Data-intensive applications with WSNs

Winter school on Wireless Sensor Systems

Centre de Développement des Technologies Avancées

Algiers, Algeria, December 14th

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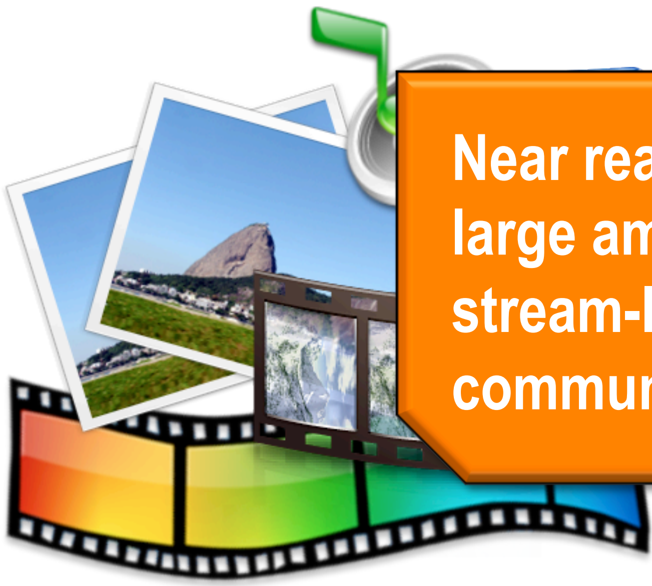
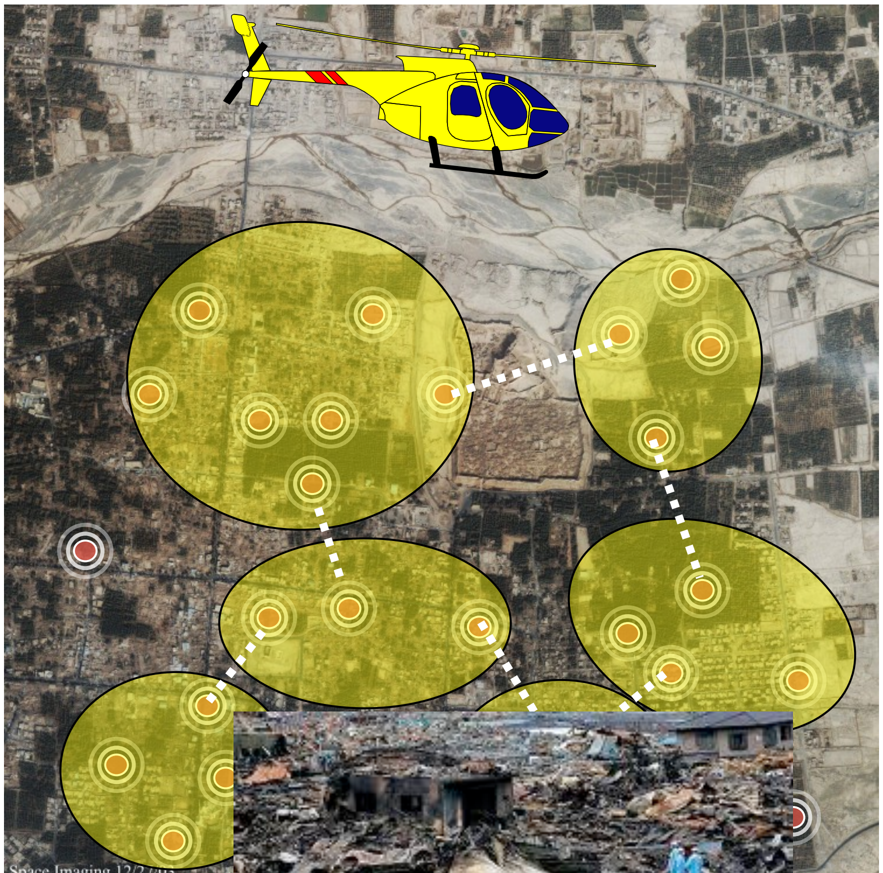
http://www.univ-pau.fr/~cpham
Université de Pau, France

Towards Multimedia Information



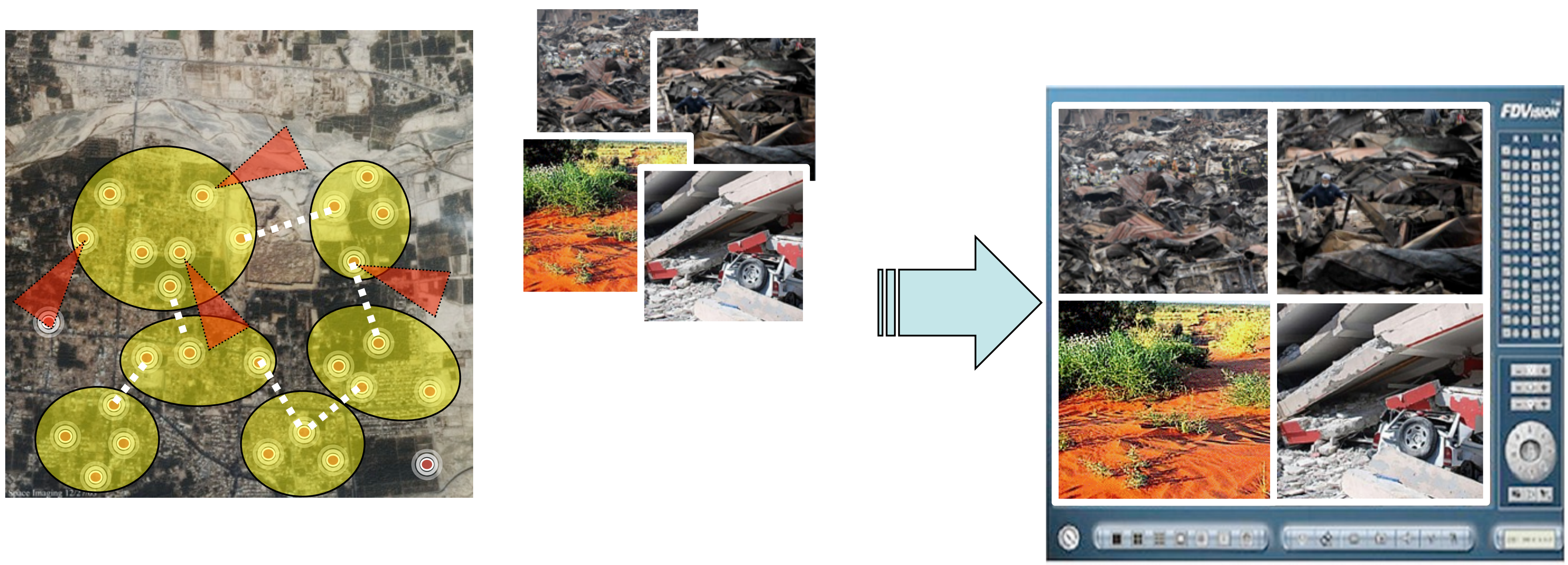
Near real-time constraints, large amount of data, stream-like communication,…

Image sensor for mission-critical apps



Disaster relief, Search & Rescue, Intrusion detection, …

Ex: Situation-awareness

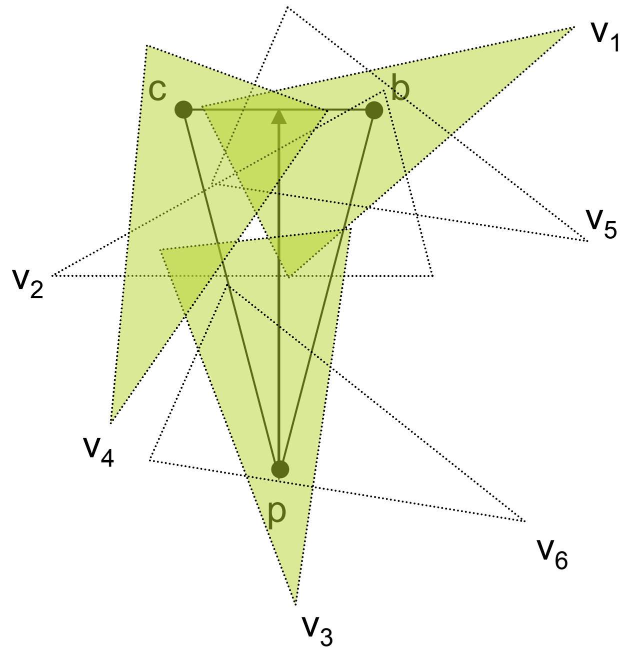


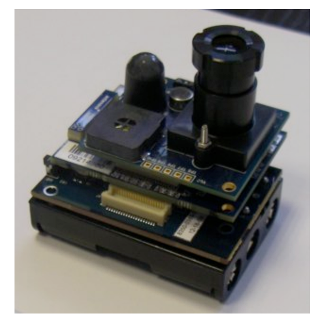
Collect data to improve the responsiveness of rescue operations

Image sensor's cover set

$Co(V)$= {
{V },
{V_1, V_3, V_4},
{V_2, V_3, V_4},
{V_3, V_4, V_5},
{V_1, V_4, V_6},
{V_2, V_4, V_6},
{V_4, V_5, V_6}
}

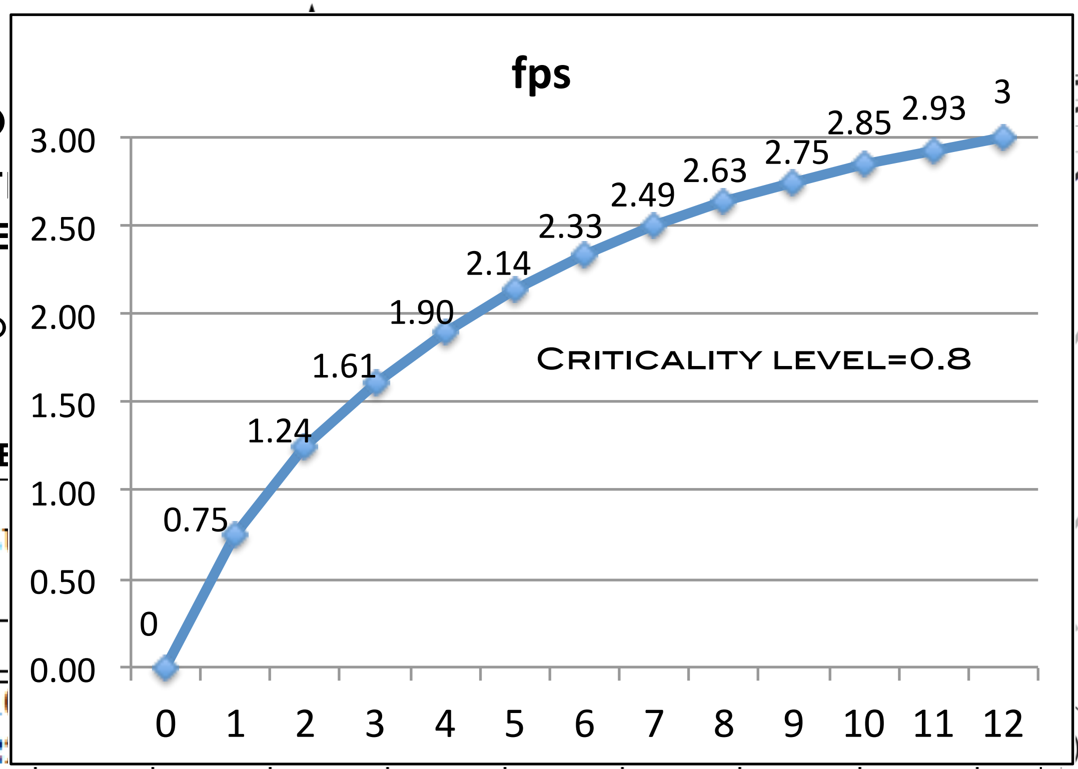
$|Co(V)| = 7$





Proposed criticality model

- r^0 can vary in [0
- Behavior funct
  (BV) defines the
  capture speed
  according to r^0
- $r^0 < 0.5$
  - Concave shape



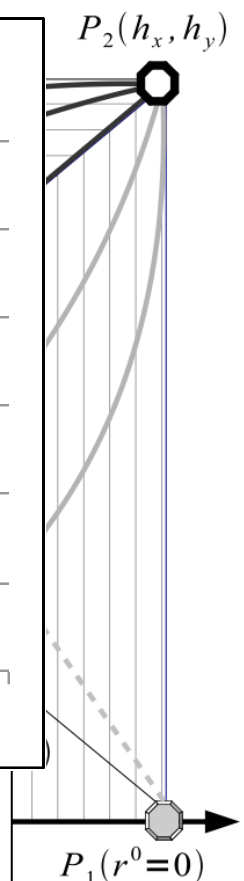


Table 1: Capt

r^0	1	2	3	4								
0	0.01	0.02	0.05	0.1								
.1	0.03	0.08	0.14	0.2								
.4	0.17	0.35	0.55	0.75	0.97	1.20	1.45	1.72	2.00	2.31	2.64	3
.6	0.36	0.69	1.00	1.28	1.55	1.80	2.03	2.25	2.45	2.65	2.83	3
.8	0.75	1.24	1.61	1.90	2.14	2.33	2.49	2.63	2.75	2.85	2.93	3
1	1.48	1.95	2.25	2.46	2.62	2.74	2.83	2.90	2.95	2.98	2.99	3

Criticality-based activity schedule

Sentry nodes have higher probability to detect events and to send alerts

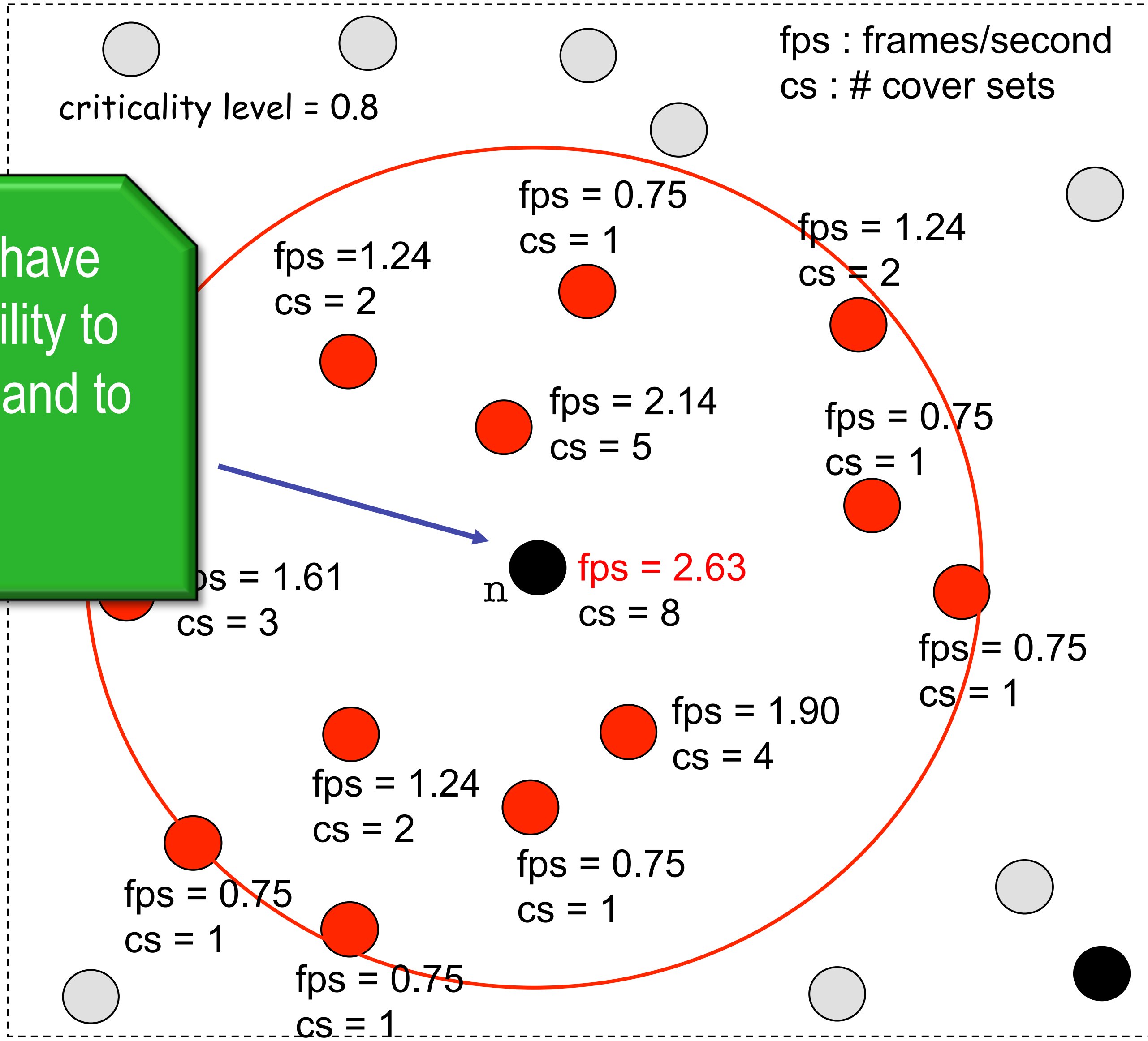
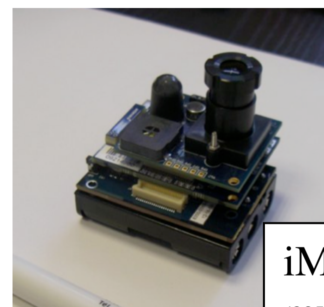
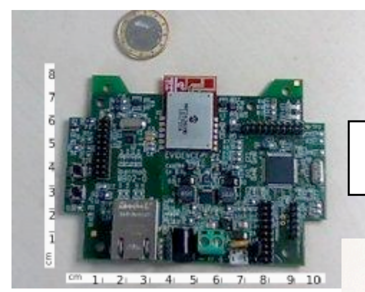


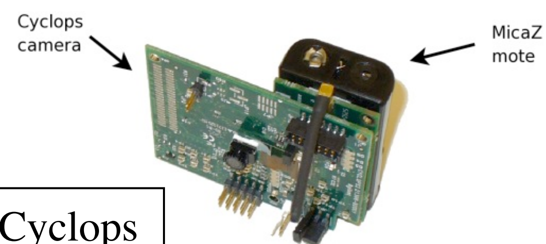
Image sensors



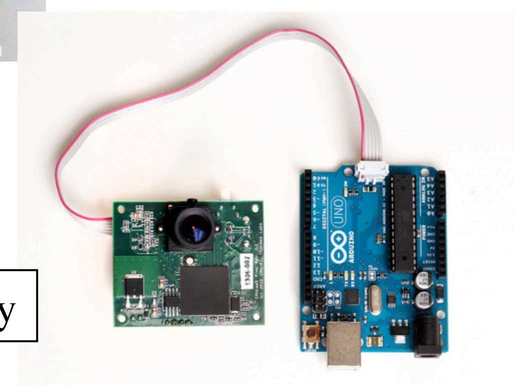
iMote2 with IMB400 multimedia board



Seedeye



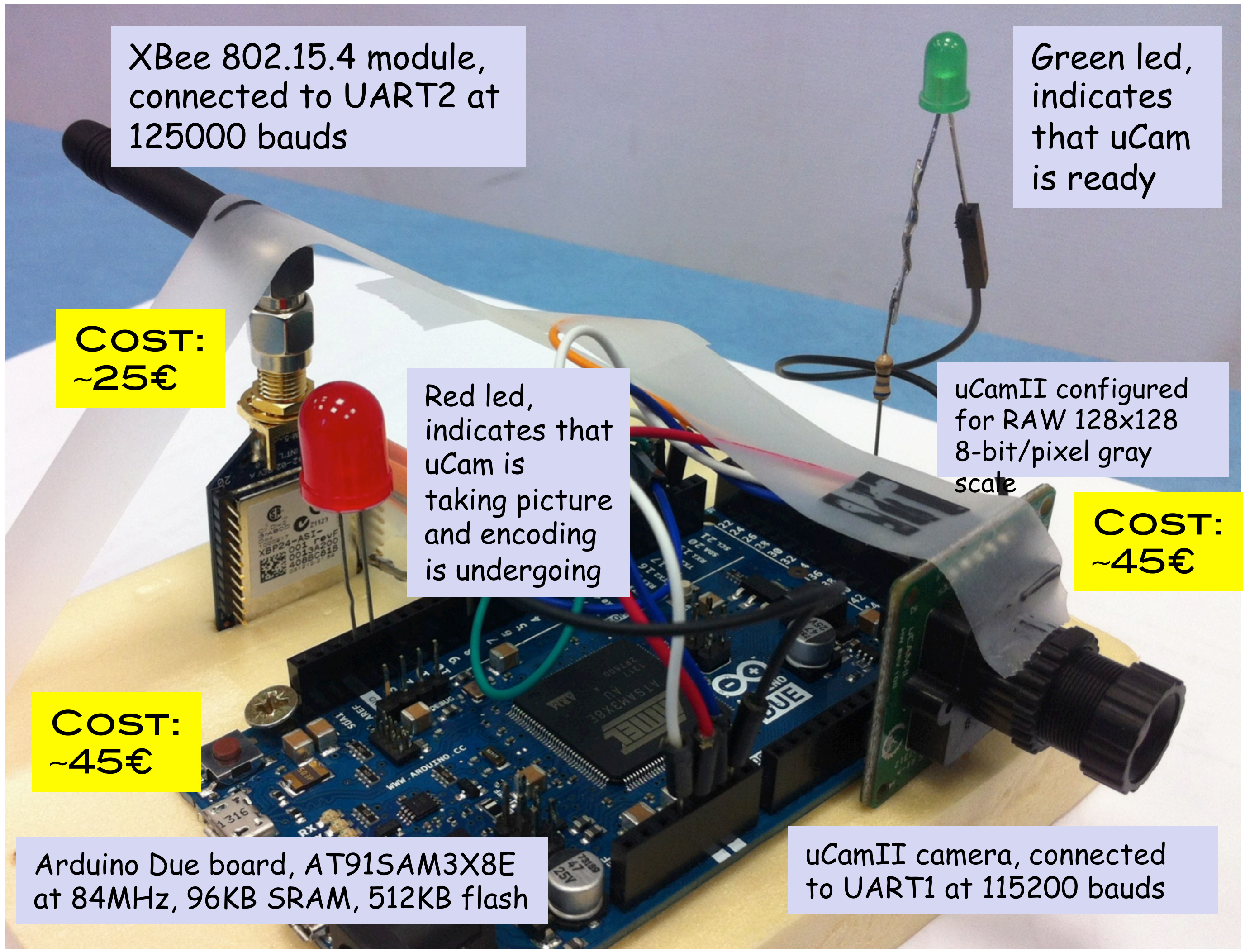
Cyclops



Pixy

Arduino Due + uCamII
128x128 images

Can be controlled wirelessly to capture, take reference image, compare image, transmit image, define packet size, image quality factor,…



ADJUSTABLE IMAGE QUALITY FACTOR Q

BMP 16384b

Q=100; 9768b

PSNR=51.344

Q=90; 5125b

PSNR=29.414

Q=80; 3729b

PSNR=28.866

Q=70; 2957b

PSNR=28.477

Q=60; 2552b

PSNR=28.024

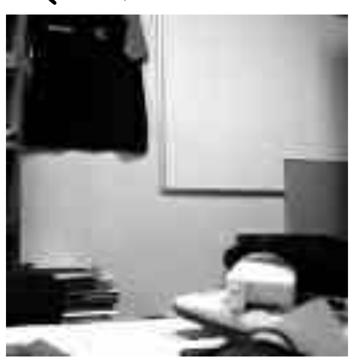
Q=50; 2265b

PSNR=27.912

Q=40; 2024b

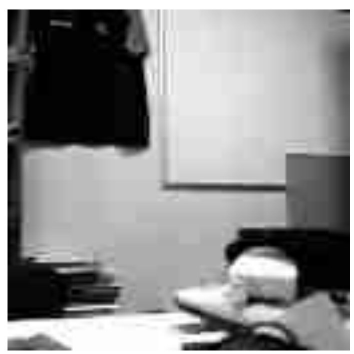
PSNR=27.423

Q=30; 1735b



PSNR=26.933

Q=20; 1366b



PSNR=26.038

Q=10; 911b

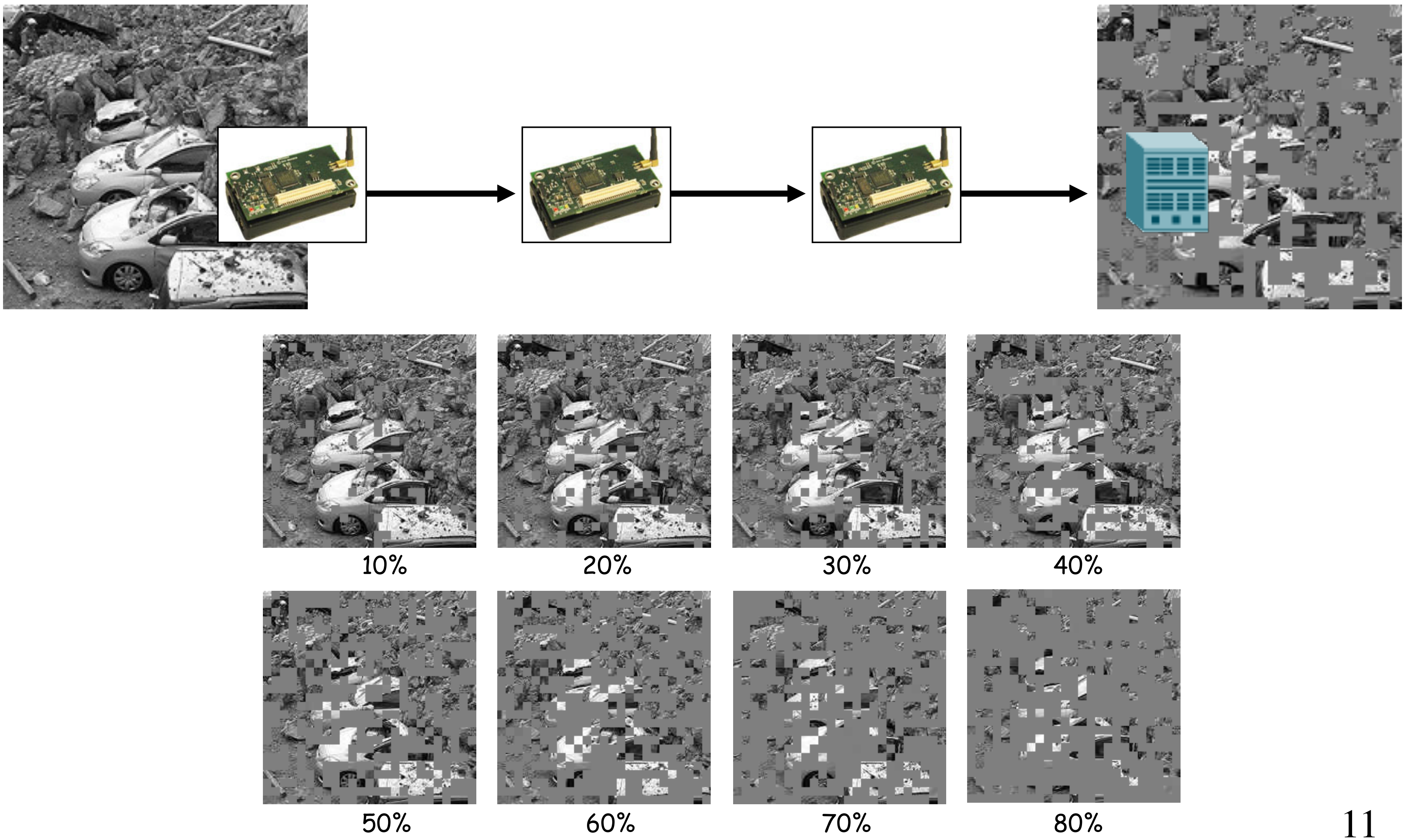
PSNR=25.283

Q=5; 576b

PSNR=23.507

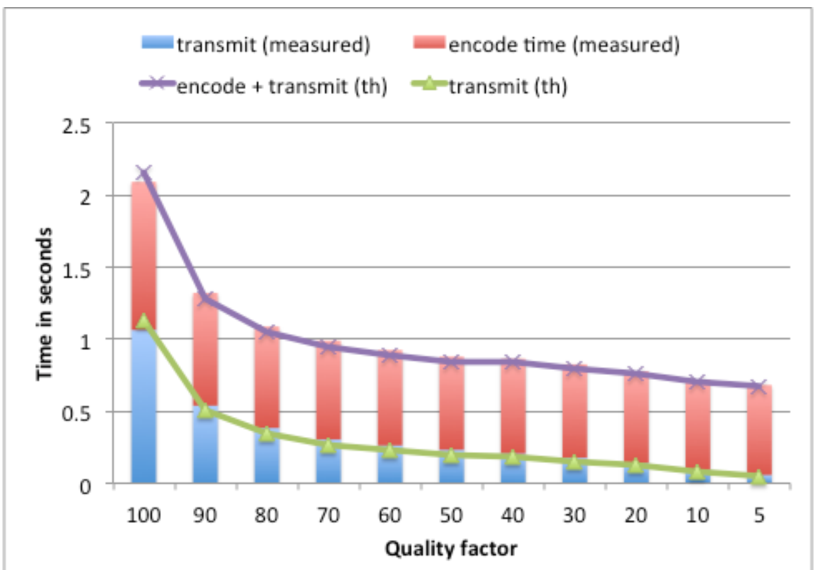
Collaboration with CRAN laboratory, Nancy, France, for robust image encoding techniques for WSN.

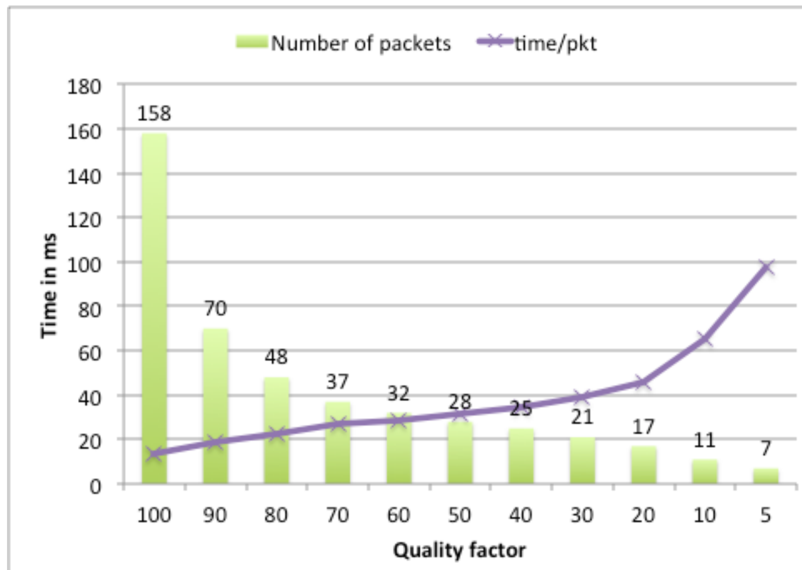
Robust to packet losses, Out of order reception



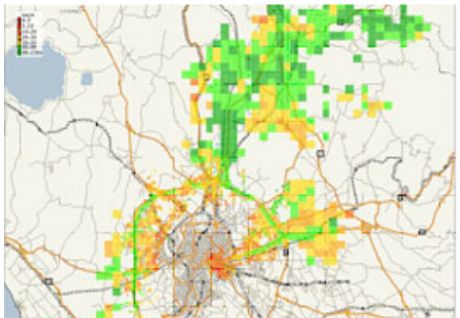
Encoding & transmission performances

Quality Factor Q	Z=90 size in bytes	Number of packets	encode time (measured)	transmit (measured)	encode + transmit	transmit (th)	encode + transmit (th)	encode time/pkt	transmit time/pkt	encode+transmit
100	9768	158	1.027	1.064	2.091	1.133	2.160	0.0065	0.0067	13.2342
90	5125	70	0.782	0.539	1.321	0.502	1.284	0.0112	0.0077	18.8714
80	3729	48	0.704	0.384	1.088	0.344	1.048	0.0147	0.0080	22.6667
70	2957	37	0.686	0.304	0.99	0.265	0.951	0.0185	0.0082	26.7568
60	2552	32	0.662	0.263	0.925	0.229	0.891	0.0207	0.0082	28.9063
50	2265	28	0.646	0.233	0.879	0.201	0.847	0.0231	0.0083	31.3929
40	2024	25	0.657	0.207	0.864	0.179	0.836	0.0263	0.0083	34.5600
30	1735	21	0.649	0.177	0.826	0.151	0.800	0.0309	0.0084	39.3333
20	1366	17	0.638	0.14	0.778	0.122	0.760	0.0375	0.0082	45.7647
10	911	11	0.628	0.093	0.721	0.079	0.707	0.0571	0.0085	65.5455
5	576	7	0.624	0.058	0.682	0.050	0.674	0.0891	0.0083	97.4286





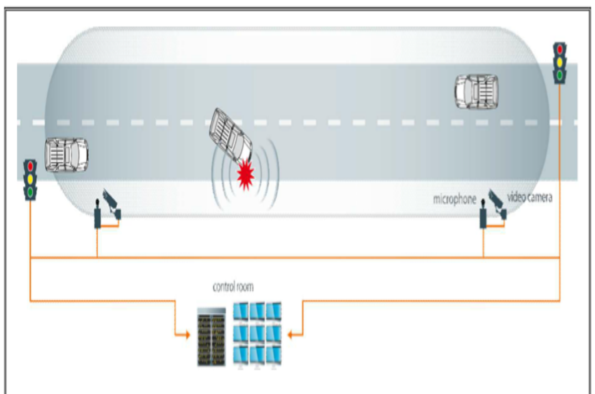
Exploiting Acoustic data FP7 EU EAR-IT



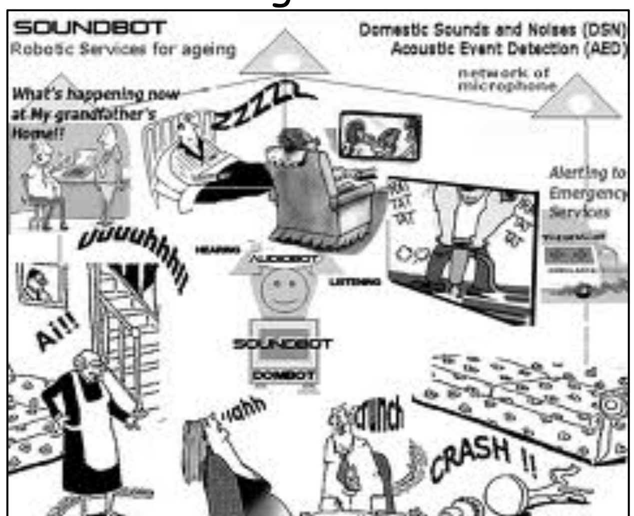
[redacted]

[redacted]
Management

[redacted]
efficiency



[redacted]



[redacted]

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Surveillance

From EAR-IT slides

EAR-IT test-beds

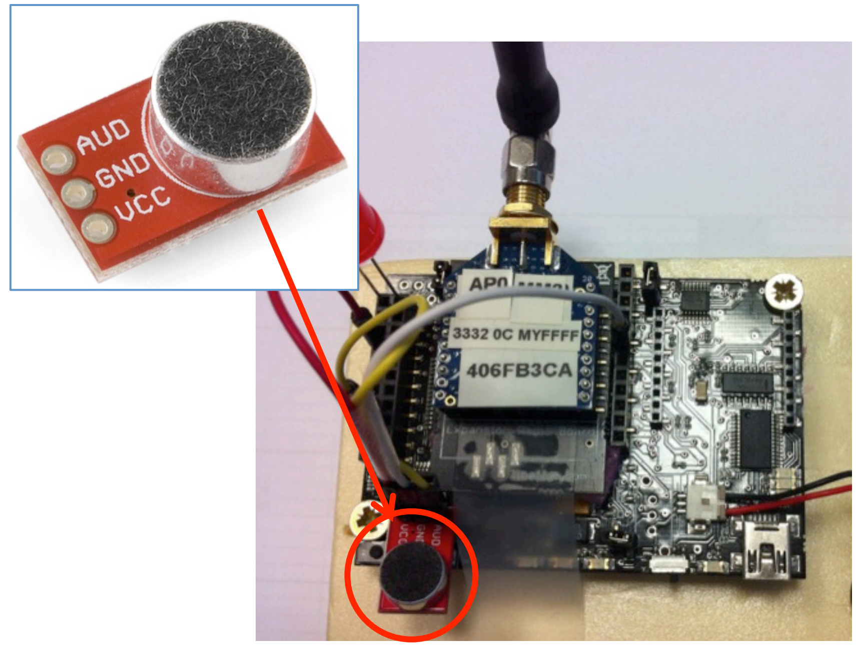
Experimenting Acoustics in Real environment using Innovative Test-beds

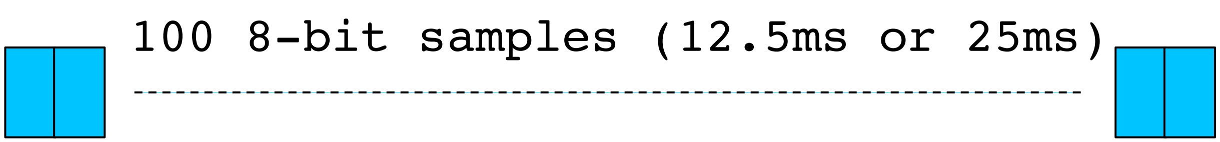
From EAR-IT slides

Low-resource IoT node to enhance acoustic services

Simple audio Mote

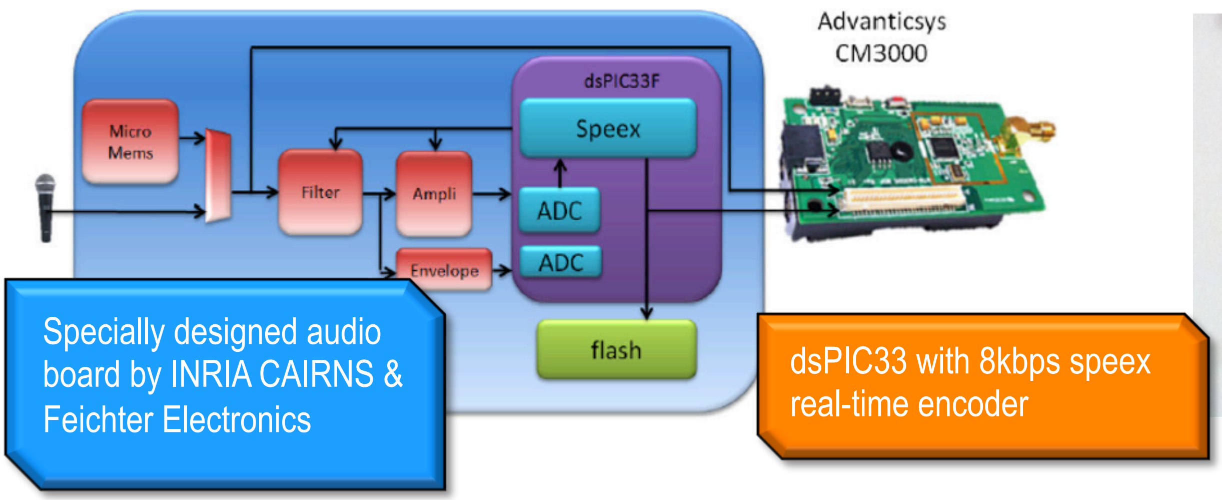
- Electret mic with amplifier on ADC input pin
- Convert from 10-bit to 8-bit sample
- 8Khz sampling gives 64000bps
- 4Khz sampling gives 32000bps





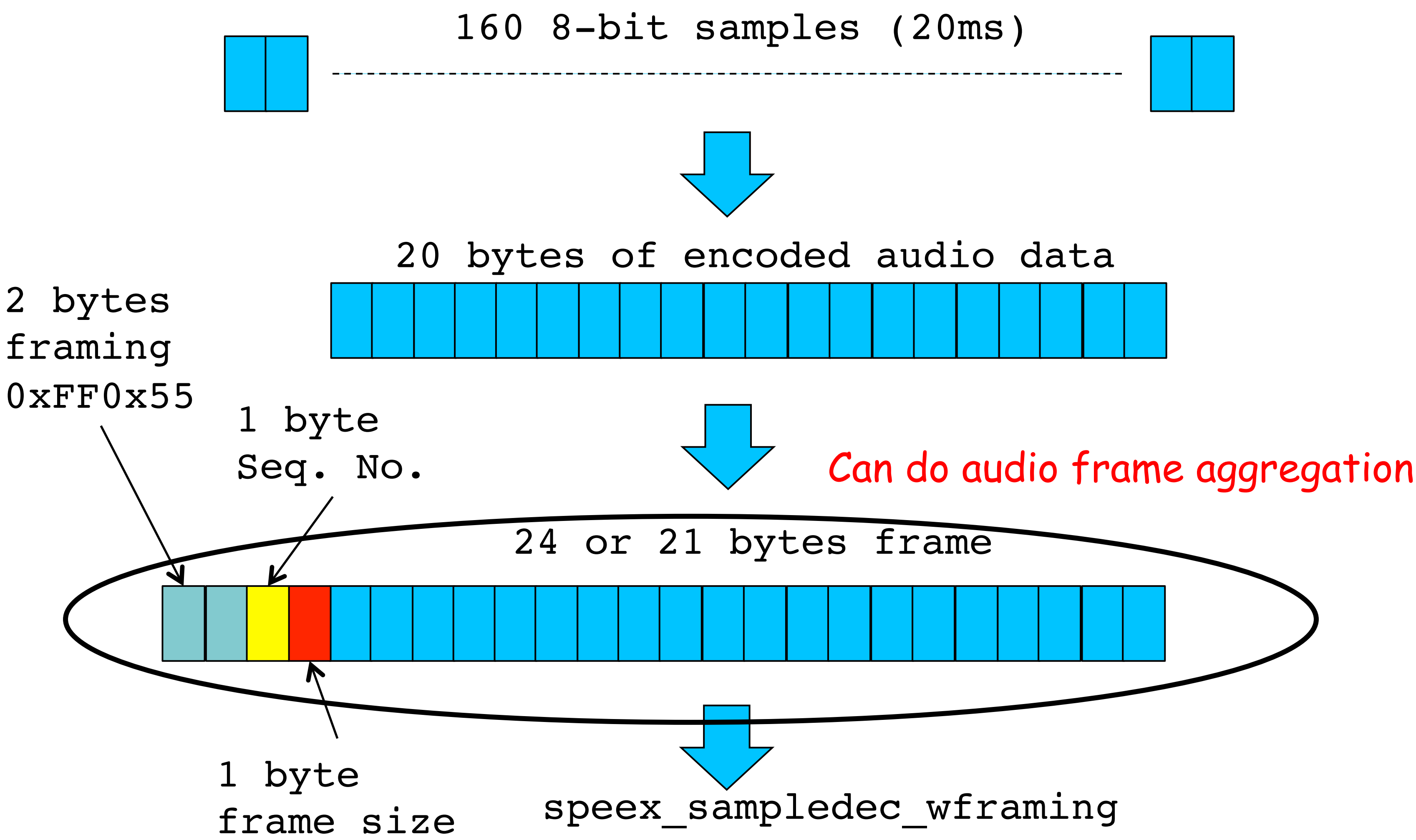
Development of Audio Board

- Use dedicated audio board for sampling/storing/encoding



- Encoding scheme is Speex at 8kbps
- Designed for multi-platform motes
- Can be plugged to other boards (UART)

SPEEX AT 8KBPS



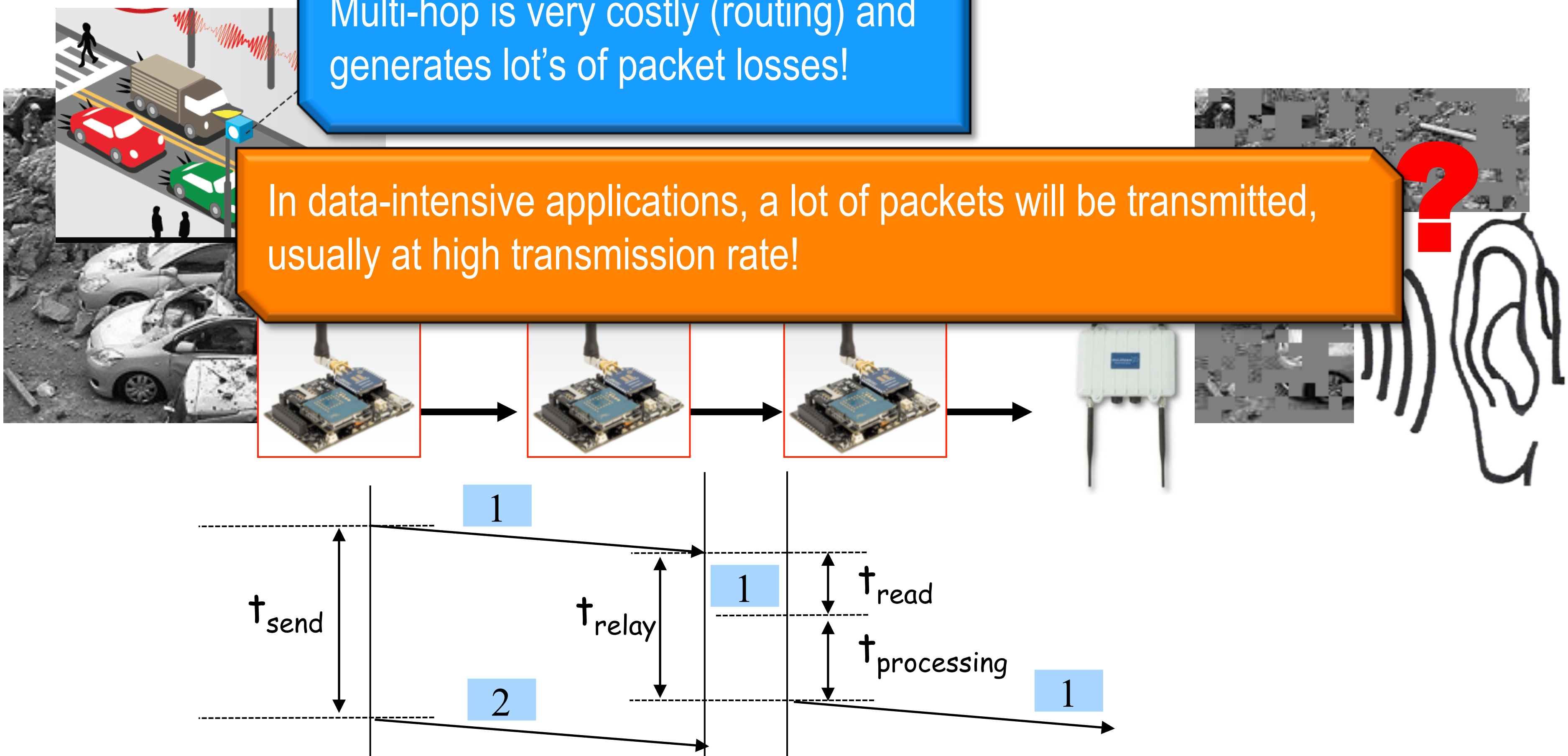
Summary of audio constraints

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

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!

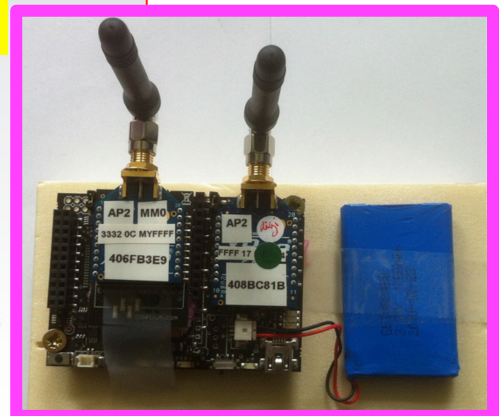


What level of performances can we expect?

Mass-market sensors

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

Cost:
~100€



Libelium WaspMote

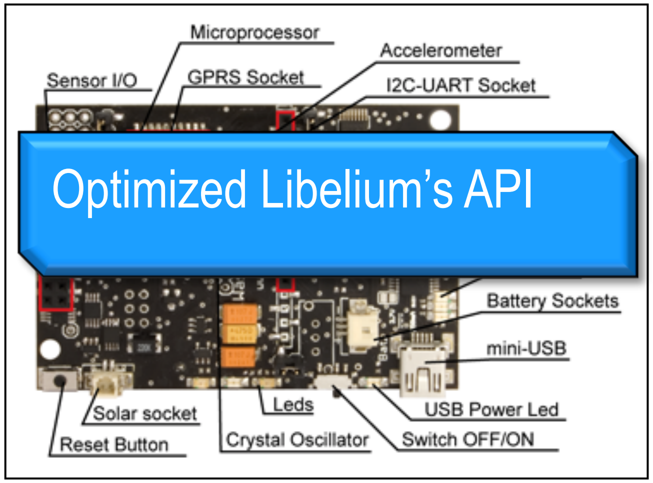
Cost:
~55€

Arduino Mega2560

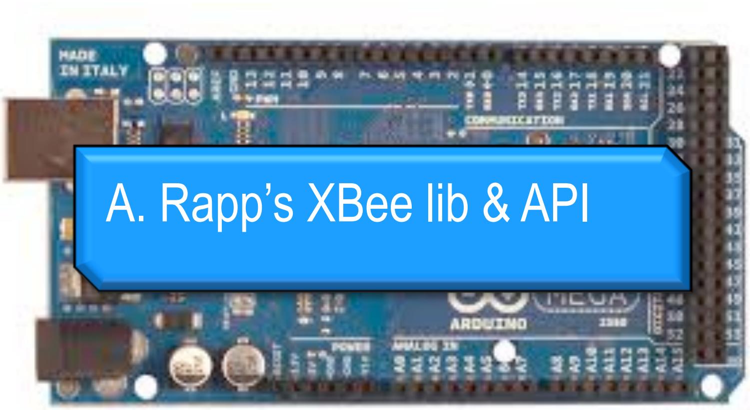
16MHz Atmega1281
8kB SRAM, 128kB Flash
Xbee radio

Sensor's HW&SW

Libelium WaspMote



Optimized Libelium's API



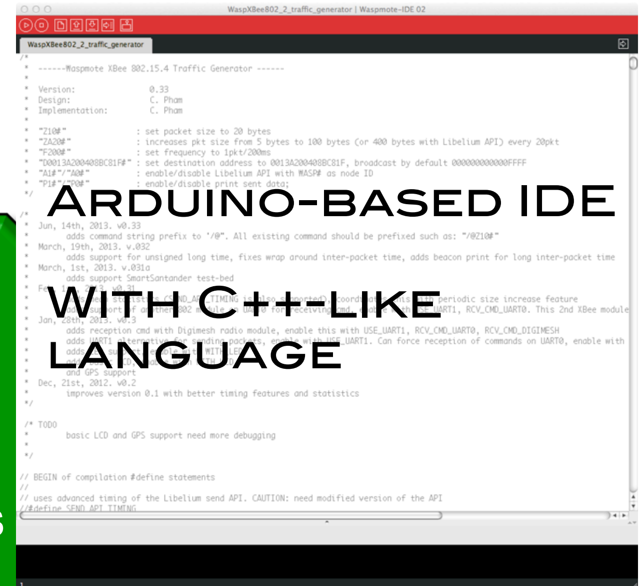
A. Rapp's XBee lib & API

Arduino Mega2560

UART-based connection to micro-controller

Default speed is usually 38400 bauds

Higher baud rate are possible but…

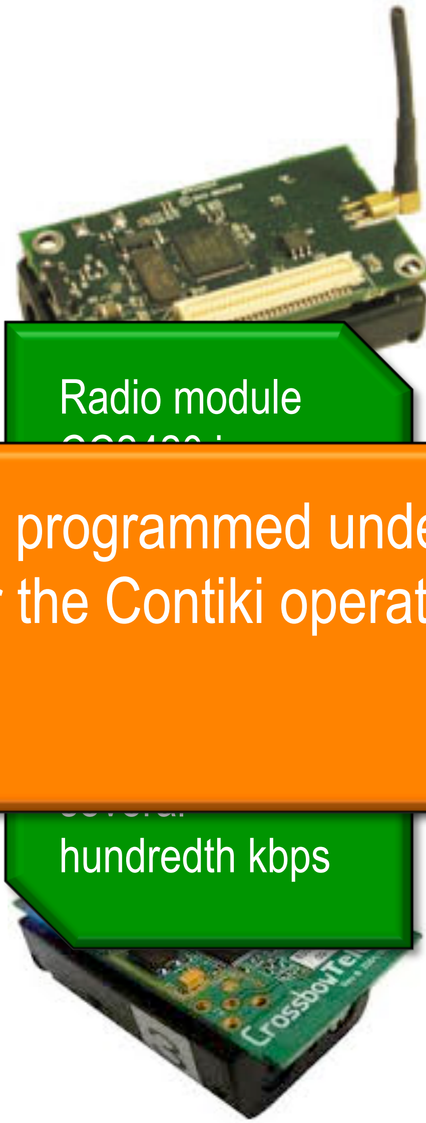


Arduino-based IDE with C++-like language

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
…
hundredth kbps

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

AdvanticSys CM5000 & CM3000
TelosB-like mote

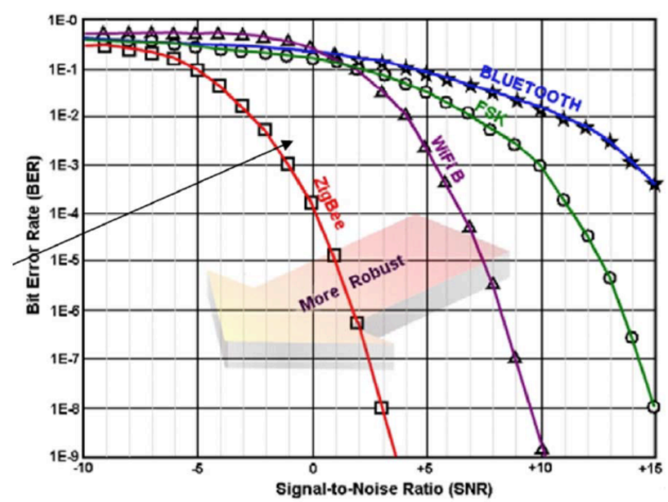
iMote2 with IMB400 multimedia board

TelosB

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

IEEE 802.15.4

- Low-power radio offering up to 250kbps throughput at physical layer
- Power transmission from 1mW to 100mW for range from 100m to about 1km is LOS
- CSMA/CA (beacon & non beacon)
- Used as physical layer in many stacks



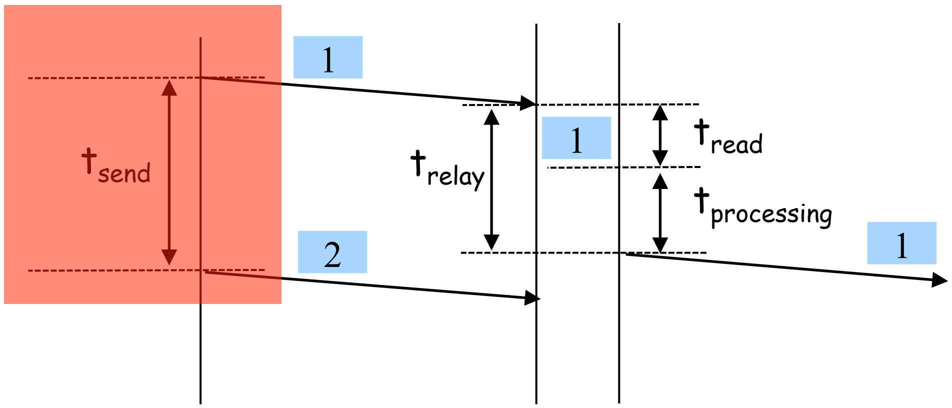
Communication performances

- 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



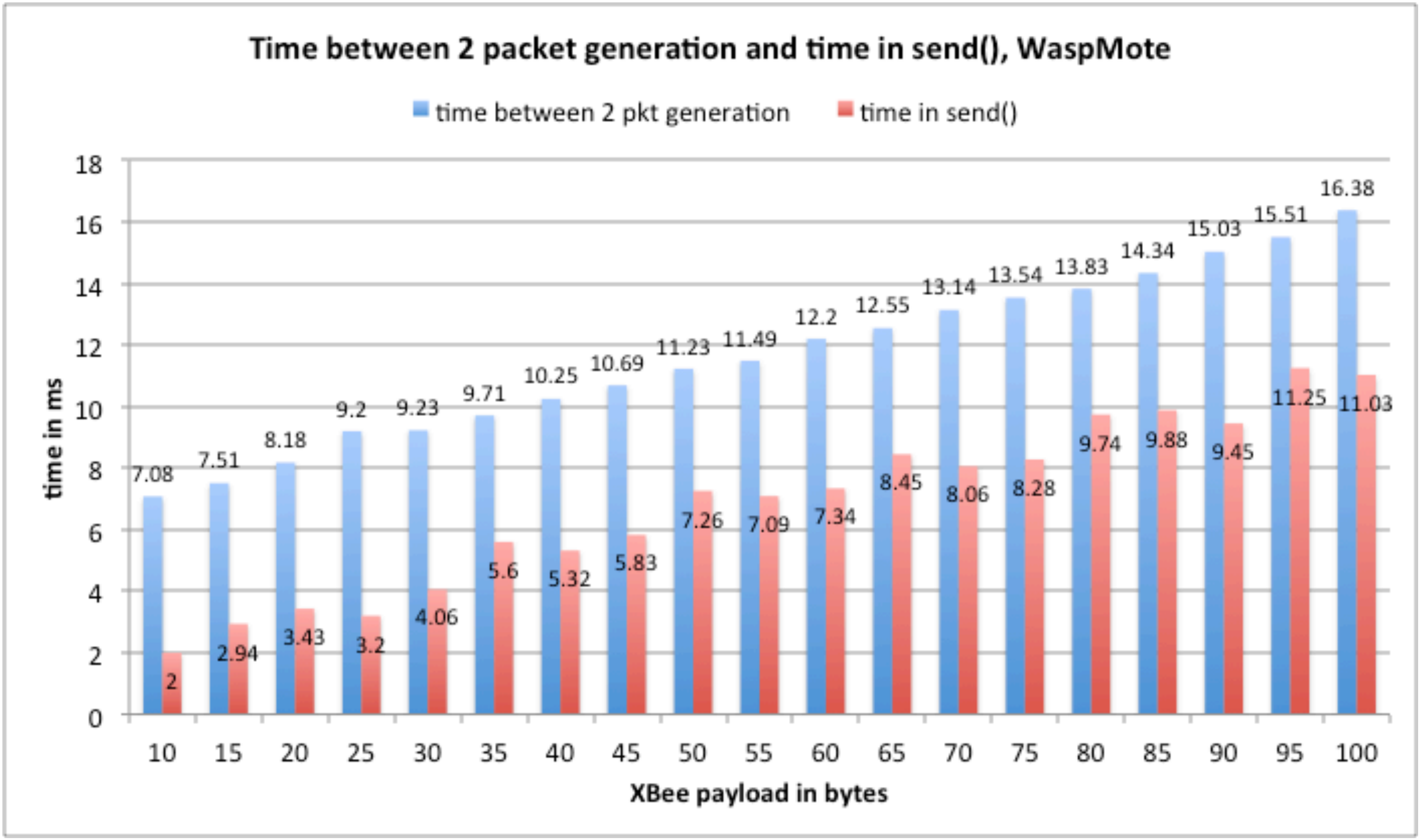
Traffic Generator

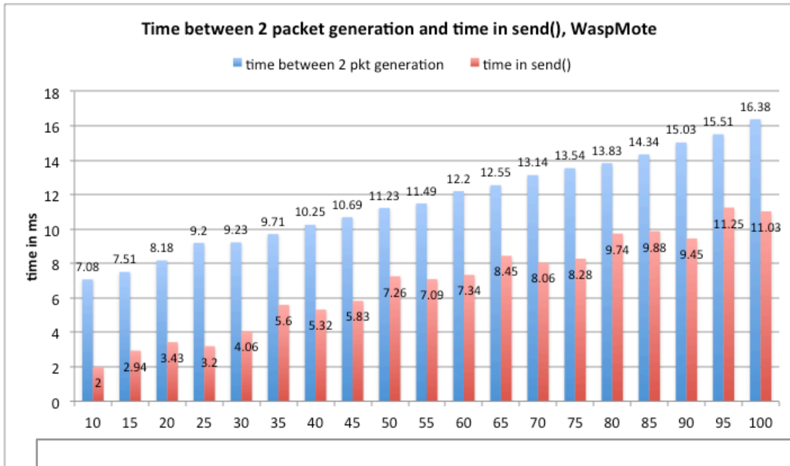
```
void loop() {
        T0;
        L0=T0;
        ...
        T1;
        send(buf);
        T2;
        ...
}
```

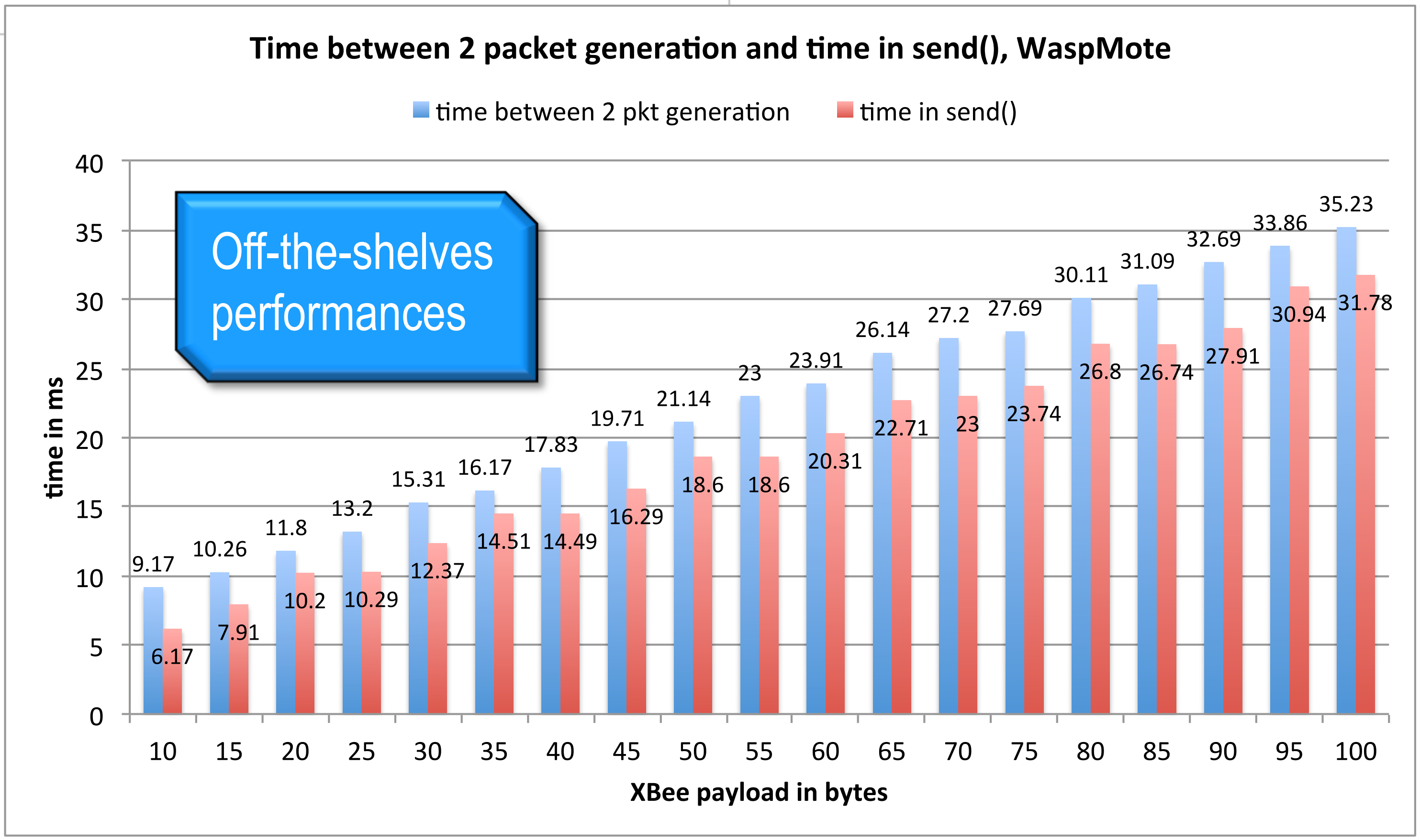
Measure the time in various part of API `send()` when possible.

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

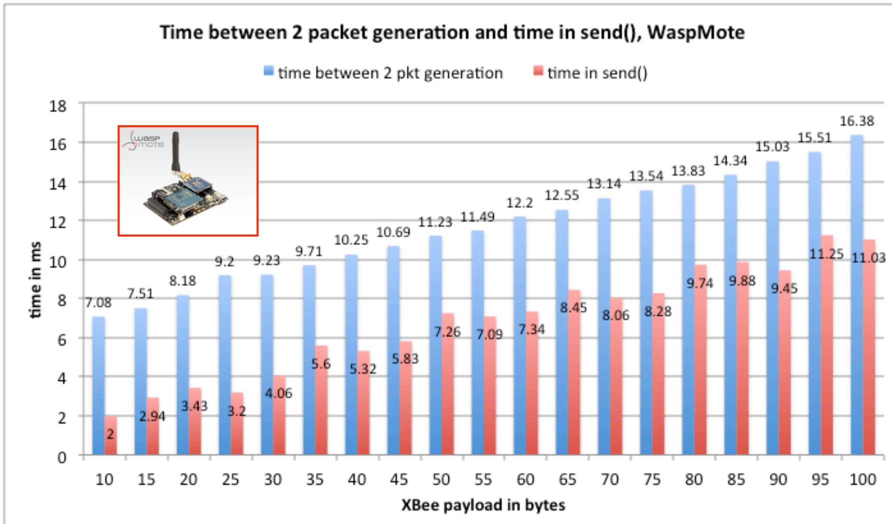
Sending performances

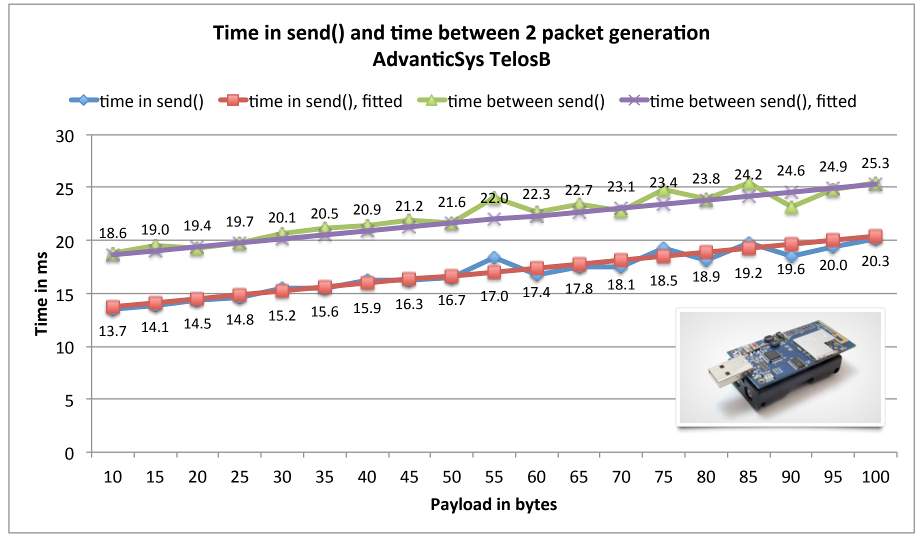


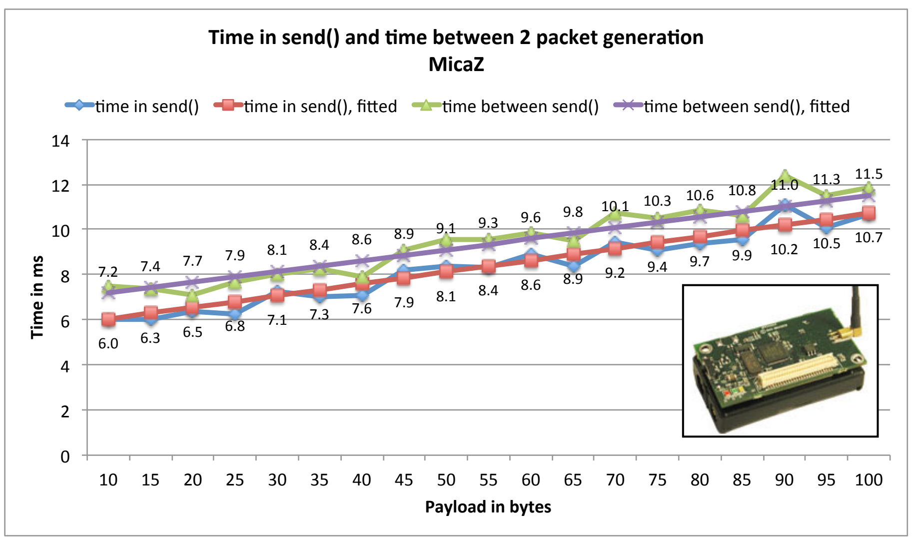

Time between 2 packet generation and time in send(), WaspMote
time between 2 pkt generation
time in send()
time in ms
0 2 4 6 8 10 12 14 16 18
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
7.08 7.51 8.18 9.2 9.23 9.71 10.25 10.69 11.23 11.49 12.2 12.55 13.14 13.54 13.83 14.34 15.03 15.51 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

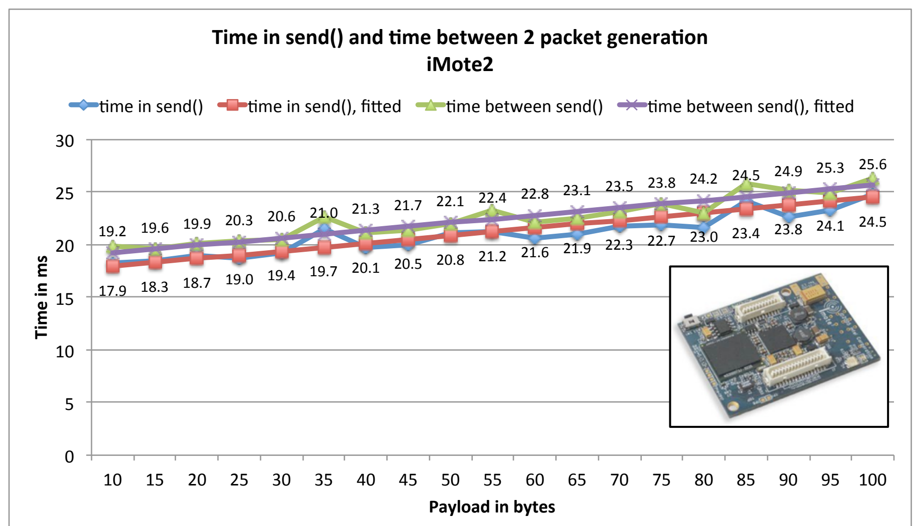

Time between 2 packet generation and time in send(), WaspMote
time between 2 pkt generation
time in send()
Off-the-shelves performances
time in ms
0 5 10 15 20 25 30 35 40
10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
XBee payload in bytes
9.17 10.26 11.8 13.2 15.31 16.17 17.83 19.71 21.14 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

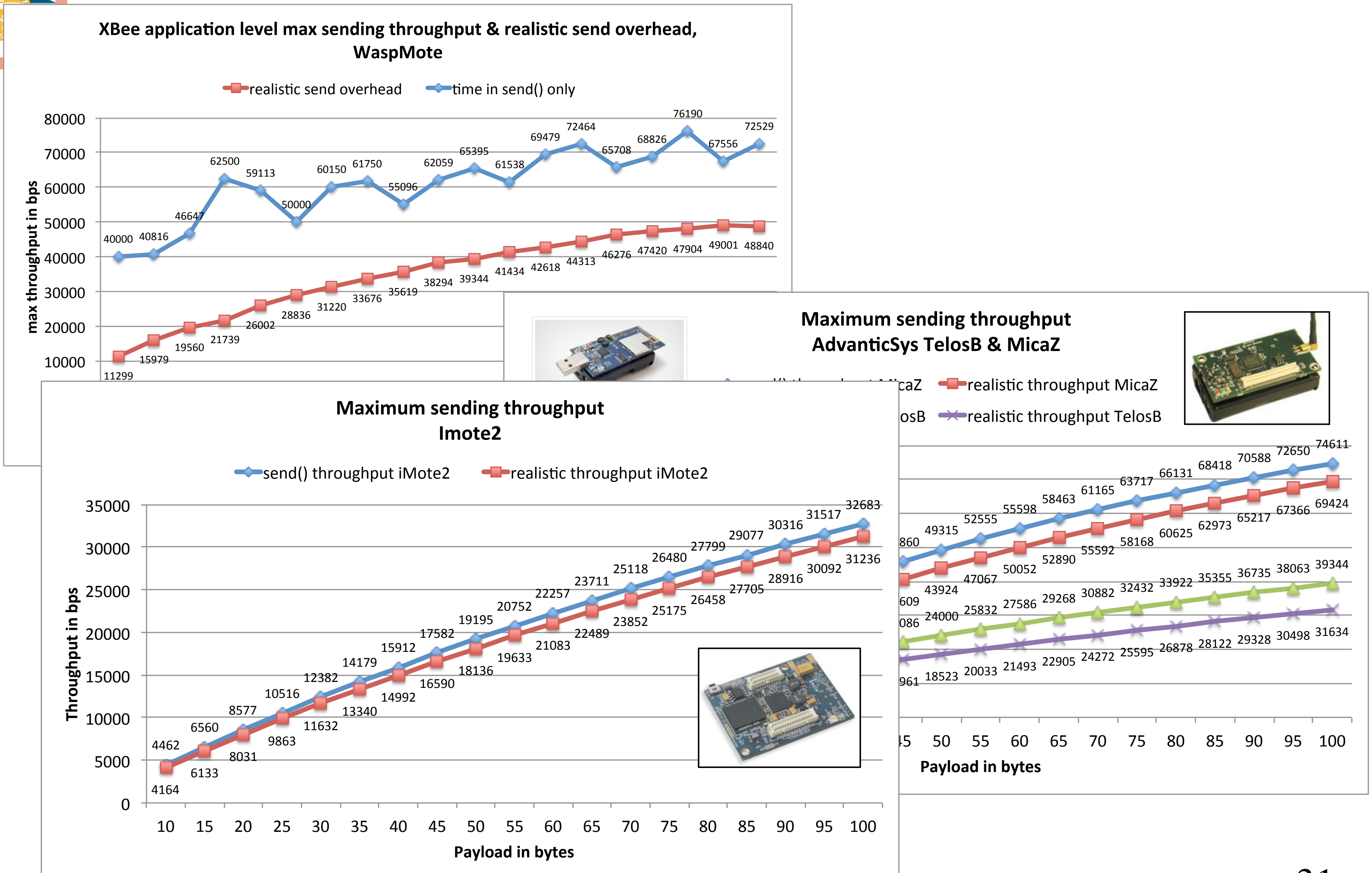




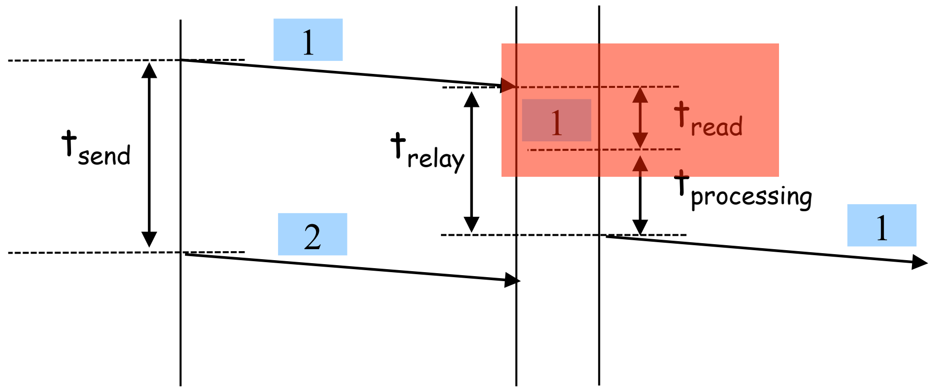




Maximum sending throughput

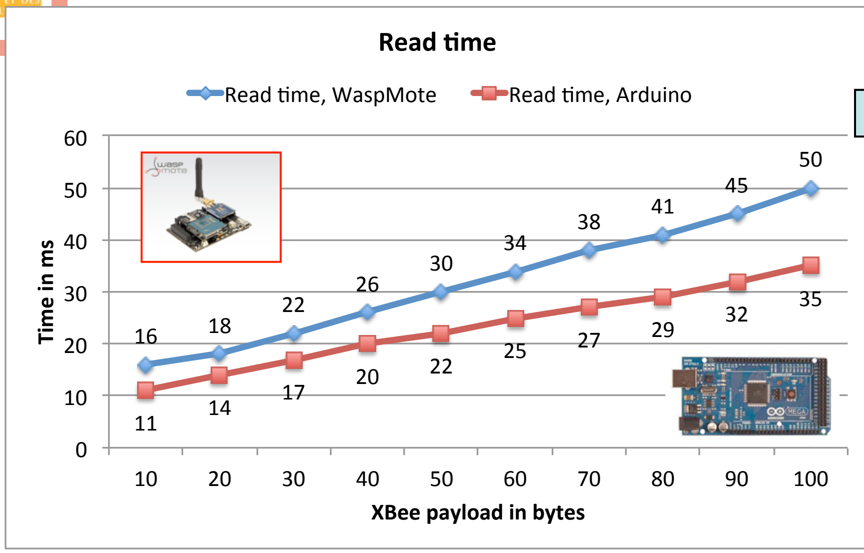


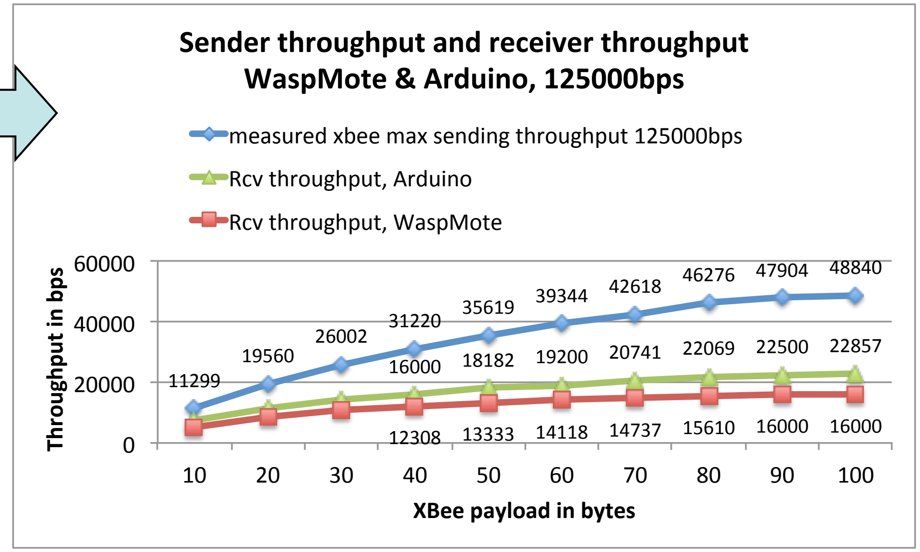
Receive performances

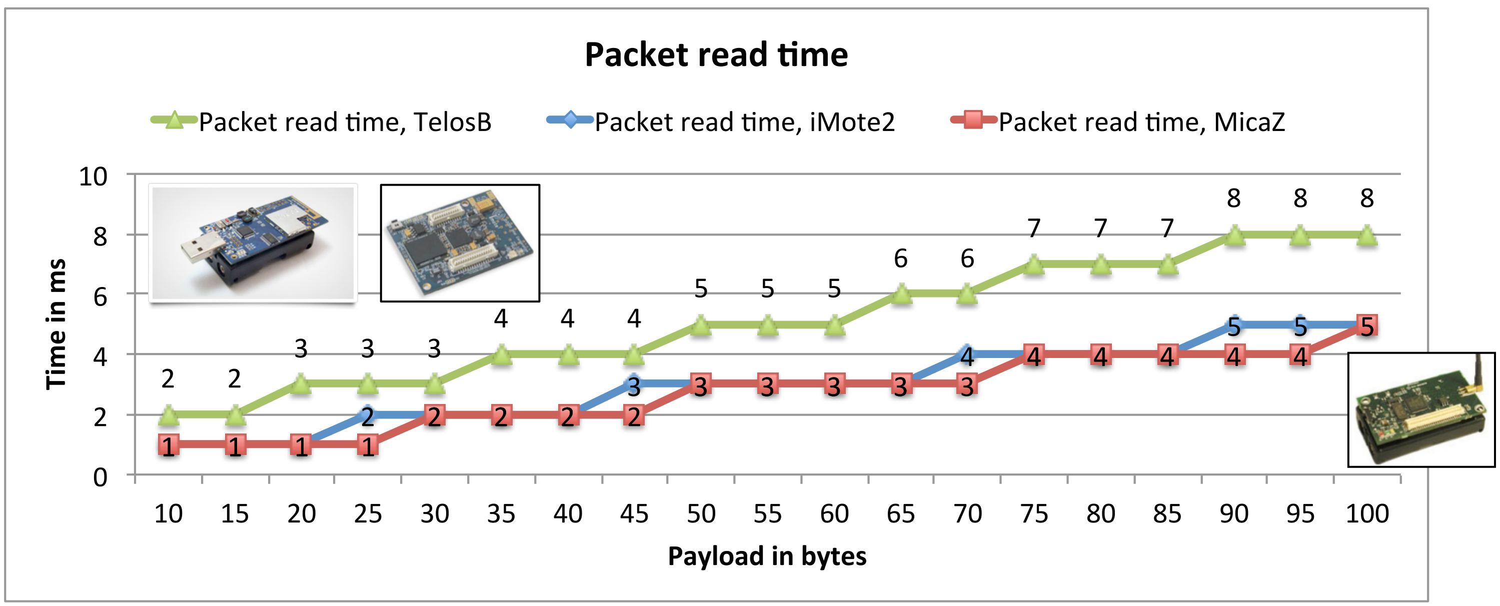


- At sender side, send as fast as possible
- At receiver side, determine T_{READ}
- ... and also compute the maximum receive throughput per packet size

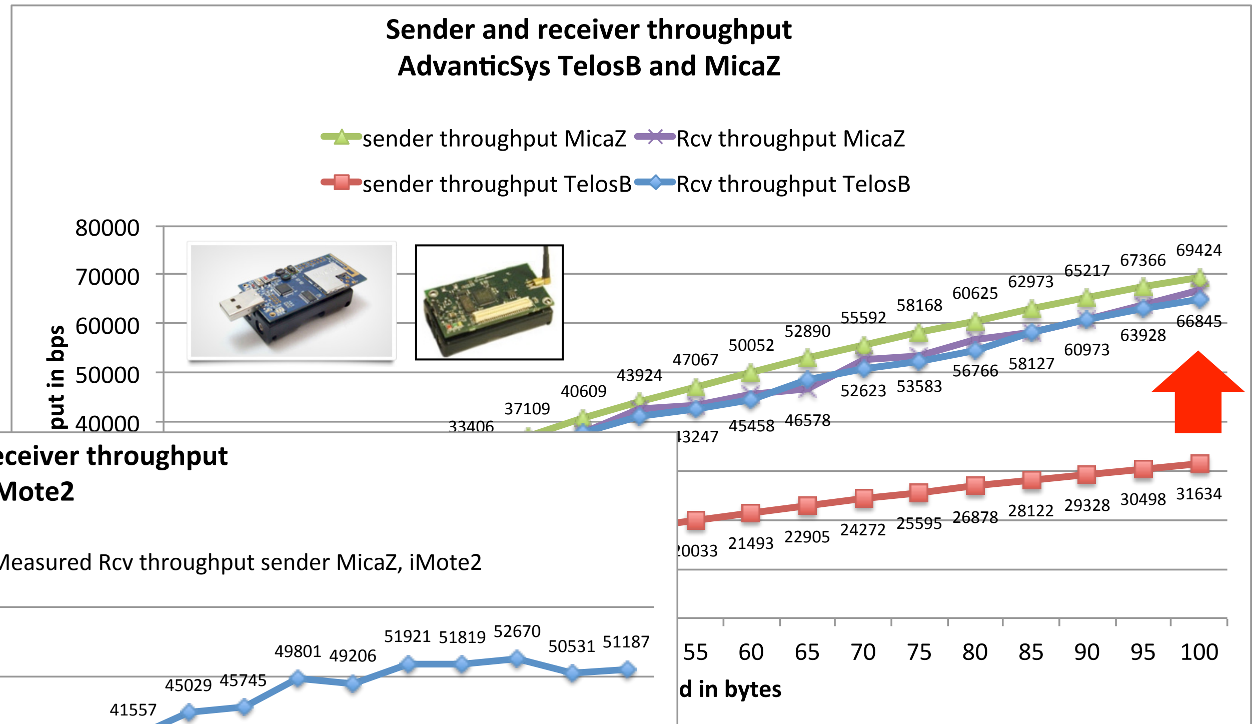
T_{READ} FOR VARIOUS MOTES

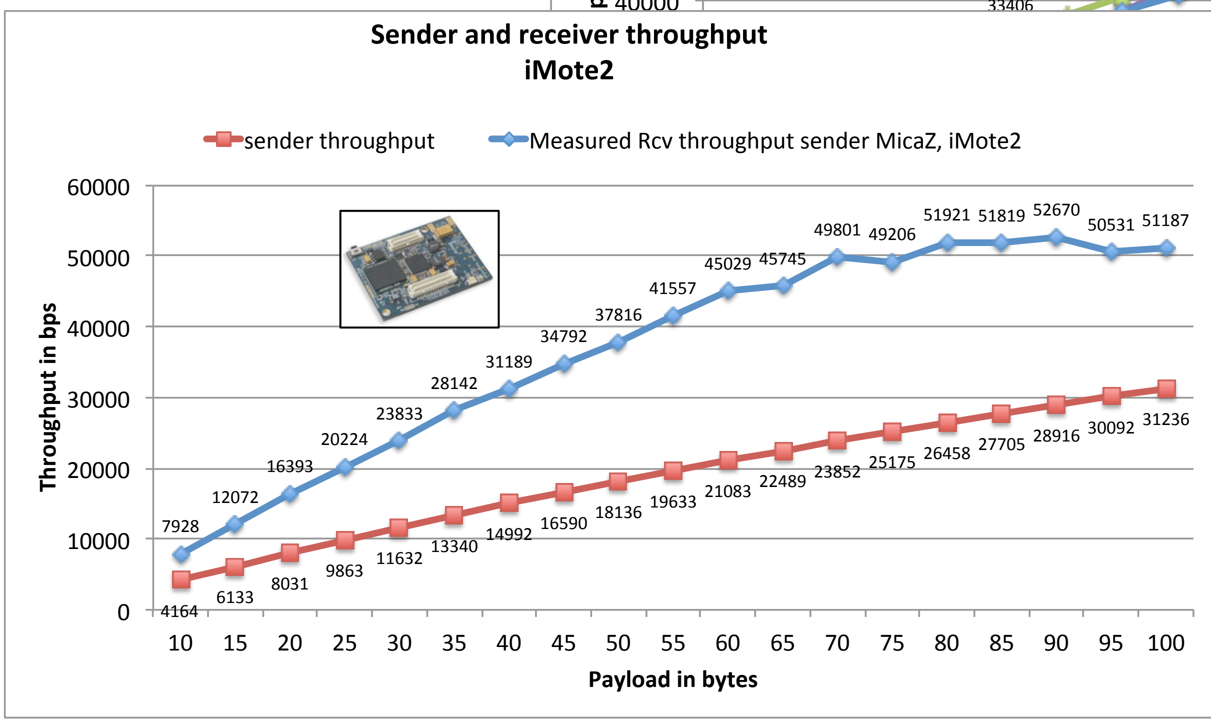




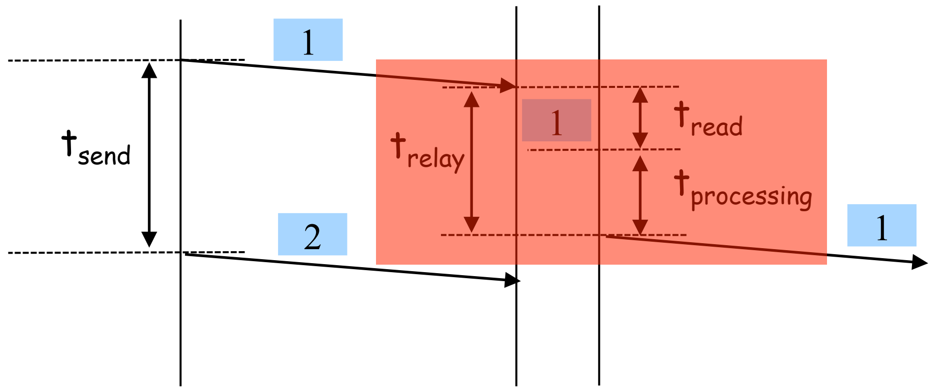


Receiver throughput



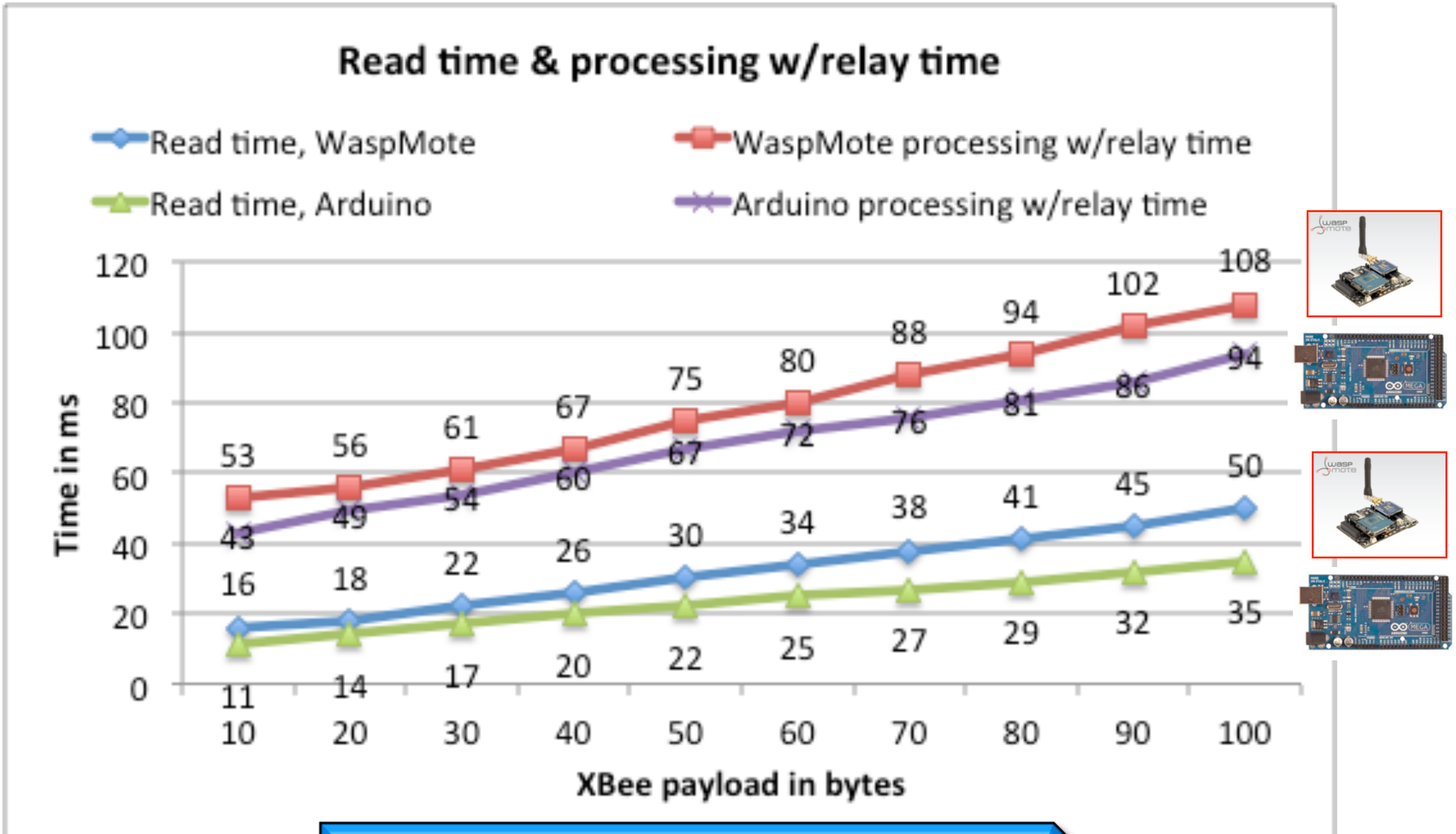


Relay performances



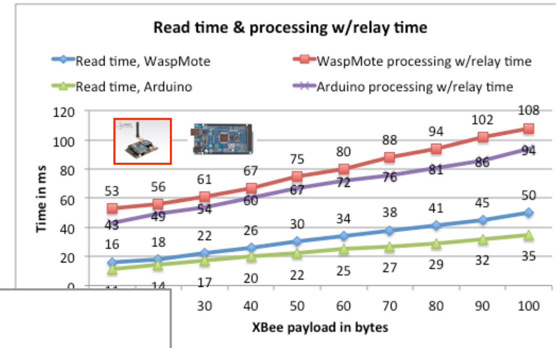
- Relaying are usually done at application-level (even OS level is considered app-level for the mote)
- Relaying means:
  - Read the packet in memory
  - Send the packet to next hop

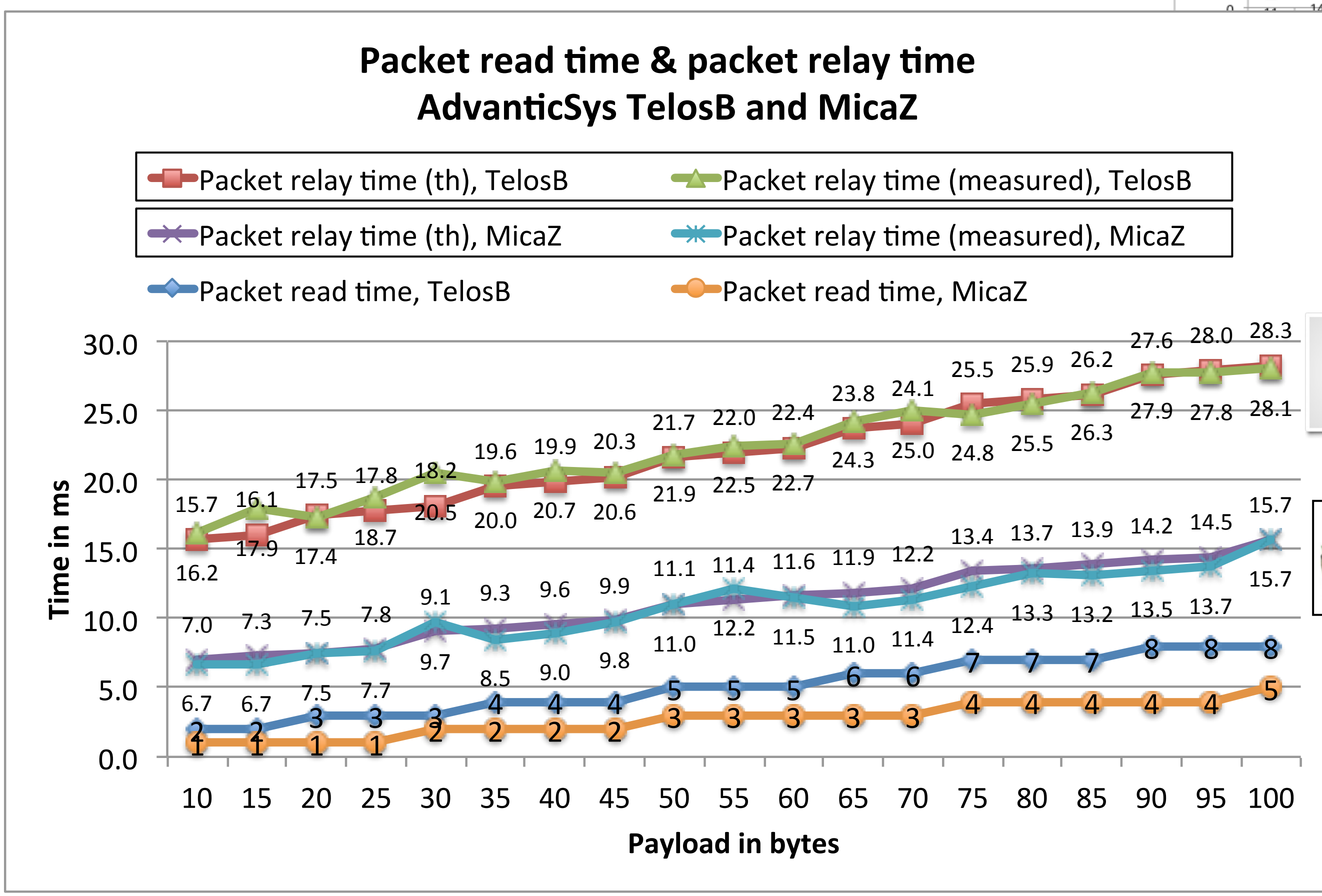
Read time and relay time

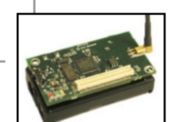


Read time is quite independant from the UART baud rate, but depends on microcontroller frequency

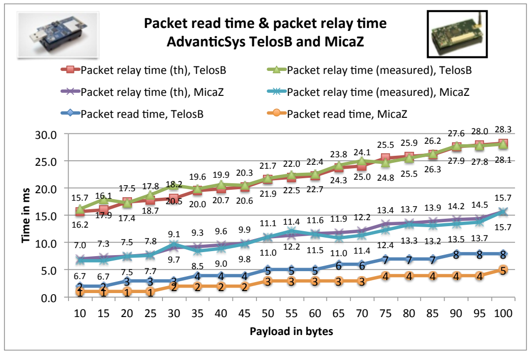
Read time and relay time

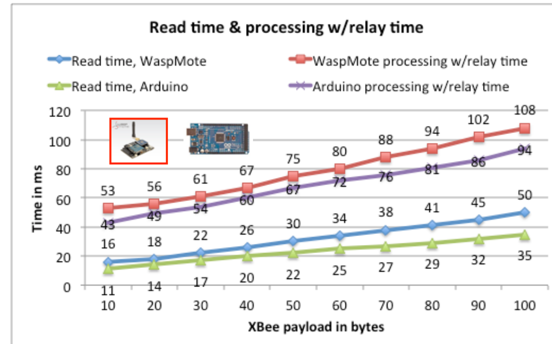


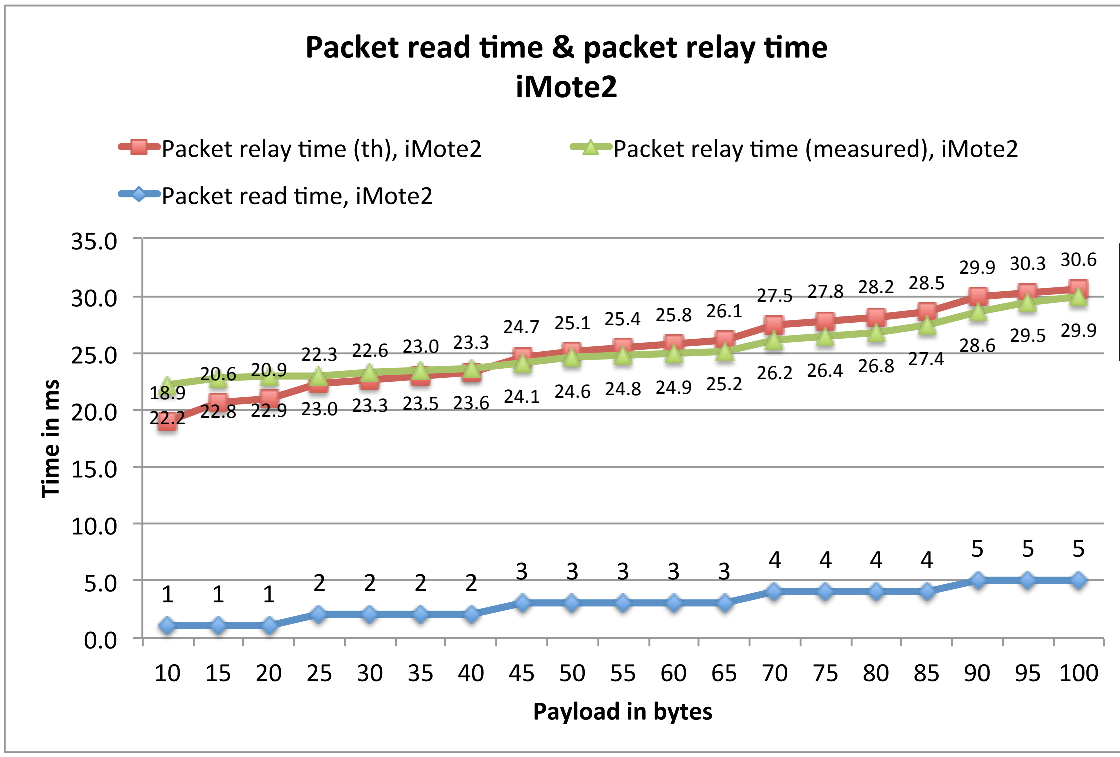


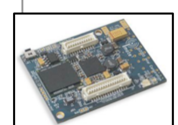


Read time and relay time

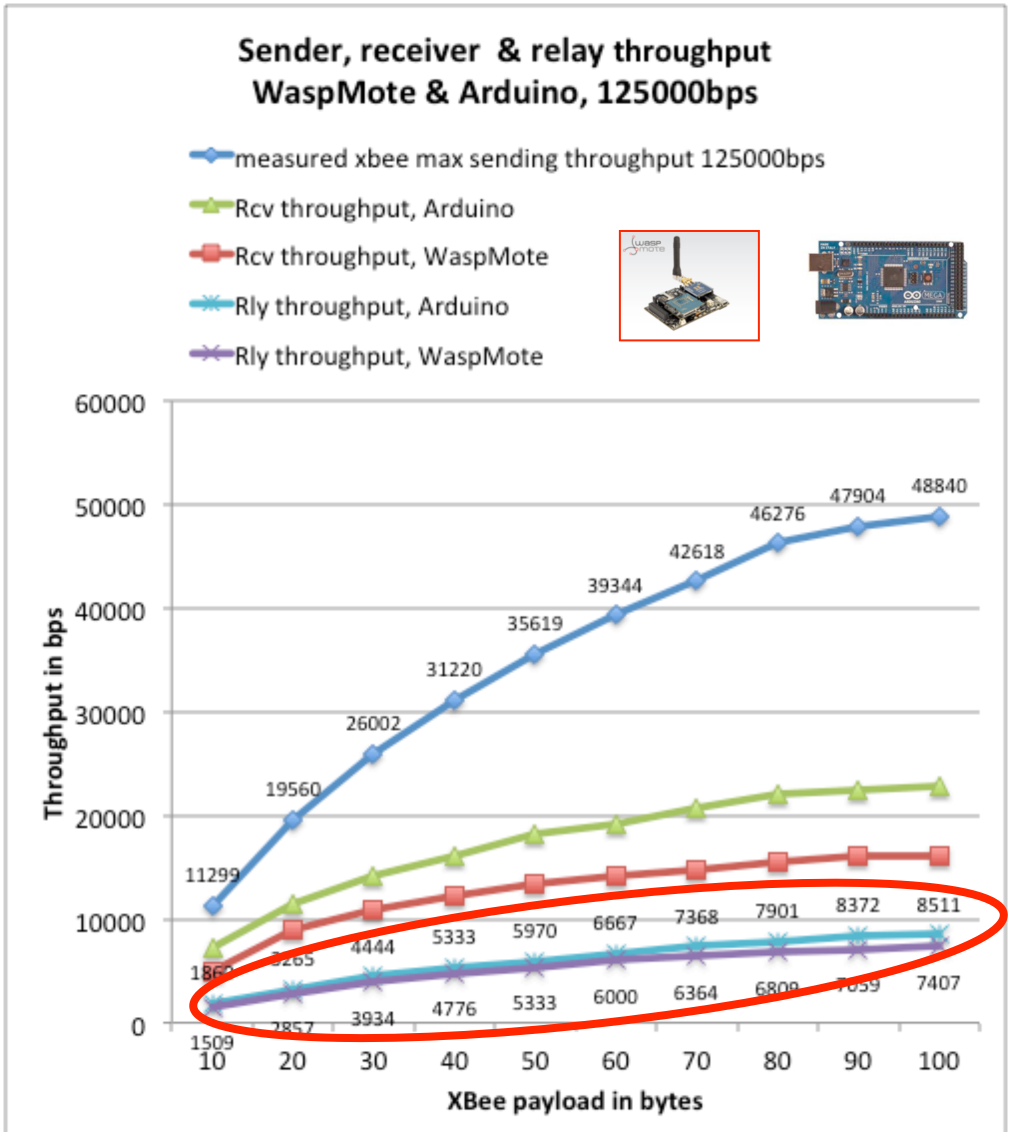




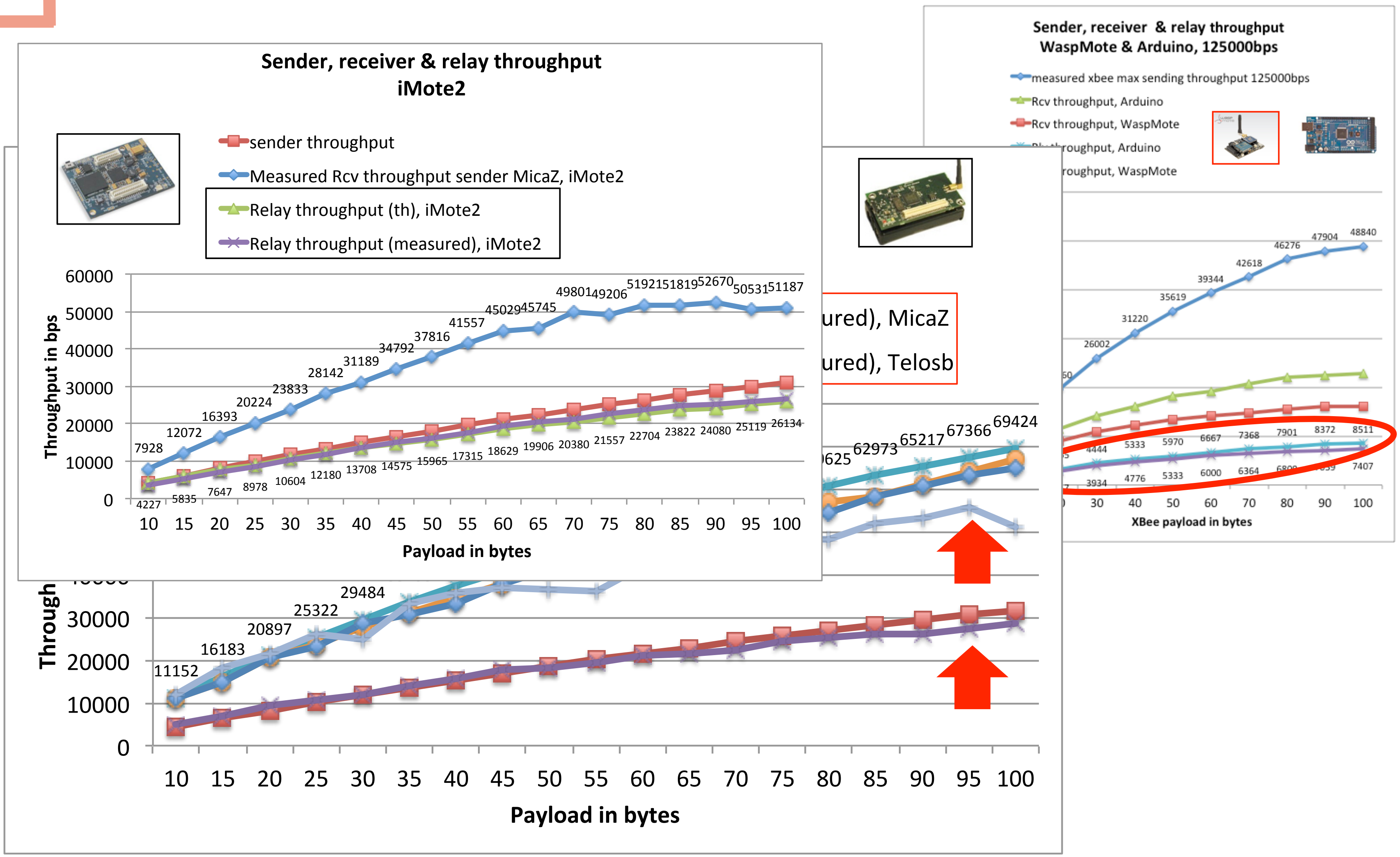




Maximum expected throughput in multi-hop



Maximum expected throughput in multi-hop



Use case
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.

Transmission Time

Original BMP 40000b

250kbps: 1.28s

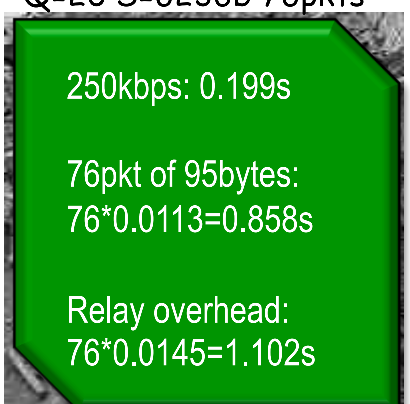
400pkt of 100bytes:
400*0.0115=4.6s

Relay overhead:
400*0.0157=6.28s

Q=50 S=11045b 142pkts

PSNR=25.1661

Q=20 S=6236b 76pkts



250kbps: 0.199s

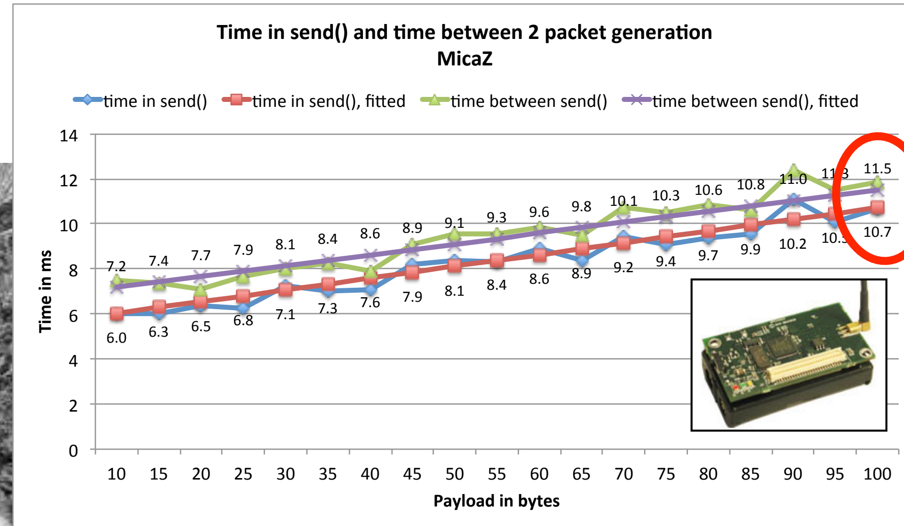
76pkt of 95bytes:
76*0.0113=0.858s

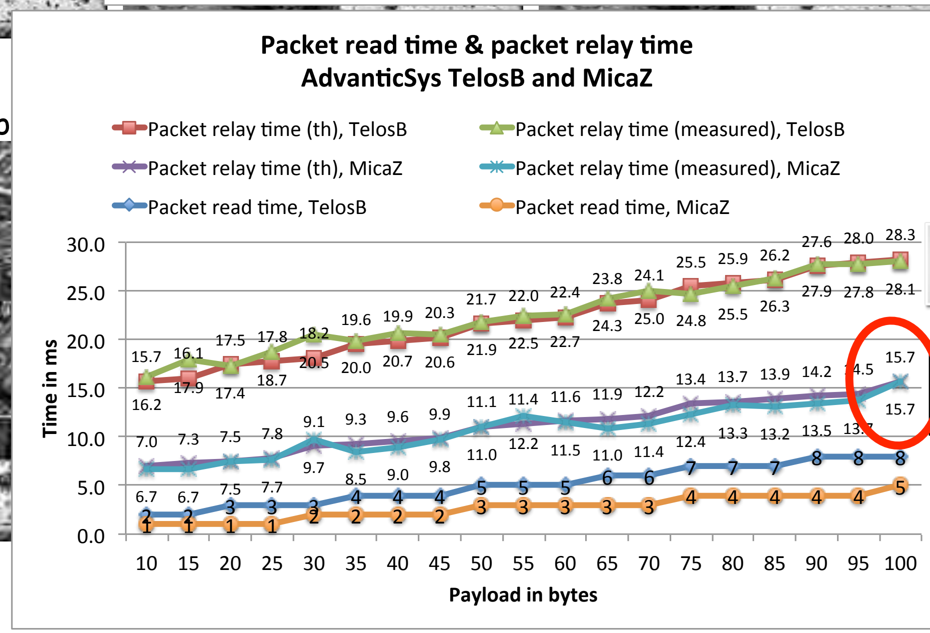
Relay overhead:
76*0.0145=1.102s

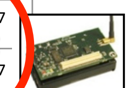
PSNR=22.1293

Q=15 S=5188b 63p

PSNR=21.4475

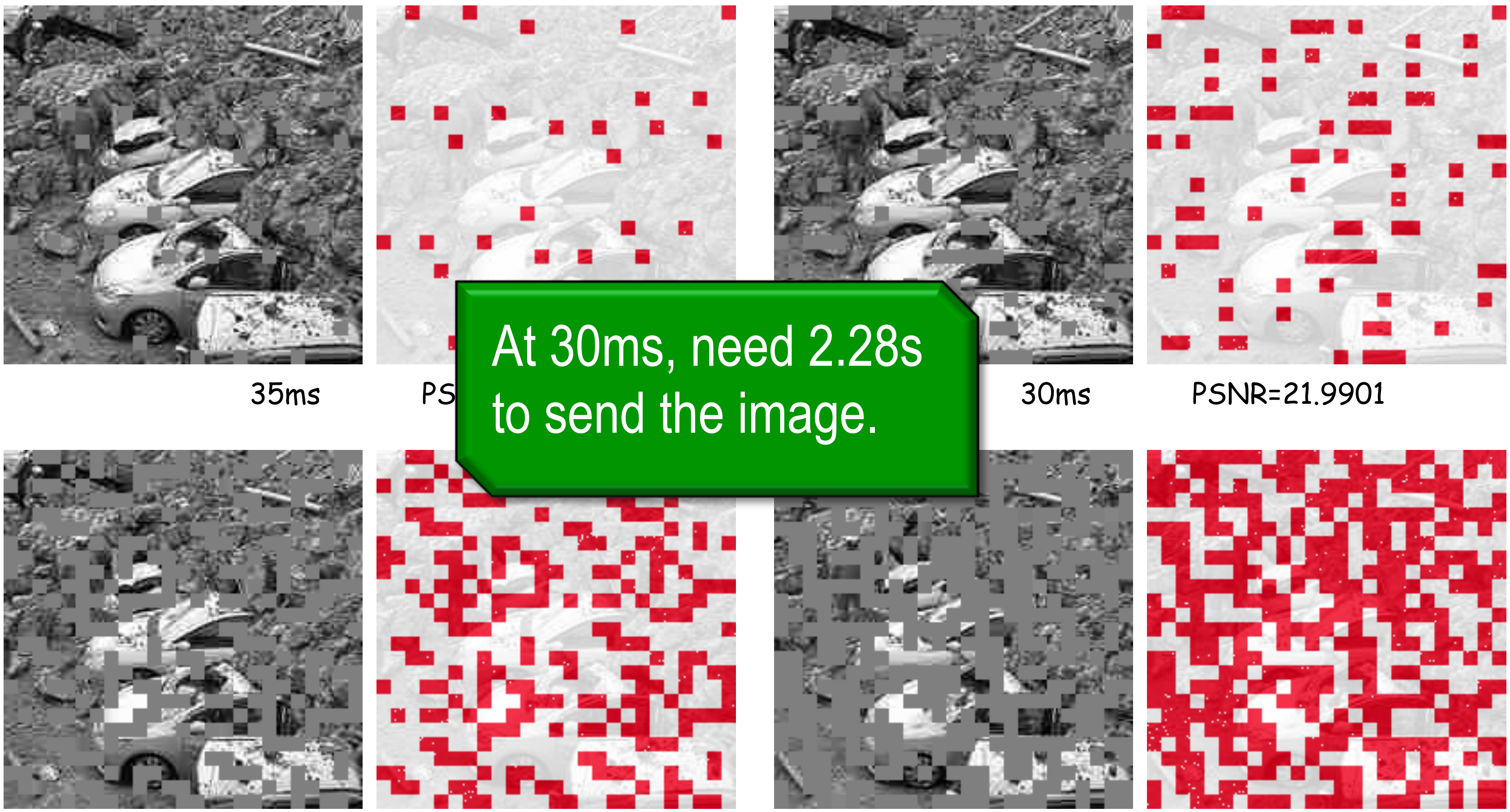






Experimental results Q=20, 76 pkts

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



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

35ms PS

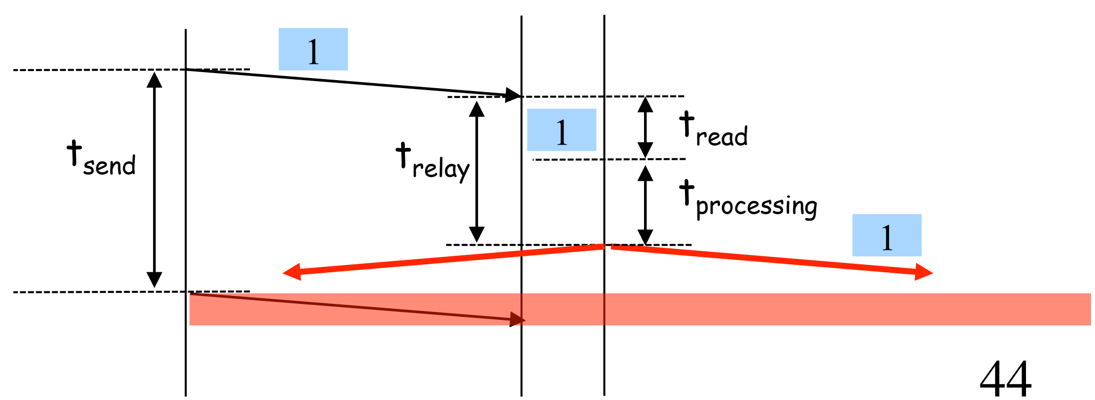
30ms PSNR=21.9901

20ms PSNR=17.265

15ms PSNR=14.2429

What impact on research?

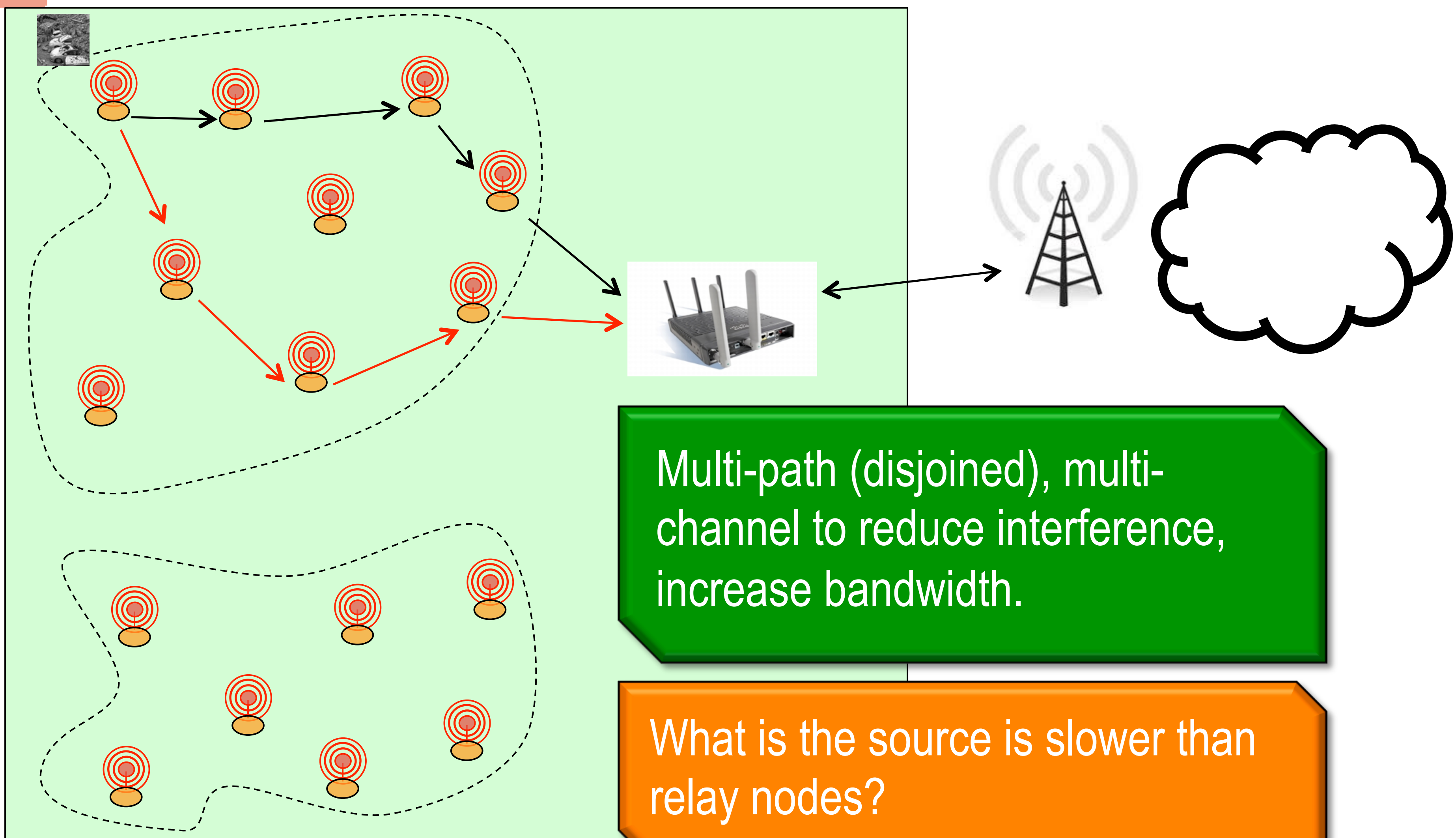
- Preparing image data and transmitting at the source can cost 20ms/pkt (or more!)
- Relaying can be reduced to about 15ms/pkt on some platforms
- Few interference from one node to another



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?

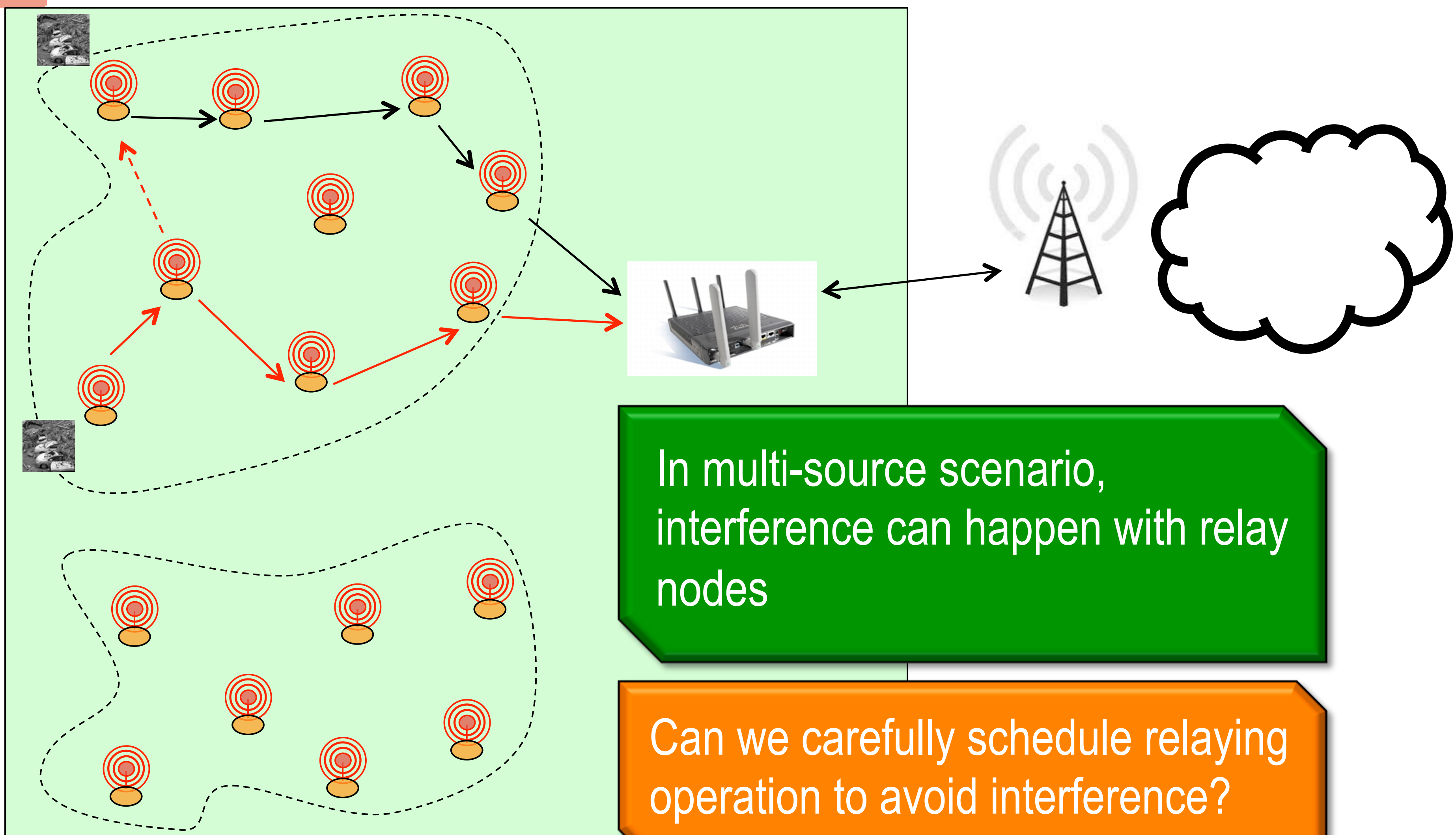
How efficient is multi-path/channel routing?



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?

Use case
Audio streaming

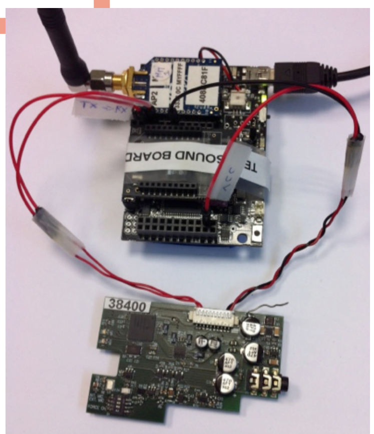
C. Pham, P. Cousin, A. Carer, "Real-time On-Demand Multi-Hop Audio Streaming with Low-Resource Sensor Motes", Proceedings of IEEE SenseApp, in conjunction with LCN 2014, Edmonton, Canada, September 2014.

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.

Summary of audio constraints

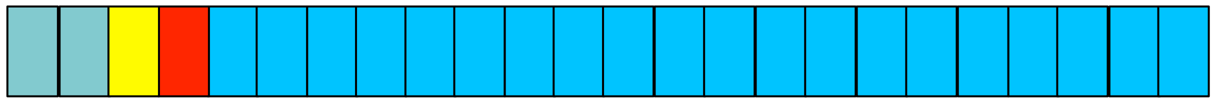
Codec	Minimum sending rate
Raw 4KHz 8KHz	 100 bytes every 25ms 100 bytes every 12.5ms
Speex 8000bps A1 A2 A3 A4	 24 bytes every 20ms 48 bytes every 40ms 72 bytes every 60ms 96 bytes every 80ms

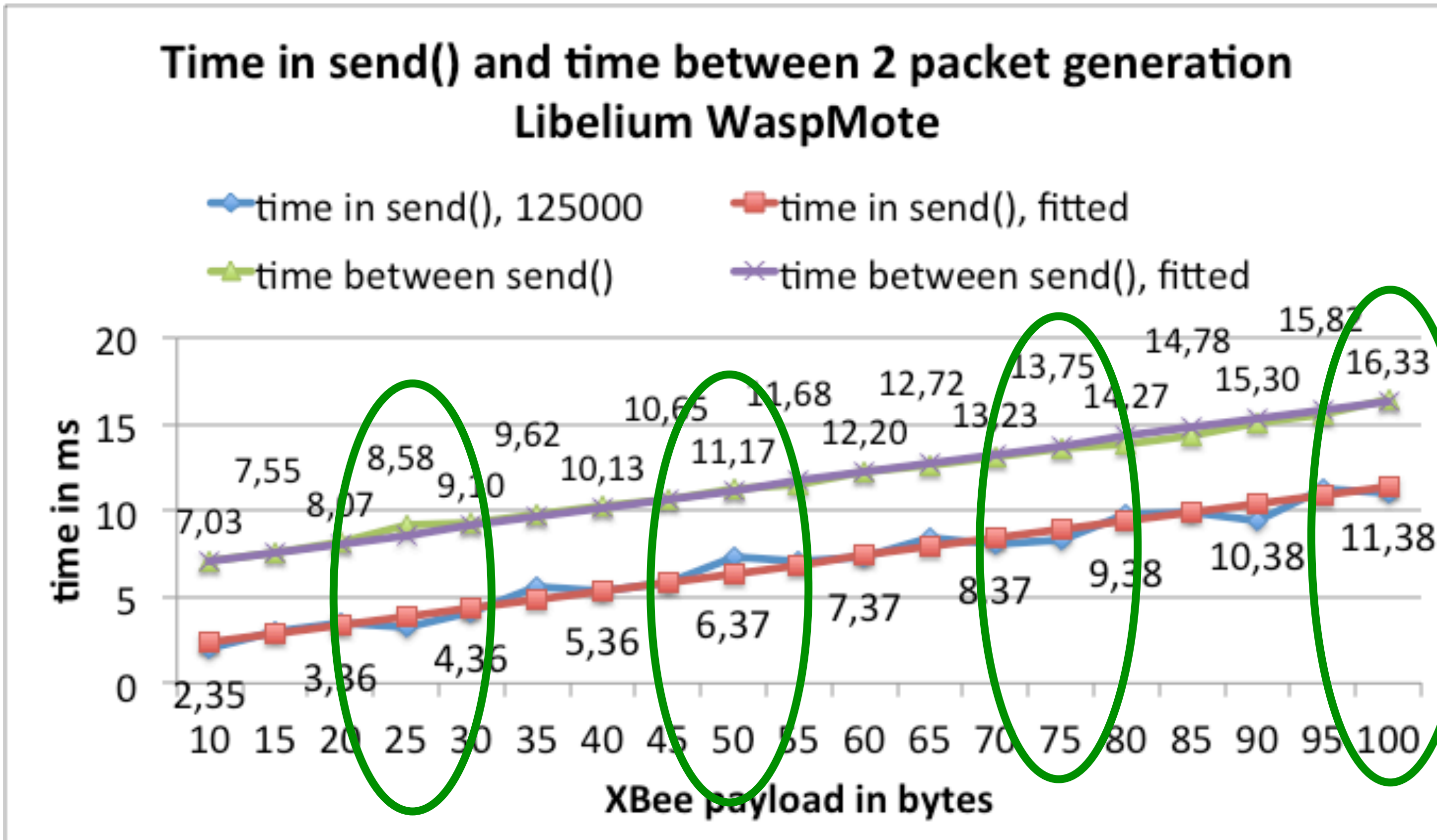
IoT node sending performance



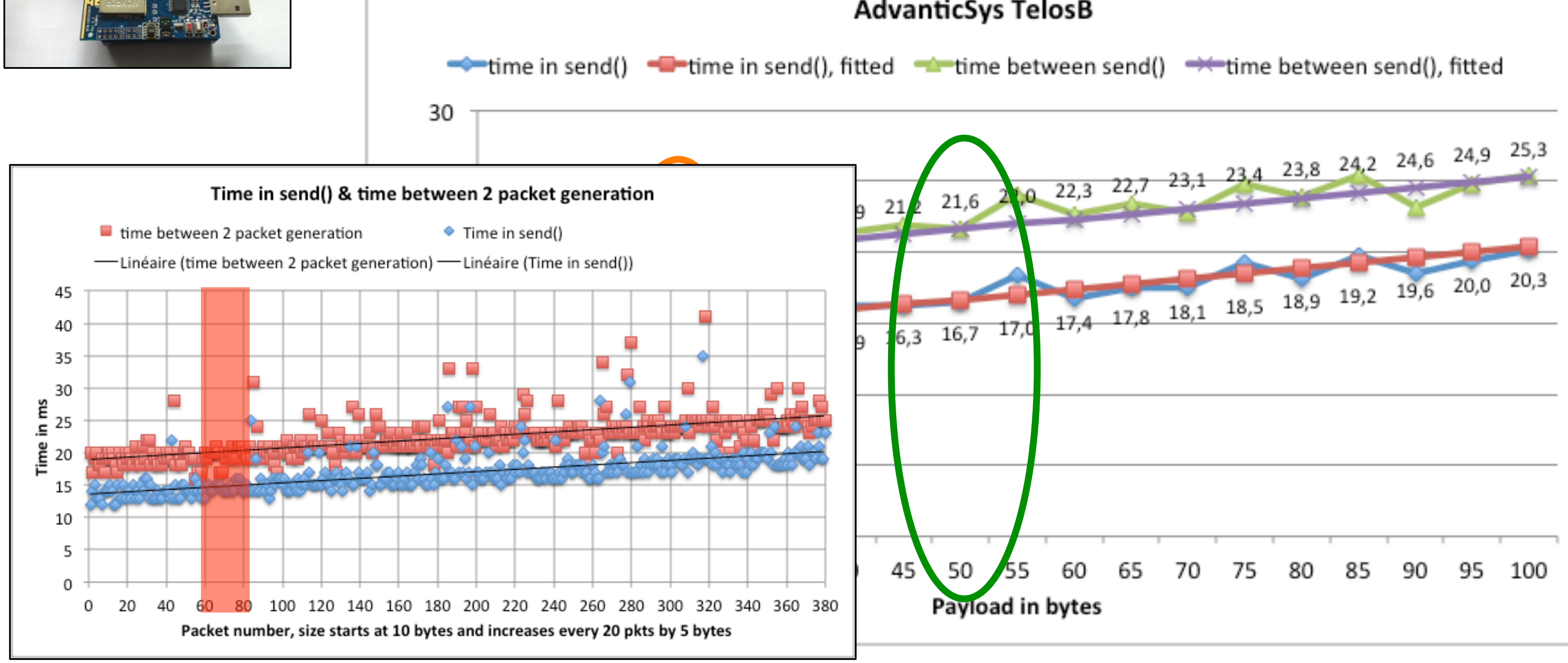
Libelium WaspMote

24 bytes every 20ms



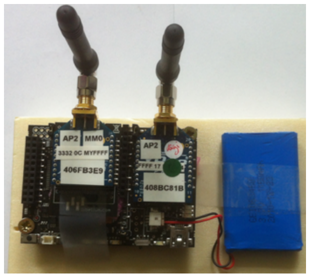


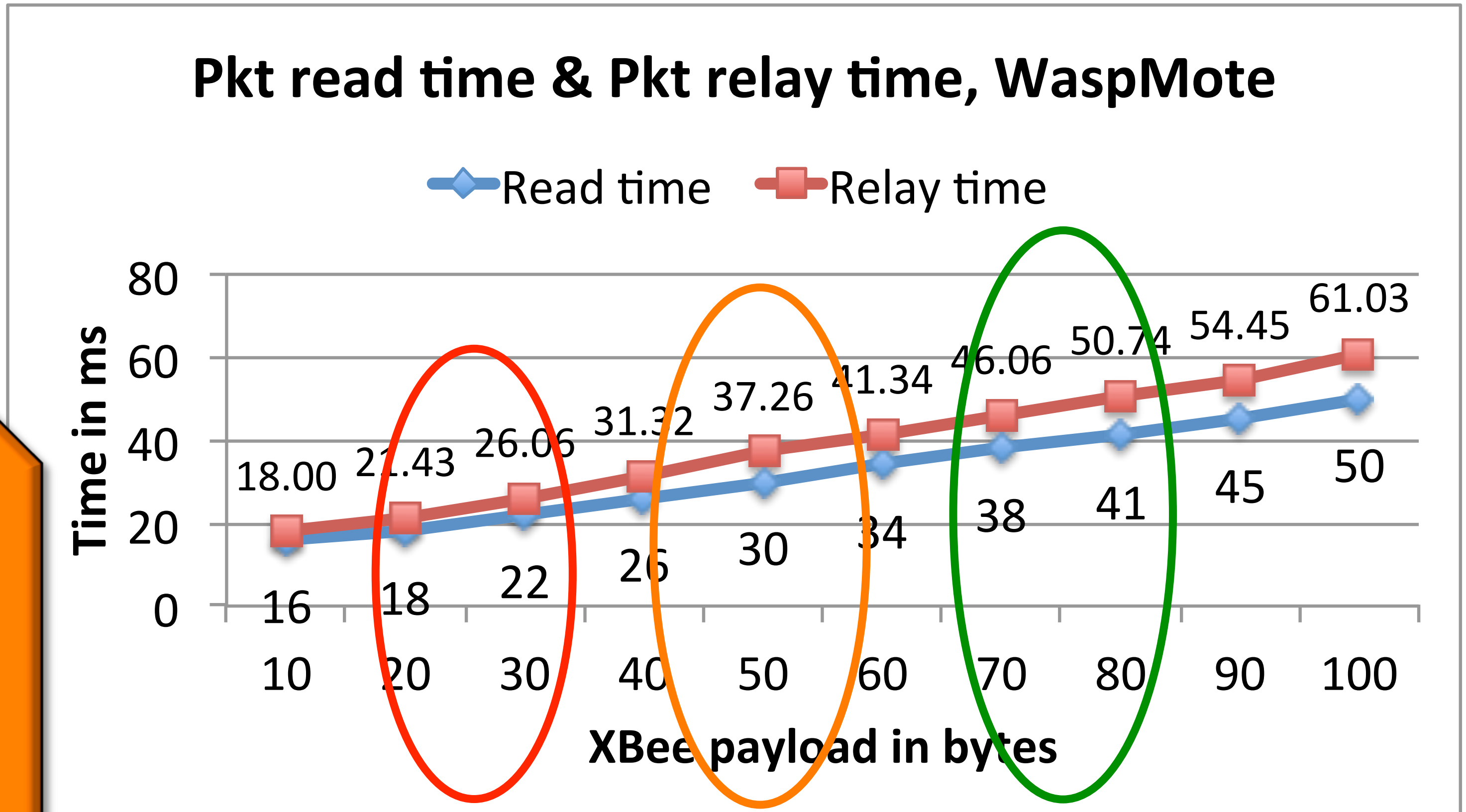
IoT node sending performance



Better with A2 agregation

Relay node performances

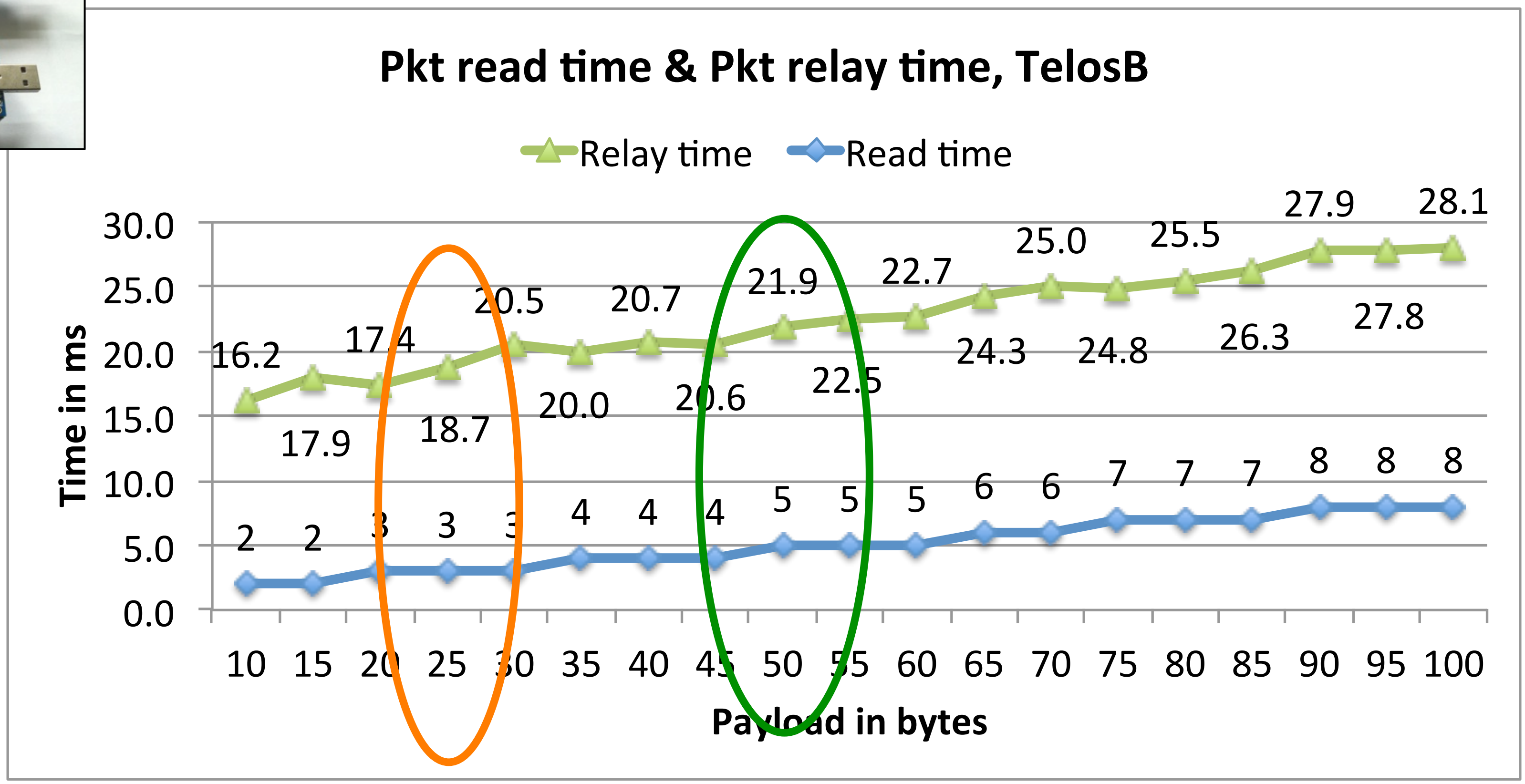




SPEEX codec at 8kbps requires to be able to relay a 25-byte packet every 20ms

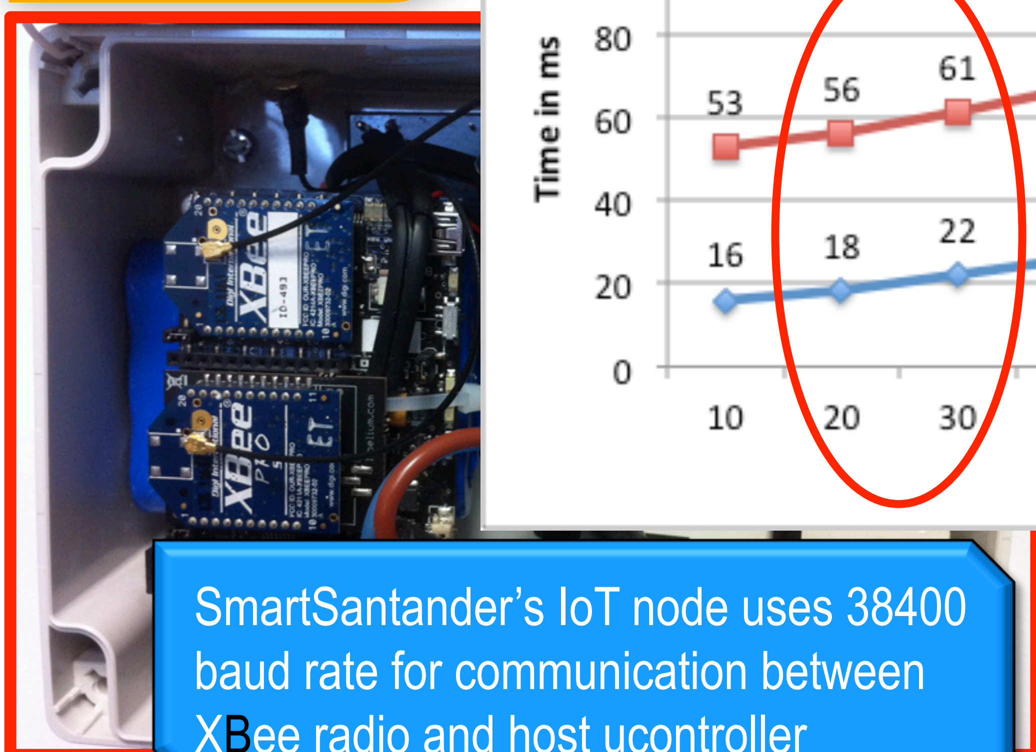
Needs A3 agregation

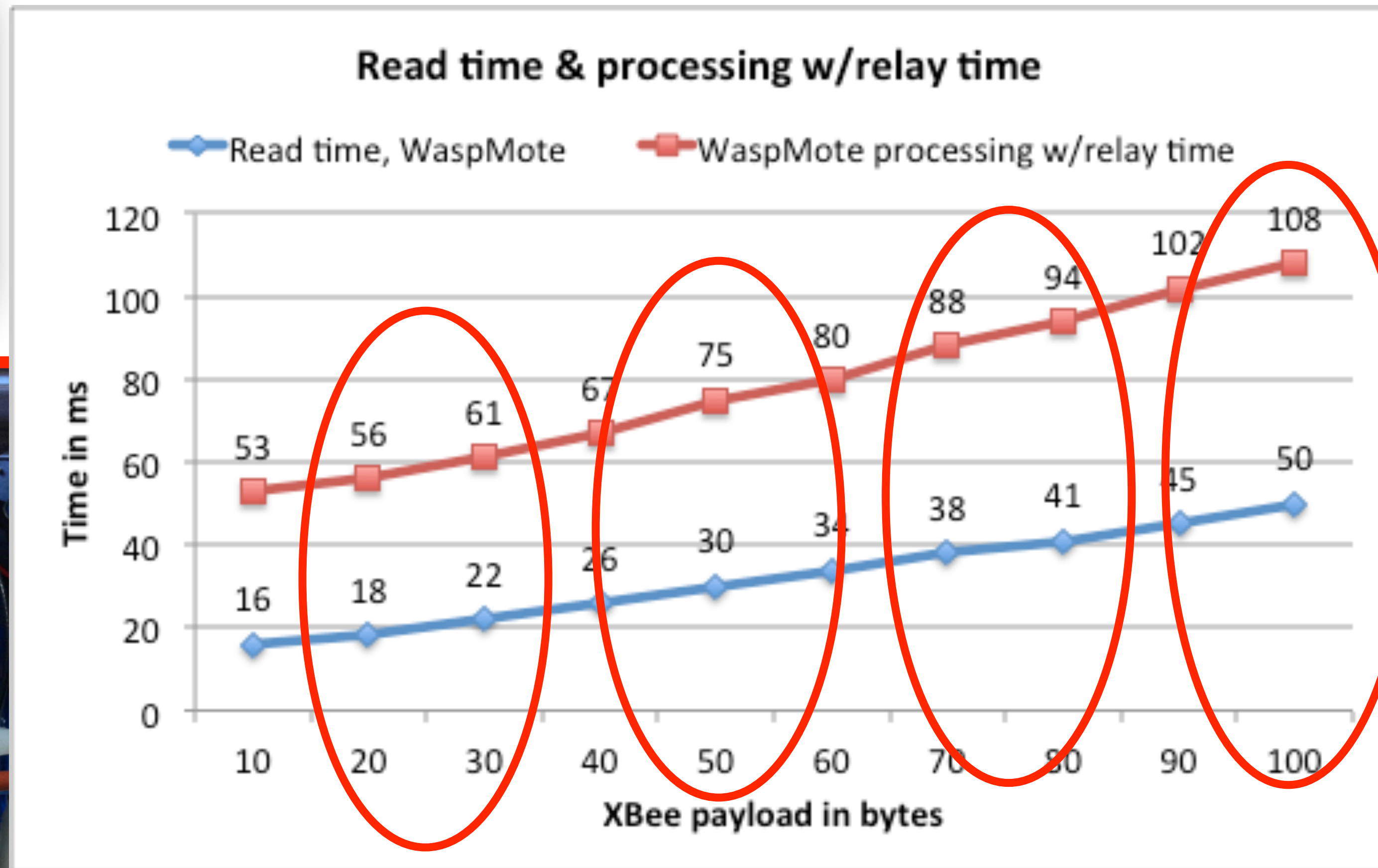
Relay node performances



Needs 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

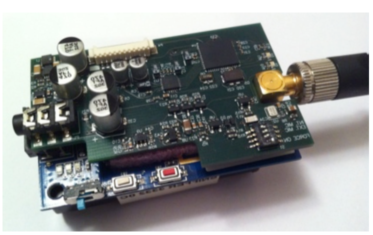
160 bytes (20ms)

20 bytes of encoded audio data

Add framing bytes

1 2 3 4 5 6 7 8

2 3 5 6 8



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

- Multimedia information can improve your surveillance application
- Data-intensive applications put strong requirements of communication performances
- Present realistic performance values
- Knowing real constraints leads to more adapted control mechanisms