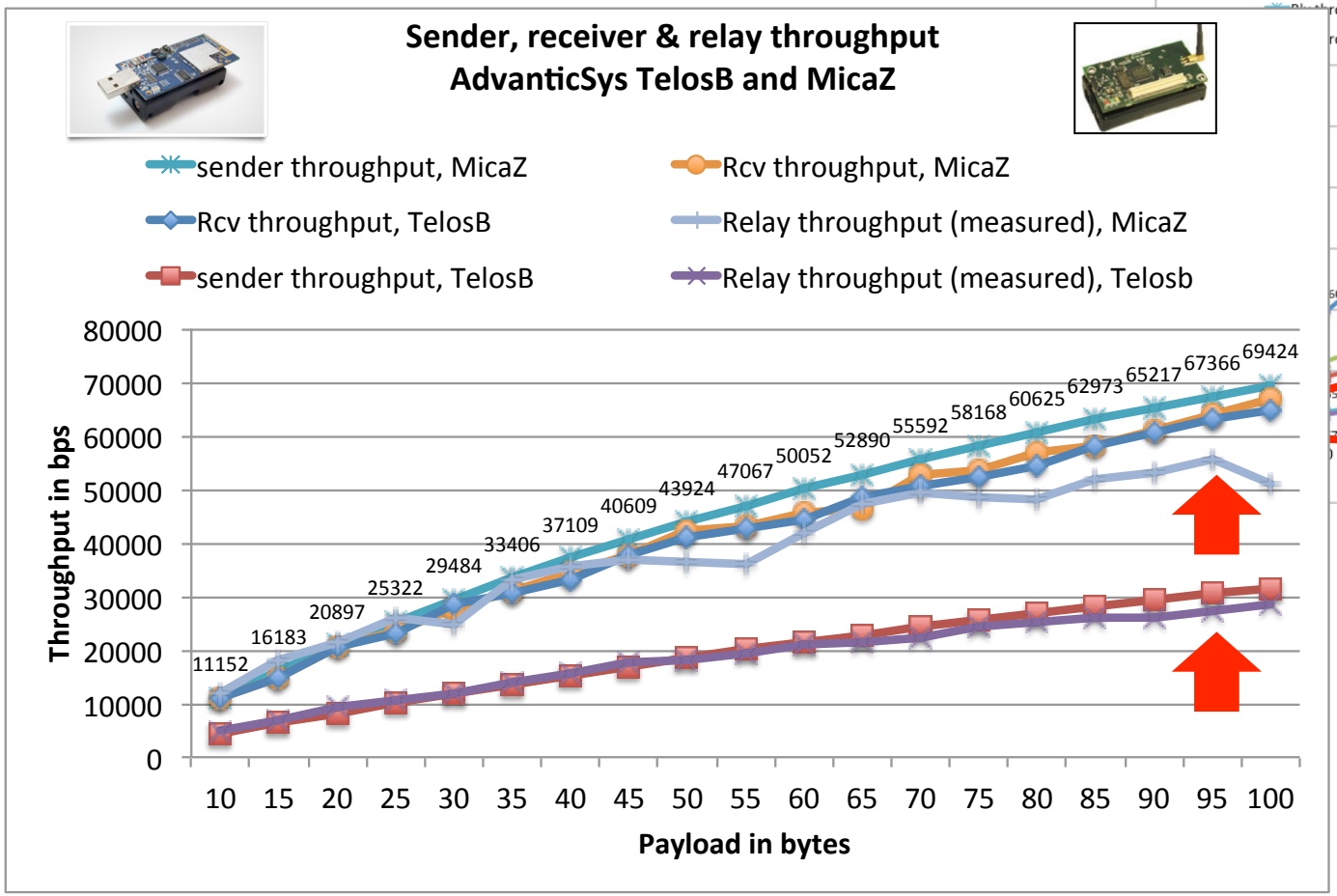


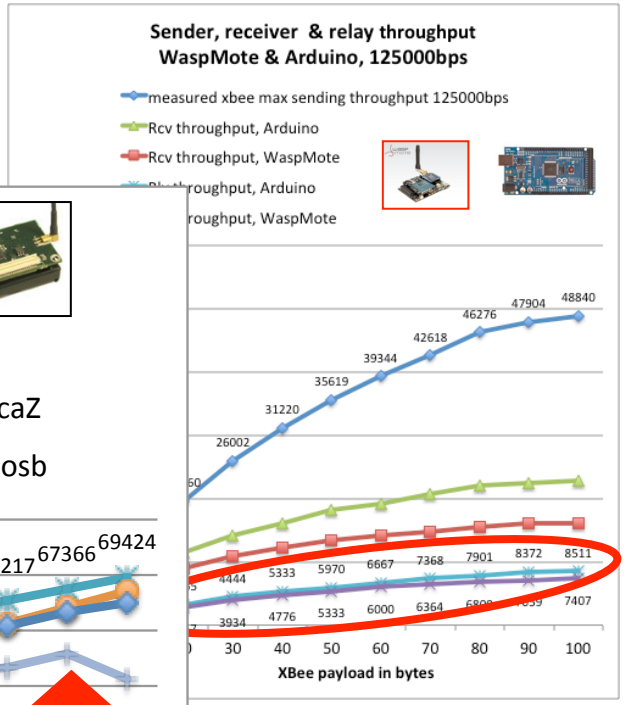


Maximum expected throughput in multi-hop

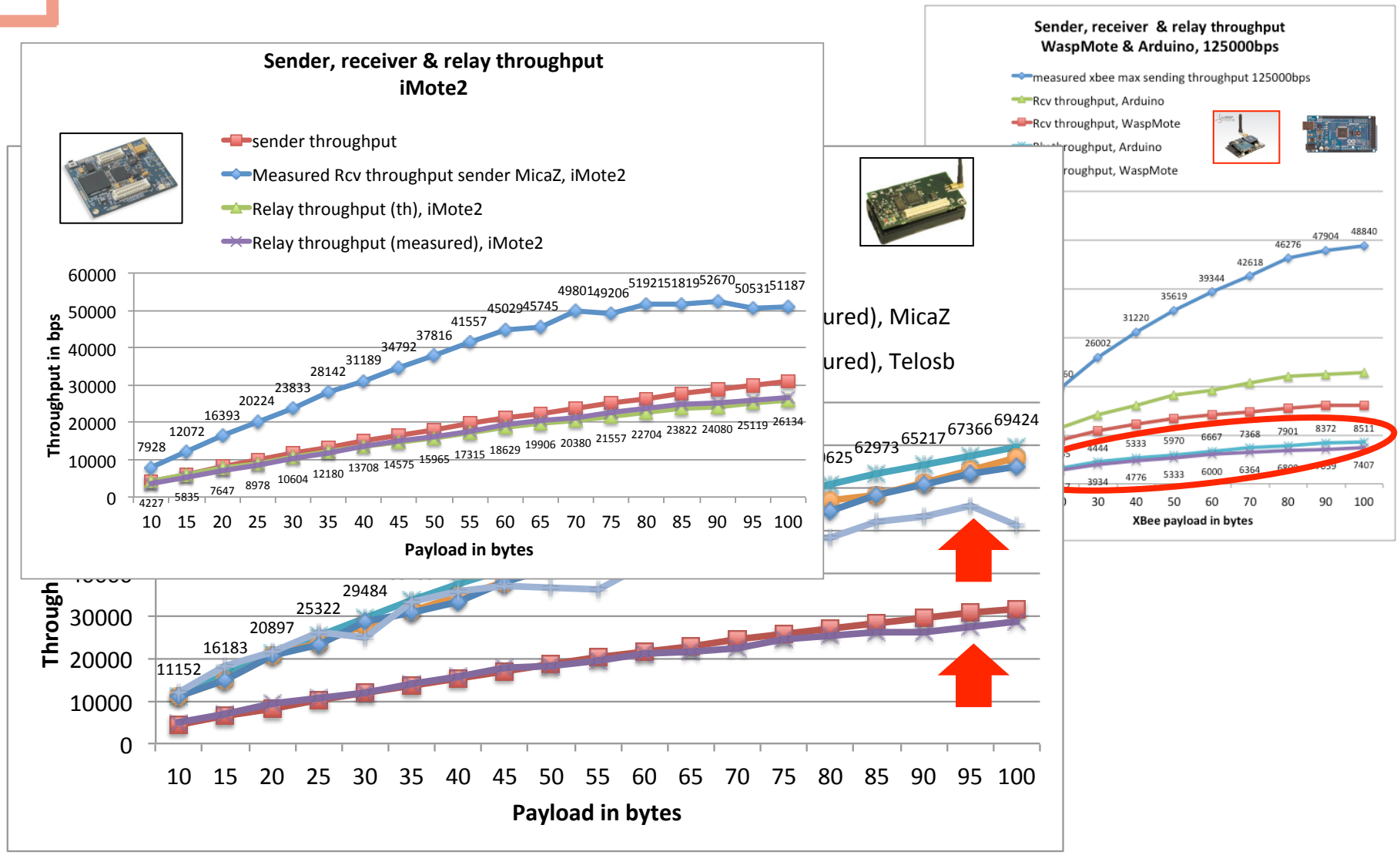


Maximum expected throughput in multi-hop





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.

Image quality? Uncompressed BMP

1617 packets, 64 bytes payload, one Hop
Loss rate: 20%, No loss bursts (radio), No duty-cycling

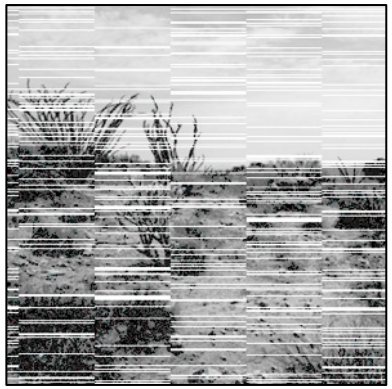


Original 320x320
256 gray levels,
BMP 102400 bytes

Max TX rate = 250 kps
(IEEE 802.15.4)

Minimum latency = 6.46s

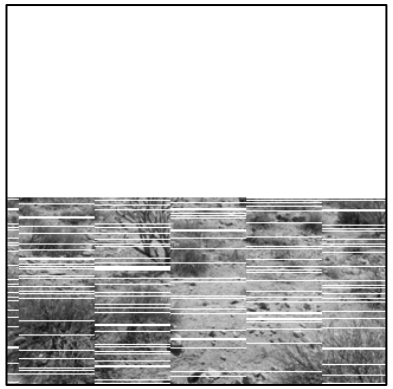
Cannot really use the compressed version of BMP using RLE.



1340 out of 1617
packets received



1303 out of 1617
packets received

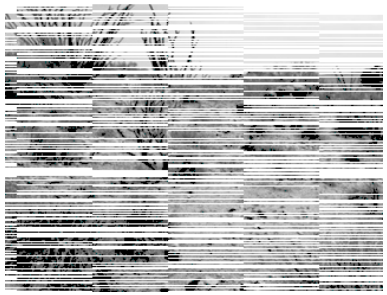


674 out of 1617
packets received

With loss bursts (radio)



921 out of 1617
packets received



689 out of 1617
packets received



913 out of 1617
packets received

Image quality? Standard JPG

427 packets, 64 bytes payload, one Hop
Loss rate: 20%, No loss bursts (radio), No duty-cycling



Original 320x320
256 gray levels,
JPG 27303 bytes

Max TX rate = 250 kps
(IEEE 802.15.4)

Minimum latency = 1.61s



348 out of 427
packets received



351 out of 427
packets received

9 out of 12 images
could not be decoded



349 out of 1617
packets received

With loss bursts (radio)



258 out of 427
packets received



270 out of 427
packets received

8 out of 12 images
could not be decoded



269 out of 427
packets received

Encoding cost of JPEG2000 is too high for these devices.

Improving image robustness

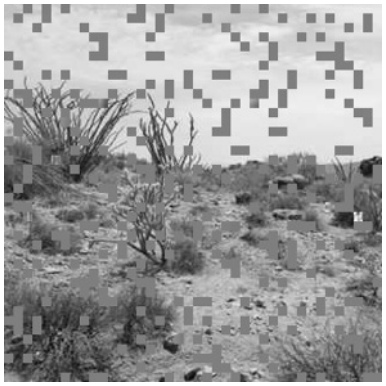
302 packets, 64 bytes payload, one Hop
Loss rate: 20%, No loss bursts (radio), No duty-cycling



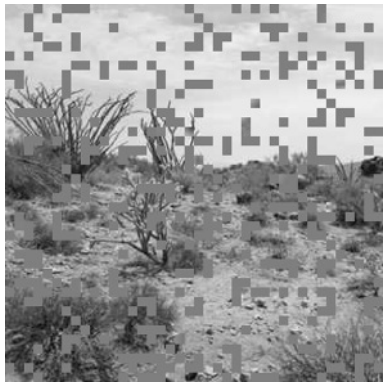
Original 320x320
256 gray levels,
WSN specific 17199 bytes

Max TX rate = 250 kps
(IEEE 802.15.4)

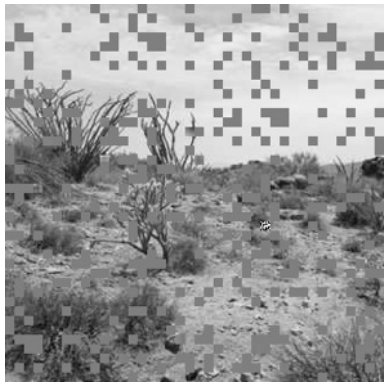
Minimum latency = 1.14s



248 out of 302
packets received

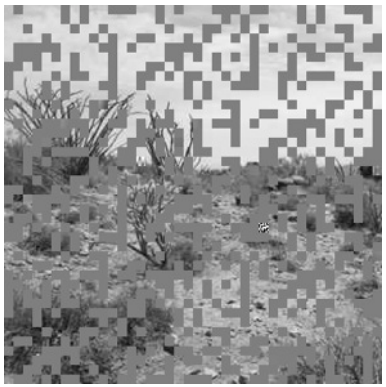


236 out of 302
packets received

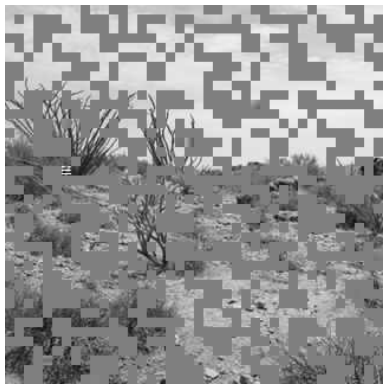


243 out of 302
packets received

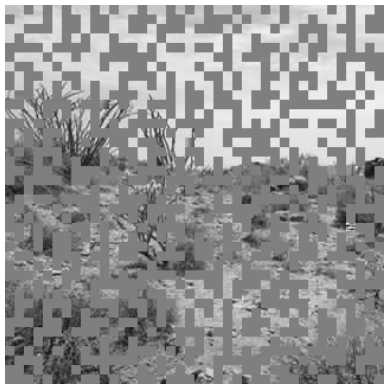
With loss bursts (radio)



188 out of 302
packets received



167 out of 302
packets received



158 out of 302
packets received

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

Dynamic Quality Factor 128x128

Original BMP 16384b



Q=50 S=4800b 63pkts



PSNR=24.6765

Q=40 S=4268b 56pkts



PSNR=23.4172

Q=30 S=3604b 46pkts



PSNR=22.0078

Q=20 S=2781b 34pkts



PSNR=20.4087

Q=15 S=2268b 28pkts



PSNR=19.5864

Q=10 S=1757b 12pkts



PSNR=18.6861

Q=5 S=1006b 12pkts



PSNR=17.3283

Dynamic Quality Factor 200x200

Original BMP 40000b



Q=50 S=11045b 142pkts



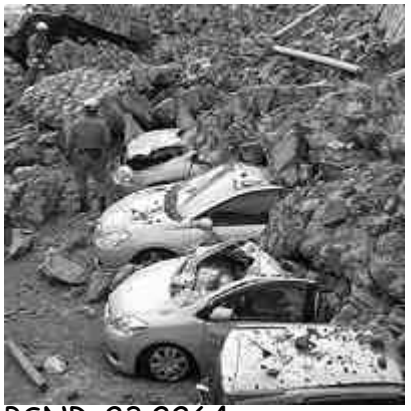
PSNR=25.1661

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

Q=5 S=2053b 24pkts



PSNR=18.937

Transmission Time

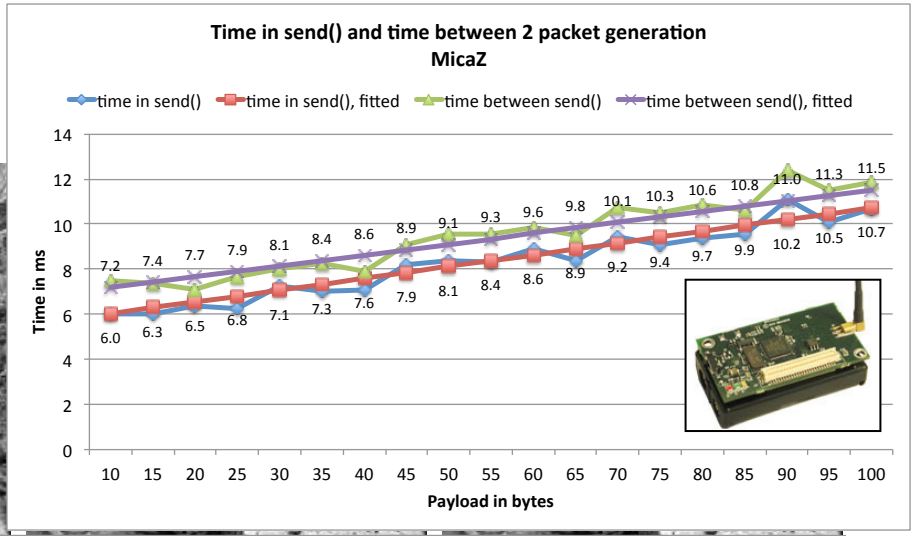
Original BMP 40000b



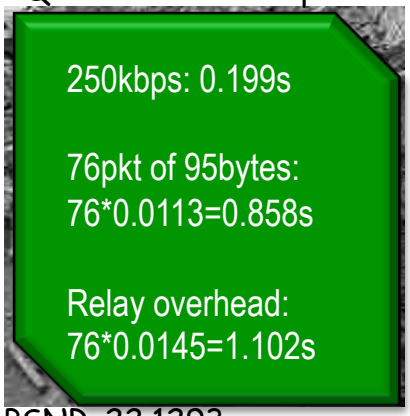
Q=50 S=11045b 142pkts



PSNR=25.1661



Q=20 S=6236b 76pkts

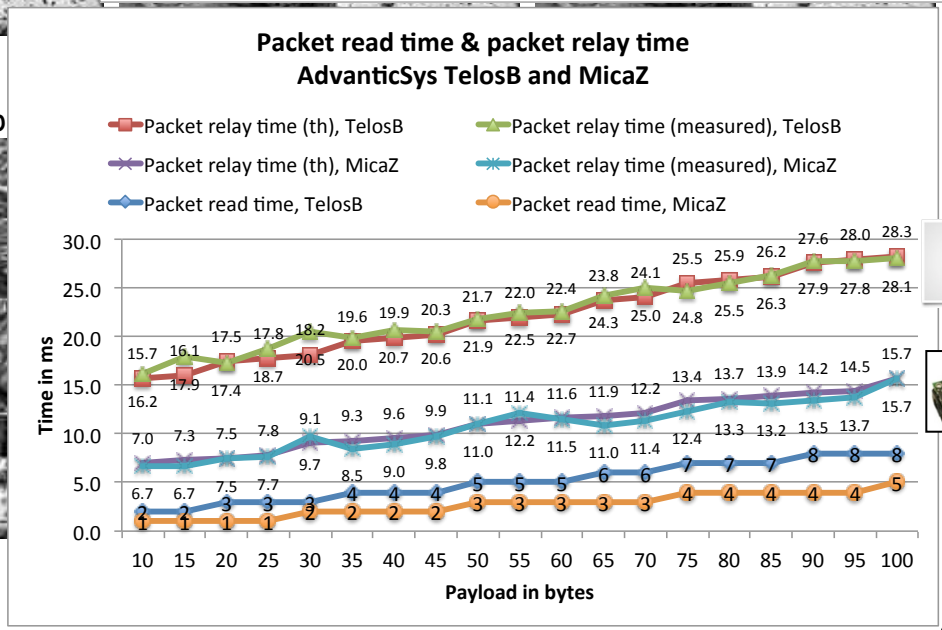


PSNR=22.1293

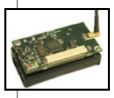
Q=15 S=5188b 63p



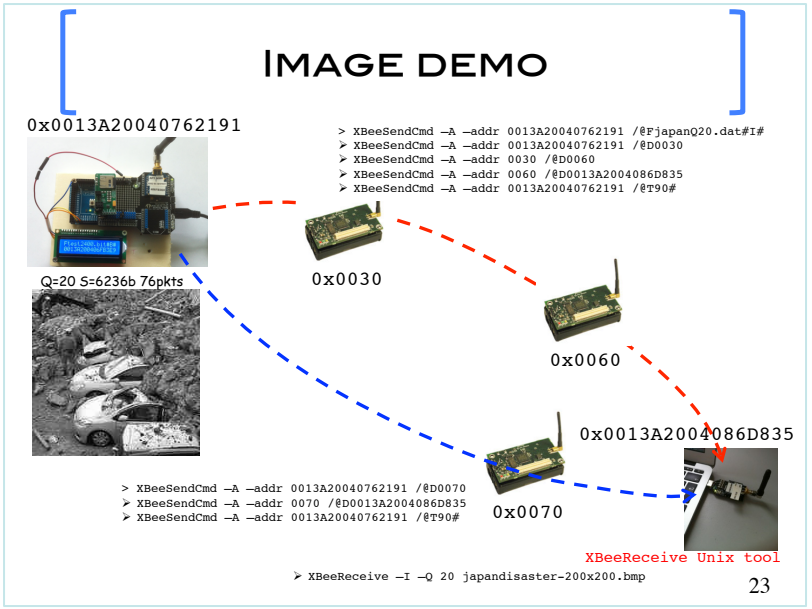
PSNR=21.4475

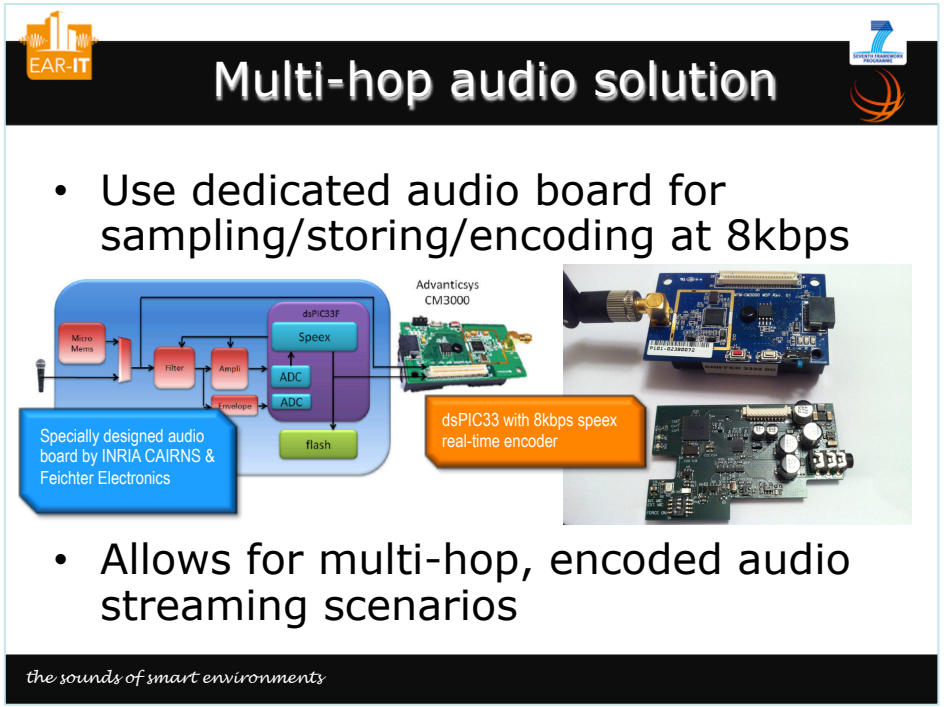






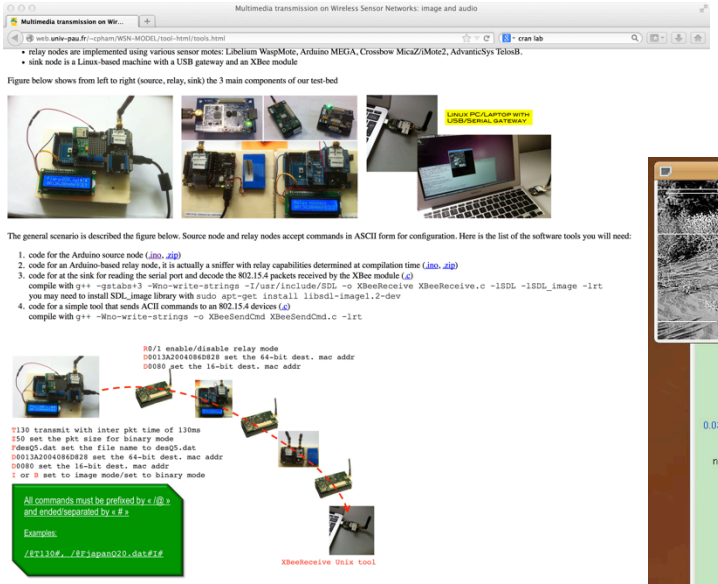
This afternoon multimedia transmission

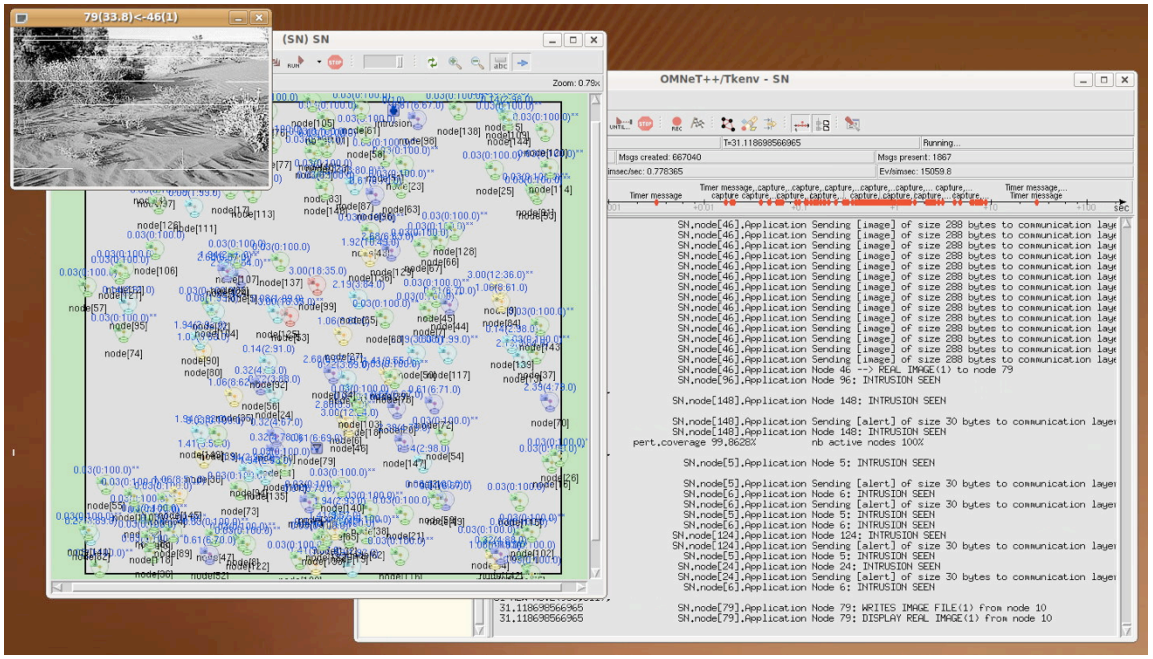




Some links

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





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