EAR-IT

the sounds of smart environment

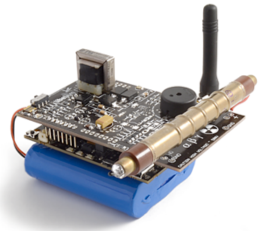
EAR-IT, Acoustic Sensing in Smart Environment: a case for audio streaming with low-resource IoT devices

C. Pham (LIUPPA lab, University of Pau & EGM)

Senzation'14, Biograd na Moru, Croatia. September 1-5, 2014

Internet of Things: Communicating Objects!

- Native communication:



- Added communication

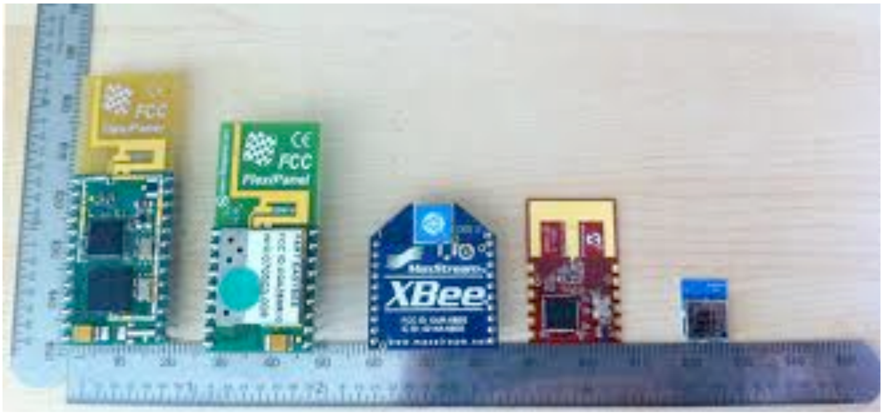
Active communication

Passive communication

NFC

Wireless Communication made easy

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



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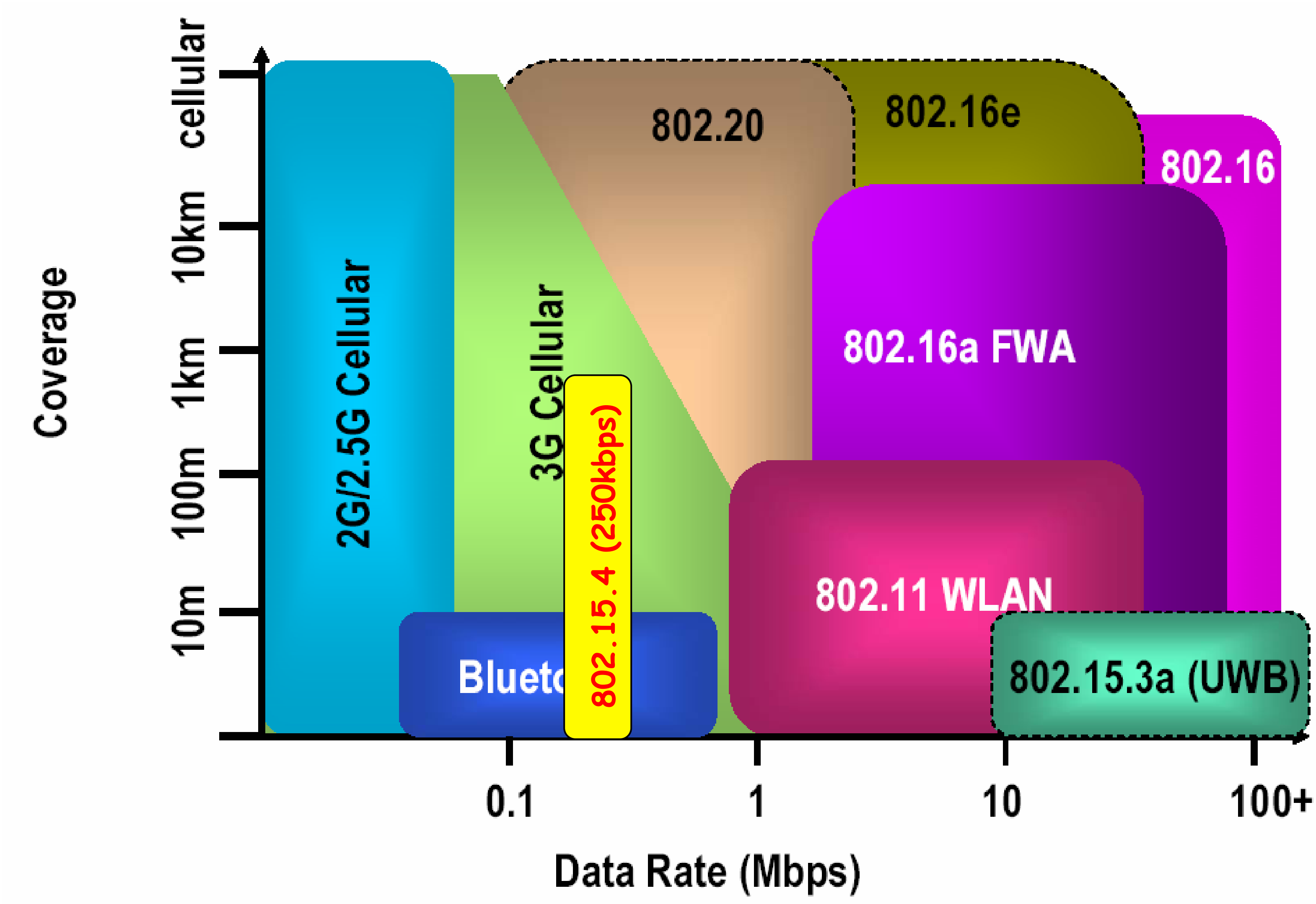
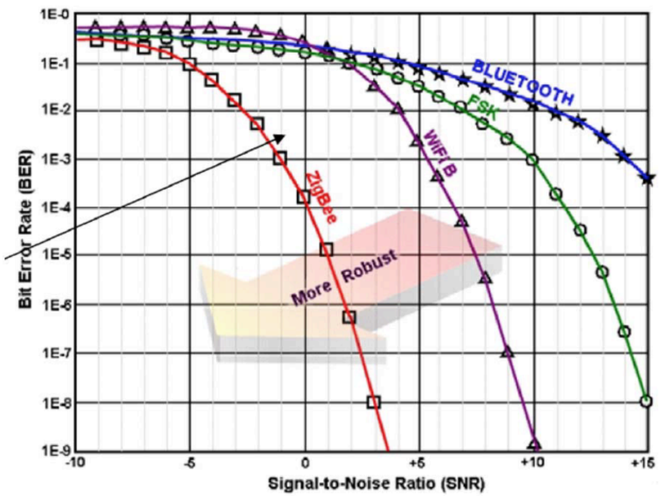
Wireless technologies



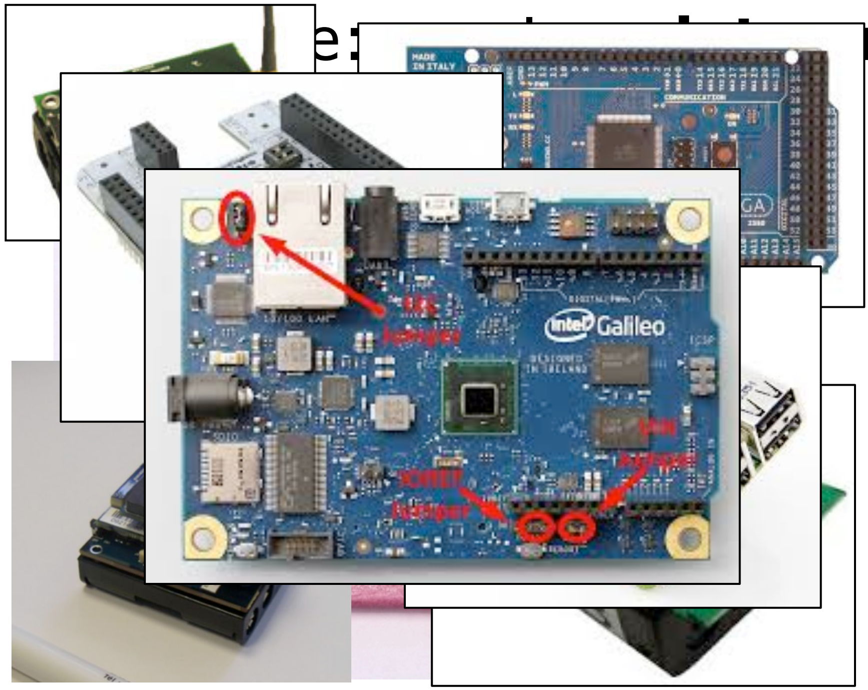
IEEE 802.15.4

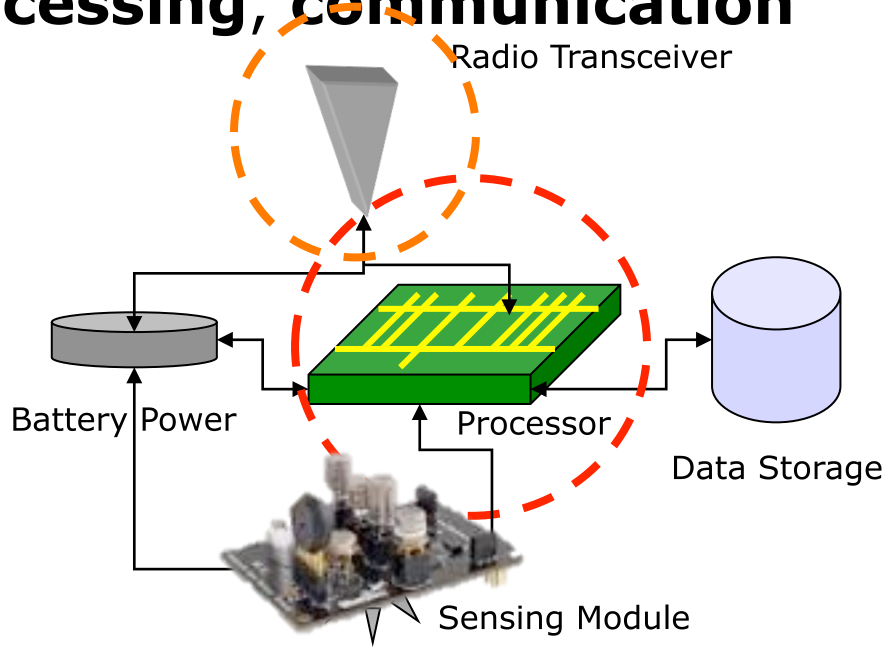
- Low-power radio in the 2.4GHz band offering 250kbps throughput at physical layer
- Power transmission from 1mW to 100mW for range from 100m to about 1km is LOS
- CSMA/CA (beacon & non beacon)
- Used as physical layer in ZigBee



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
- e: ... **rocessing, communication**



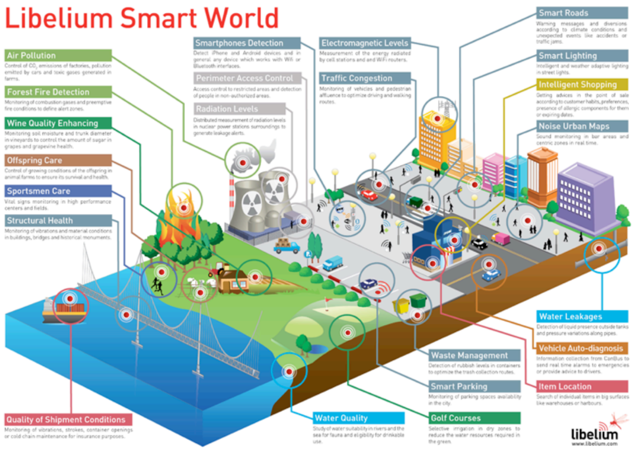


Are you I-o-T or WSN?

- 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

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

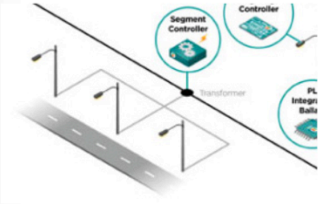
With the use of installed sensors, mobile apps, and real-time web applications like those provided in Streetline's ParkSight service, cities can optimize revenue, parking space availability and enable citizens to reduce their environmental impact by helping them quickly find an open spot for their cars.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

the sounds of smart environments

EAR-IT

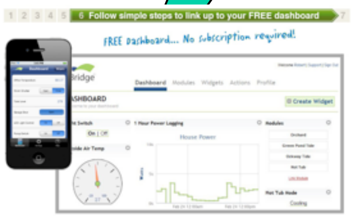
Control, optimize & instrument !

DATA ANALYSIS, OPTIMIZATION & CONTROL

PERVASIVE SYSTEMS

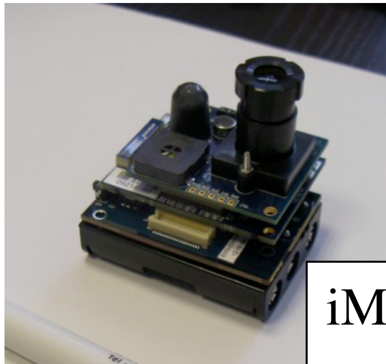
SENSING

PEOPLES, INFRASTRUCTURES, BUILDINGS, VEHICULES



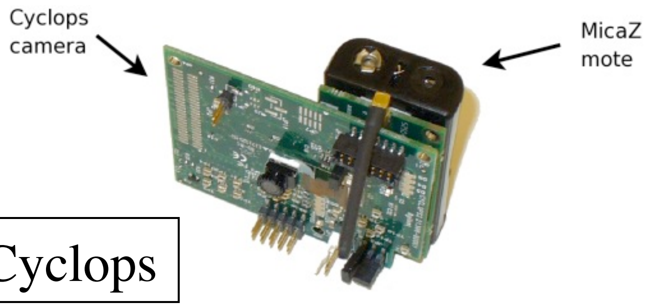
Towards multimedia information

Towards multimedia information

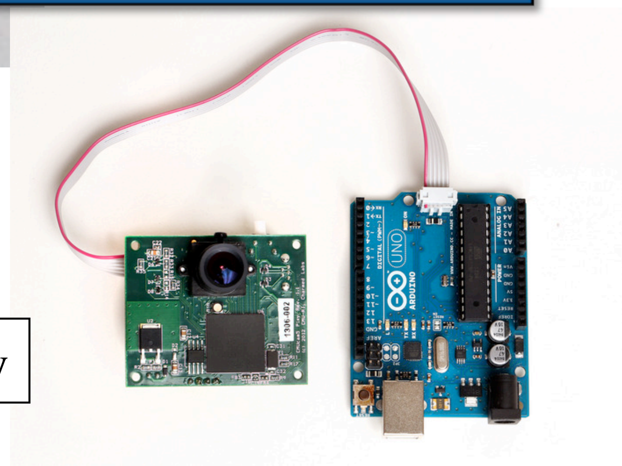


iMote2 with IMB400 multimedia board

Few studies or products for audio/acoustic sensing



Cyclops



Pixy

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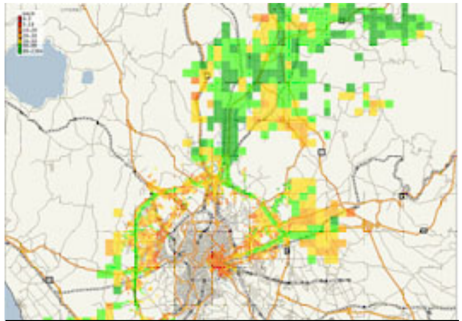
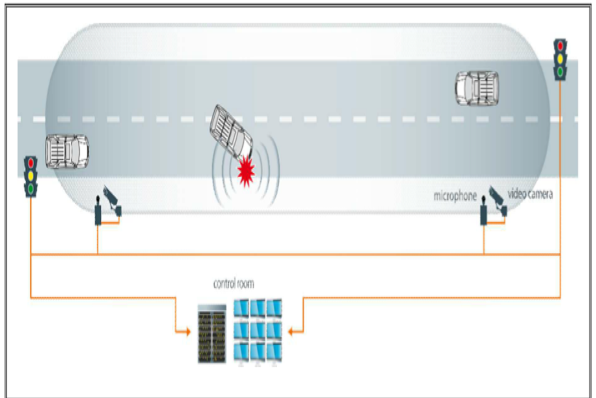
Exploiting Acoustic data



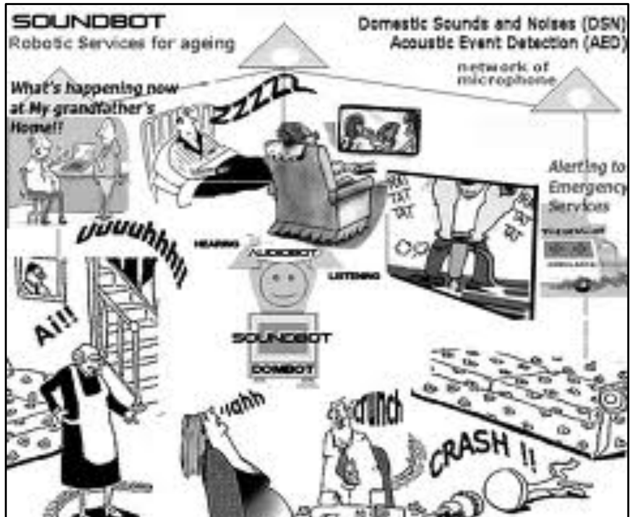
Sound Mappings

Traffic Management

Energy-efficiency



Traffic Accidents



Ambient Assisted Living

(Audio) Surveillance

From EAR-IT slides

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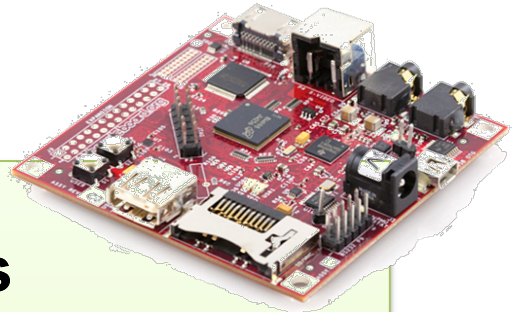
Use of Complementary Technologies

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*

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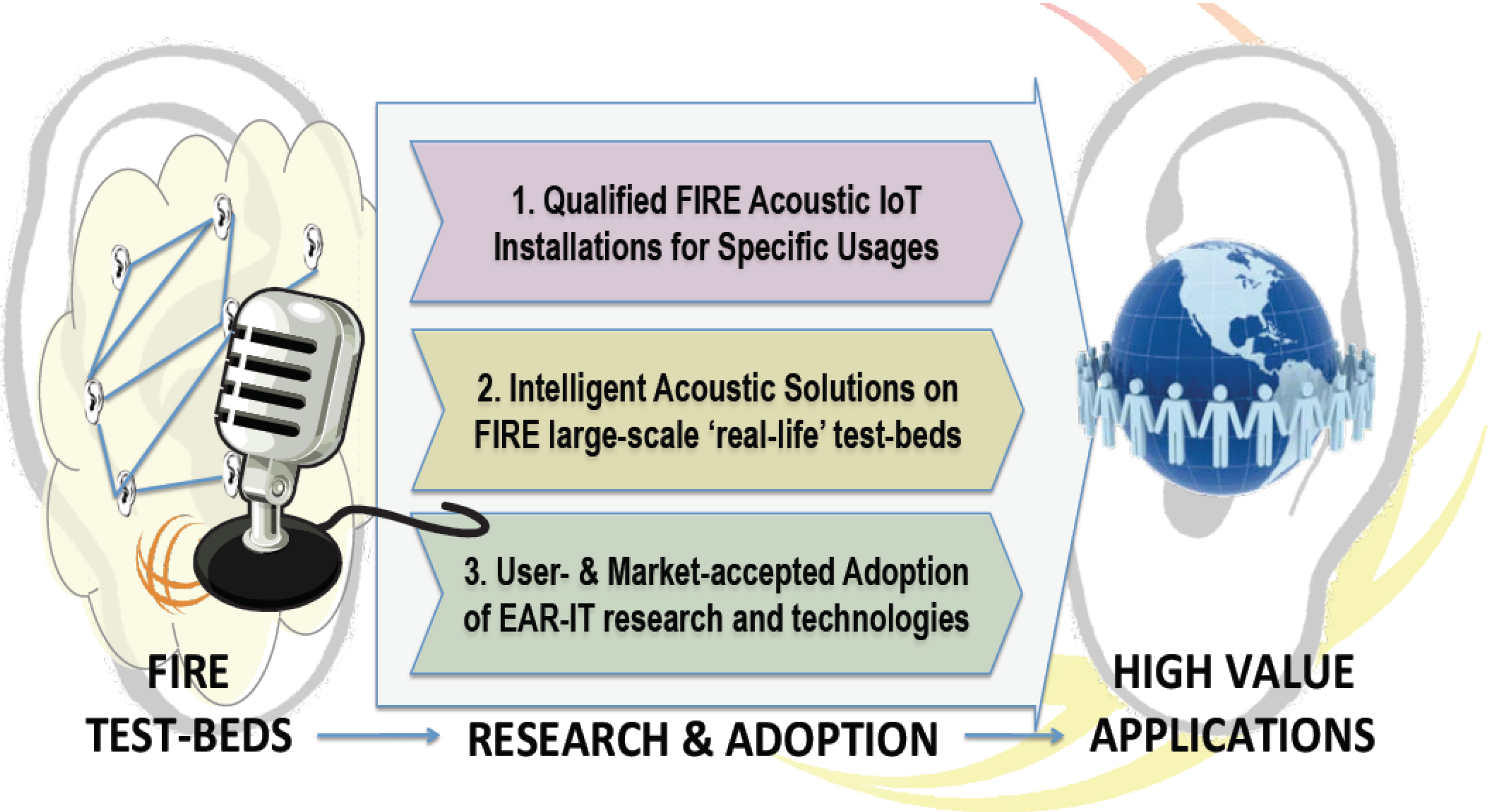
Combining the complementary Acoustic Sensing and Internet-of-Things technologies of today for value

From EAR-IT slides

EAR-IT research experiment approach



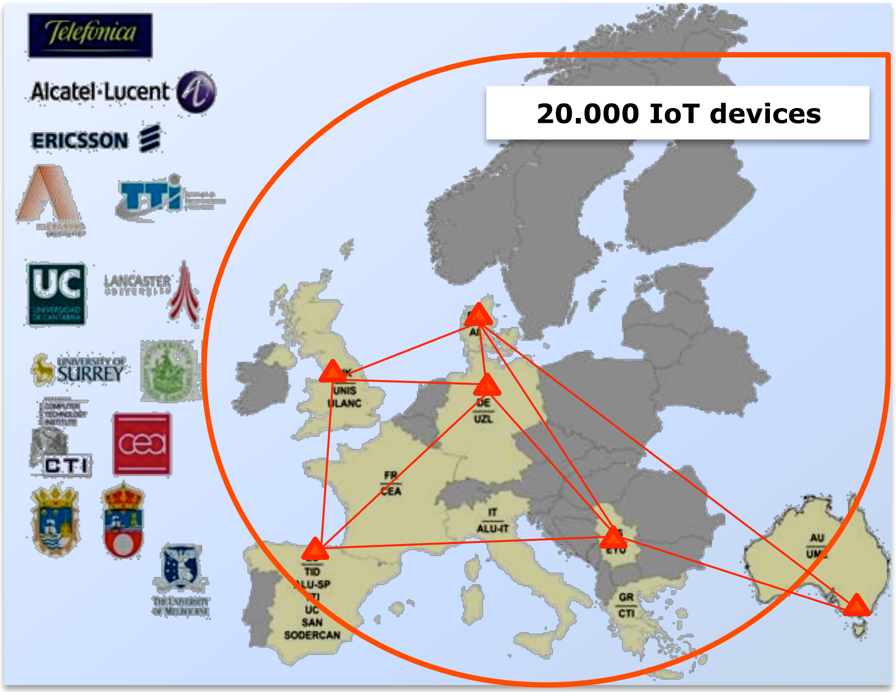
From EAR-IT slides

EAR-IT test-beds

From EAR-IT slides

SmartSantander test-bed

SmartSantander aims at providing a European **experimental test facility** for the **research** and **experimentation** of architectures, key enabling technologies, **services** and applications for the Internet of Things (IoT) in the context of the **smart city**.



Smart Santander Highlights

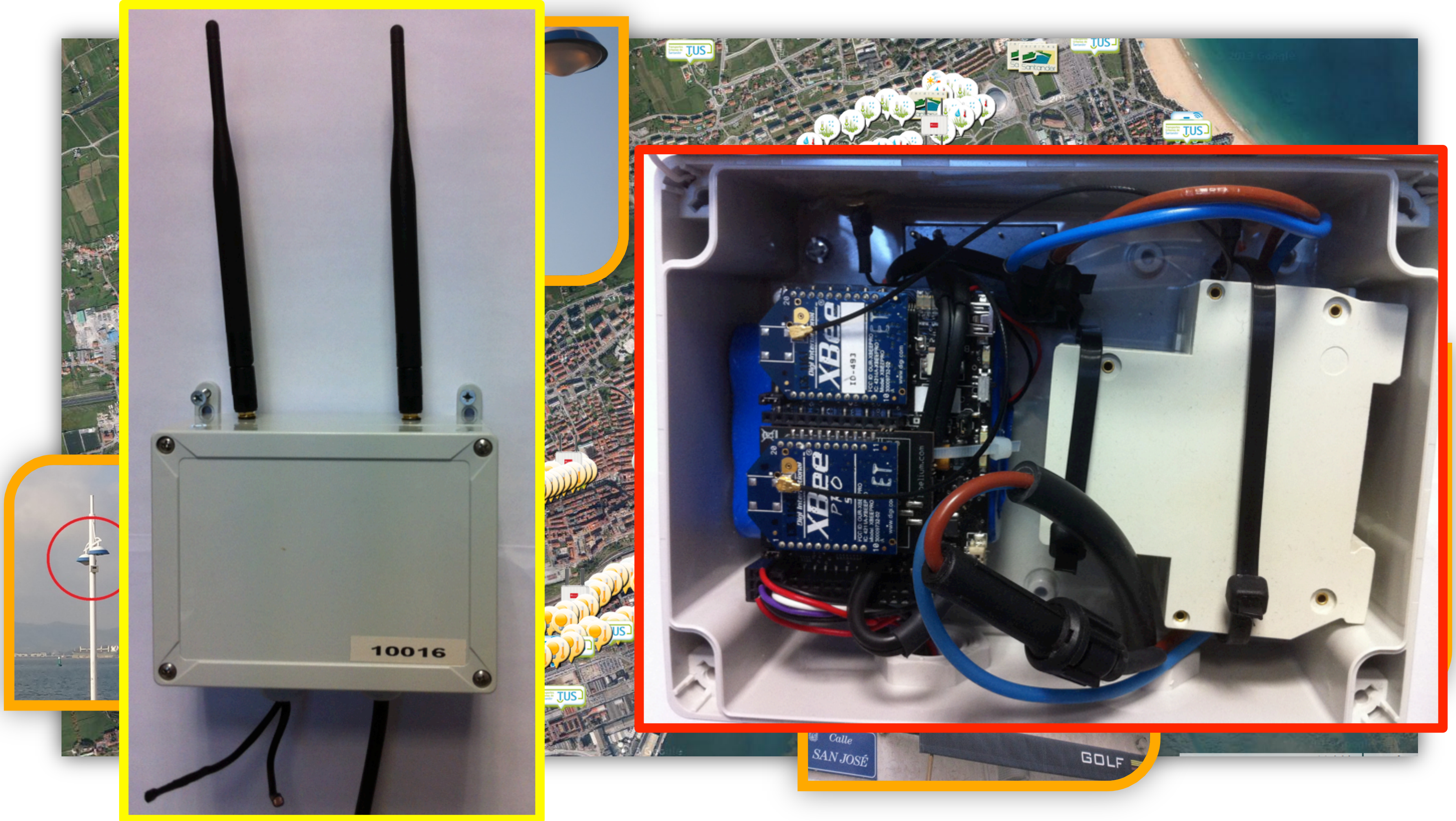
- **Targeting:**
  - Researchers
  - End users
  - Service providers
- **Duration**
  - 36 months
- **Consortium**
  - 15 Organisations
  - 8 EU countries + AU
- **Budget / Funding**
  - 8.6 M€ / 6 M€
- **Resources**
  - 746.2 PM

From EAR-IT slides

SmartSantander test-bed

Santander's sensor network deployment

SmartSantander test-bed
Santander's sensor network deployment



SmartSantander IoT node

libelium
comunicaciones inalámbricas distribuidas

ATmega1281 microcontroller

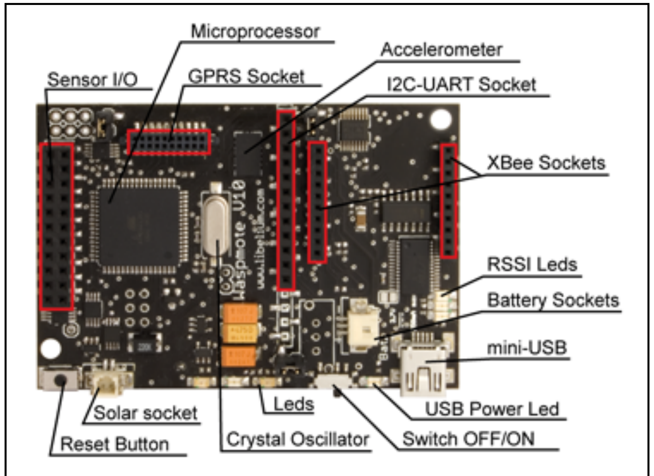
8Mhz, 4K RAM & 2G SD card.

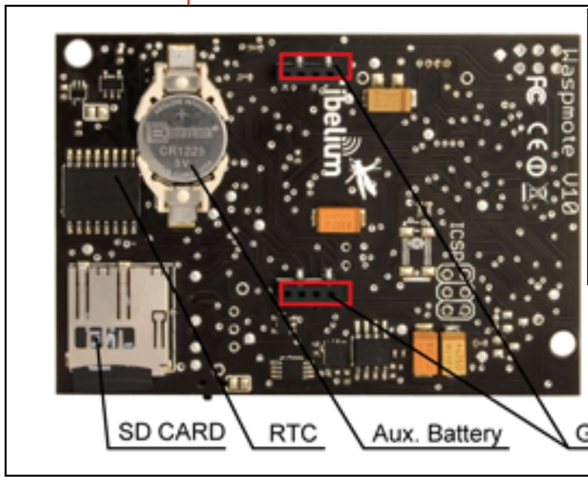
2.4GHz IEEE 802.15.4 XBee

Libelium API v031

Gases

- Carbon Monoxide – CO
- Carbon Dioxide – CO2
- Oxygen – O2
- Methane – CH4
- Hydrogen – H2
- Ammonia – NH3
- Isobutane – C4H10
- Ethanol – CH3CH2OH
- Toluene – C6H5CH3
- Hydrogen Sulfide – H2S
- Nitrogen Dioxide – NO2
- Temperature
- Humidity





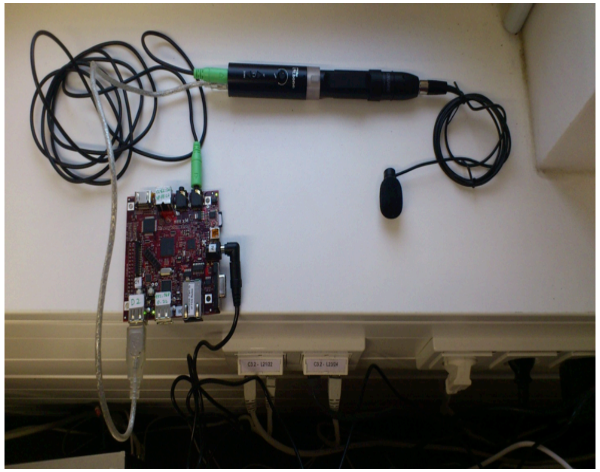
Events

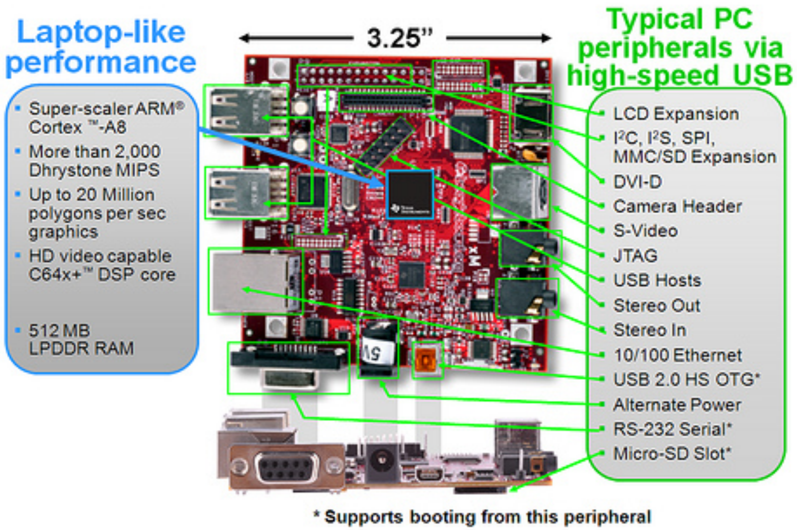
- Pressure/Weight
- Bend
- Vibration
- Impact
- Hall Effect
- Tilt
- Temperature (+/-)
- Liquid Presence
- Liquid Level
- Luminosity
- Presence (PIR)
- Stretch

Adding Acoustic Processing Units

EAR-IT's APUs – Acoustic Processing Units

- Computer-like performance processing platform able to run robust accosting sensing framework;
- "Soundboard" - high quality sound, customized and stackable sound card;
- High-quality & responsive microphones;

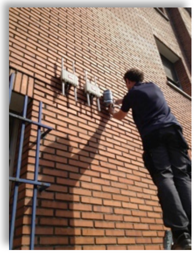


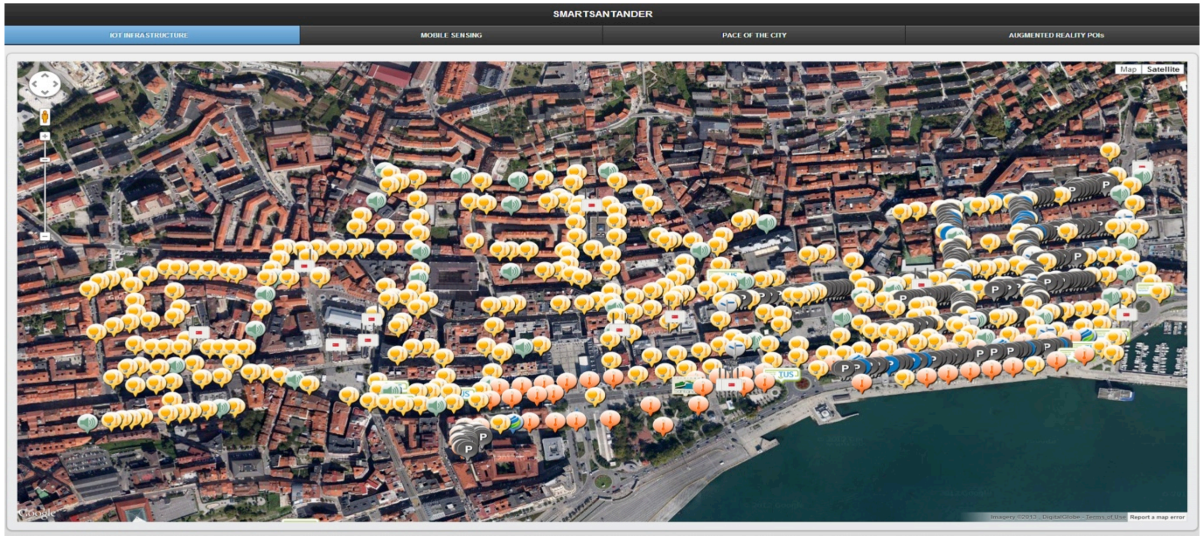


From EAR-IT slides

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

EAR-IT Use Case 1: Emergency Detection

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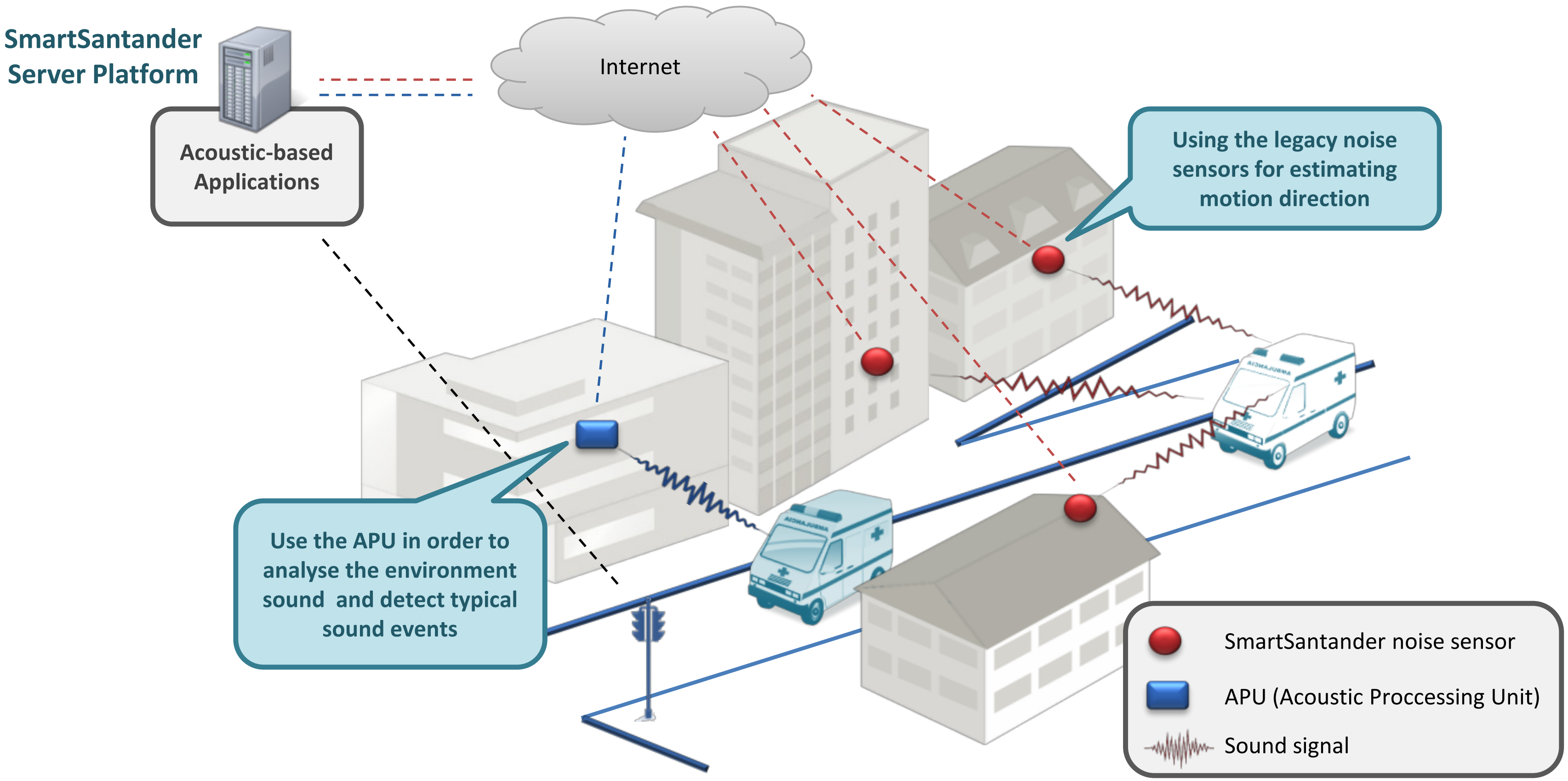
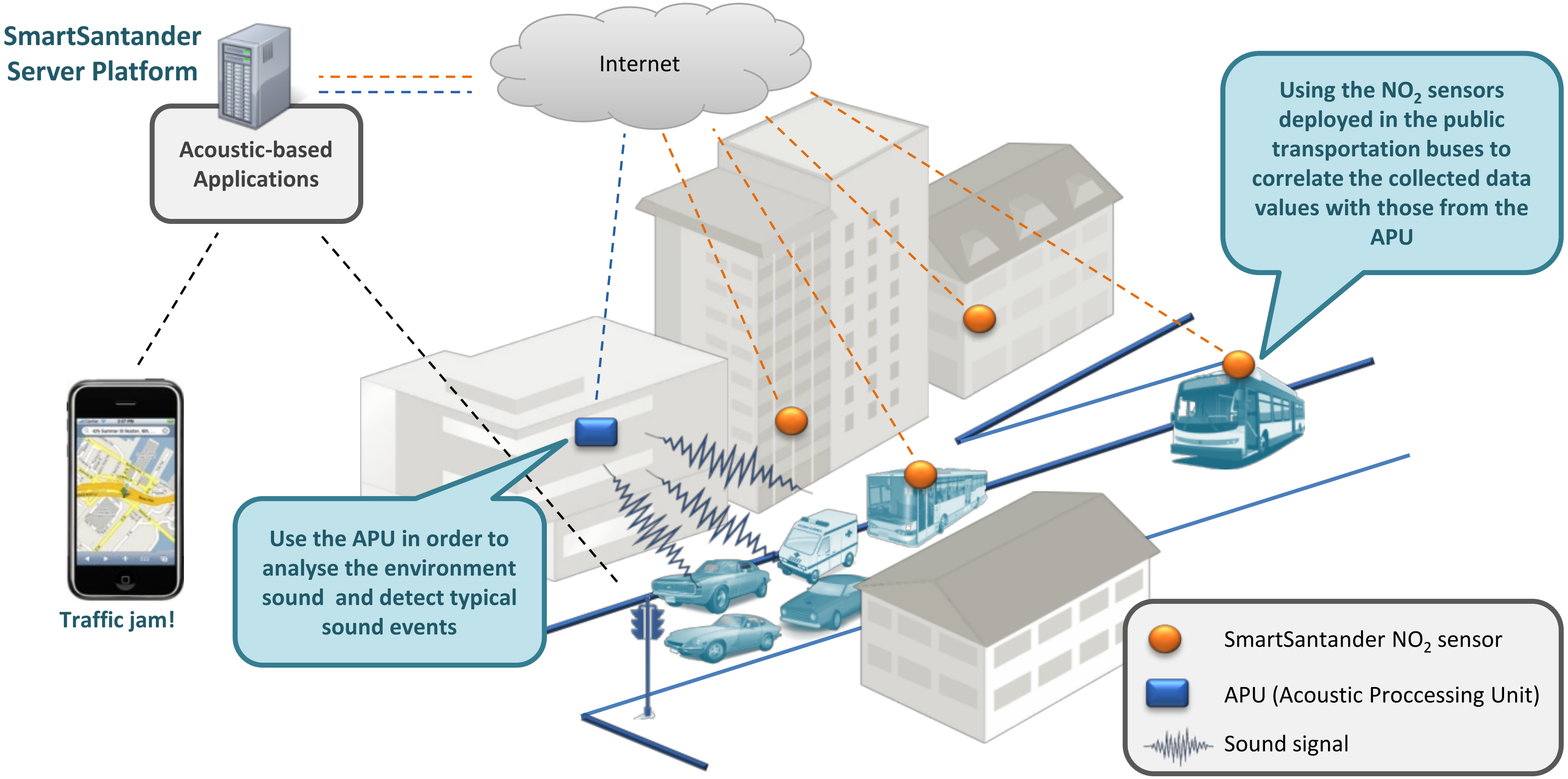
Use the APU to detect an alarm ⇒ Legacy SmartSantander noise sensors to get the direction of such an event (police car, ambulance,…).



From EAR-IT slides

EAR-IT Use Case 2 : Traffic Monitoring

Use the APU to measure the traffic density and correlating it with pollution values (NO_2, CO,…) collected by legacy fixed and mobile nodes in the area.



From EAR-IT slides

EAR-IT Use Case 2 : Traffic Monitoring

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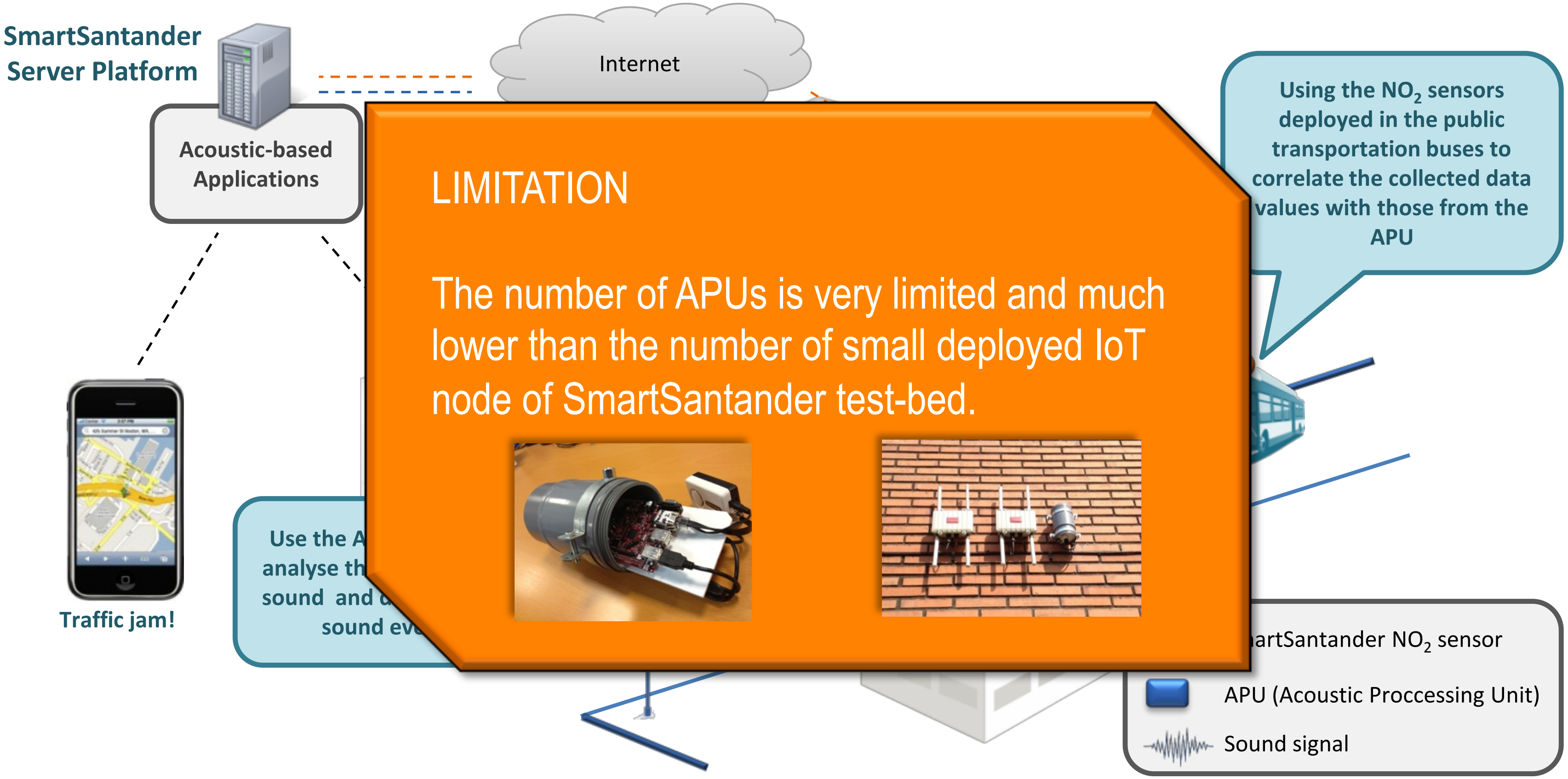

LIMITATION

The number of APUs is very limited and much lower than the number of small deployed IoT node of SmartSantander test-bed.

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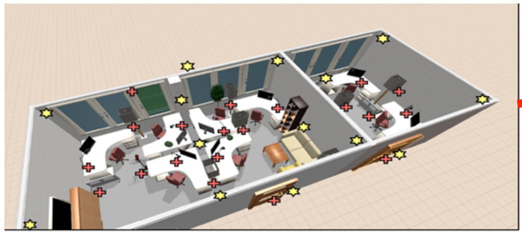
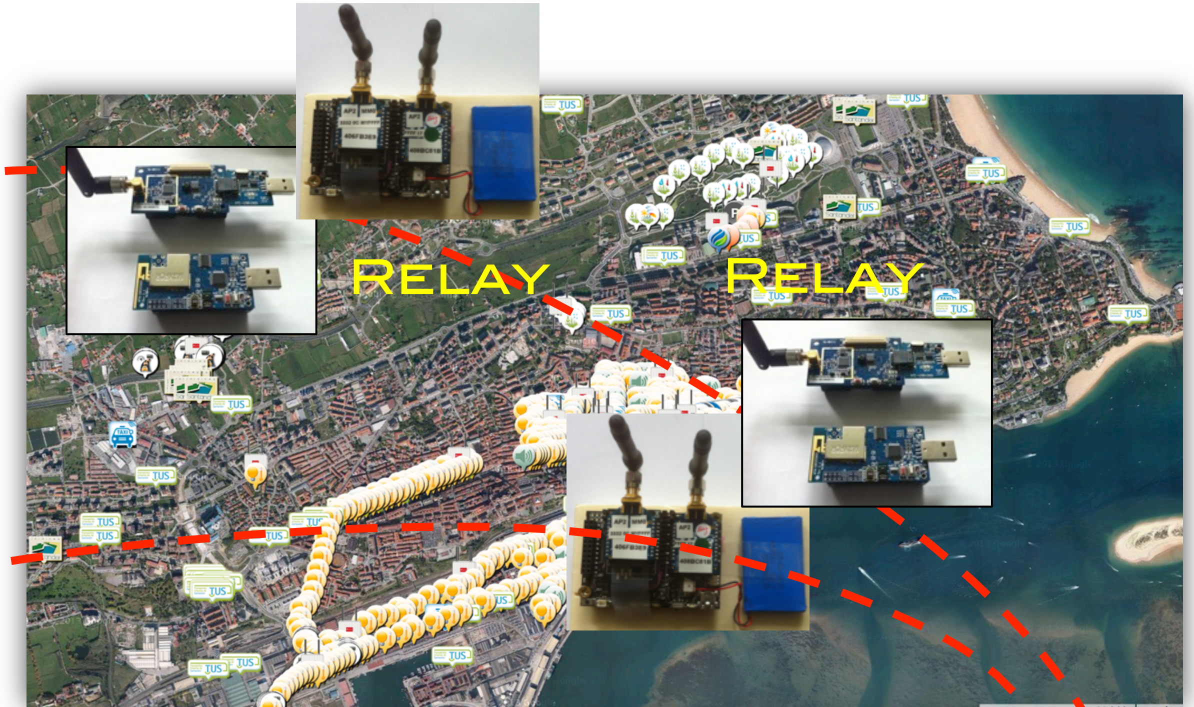
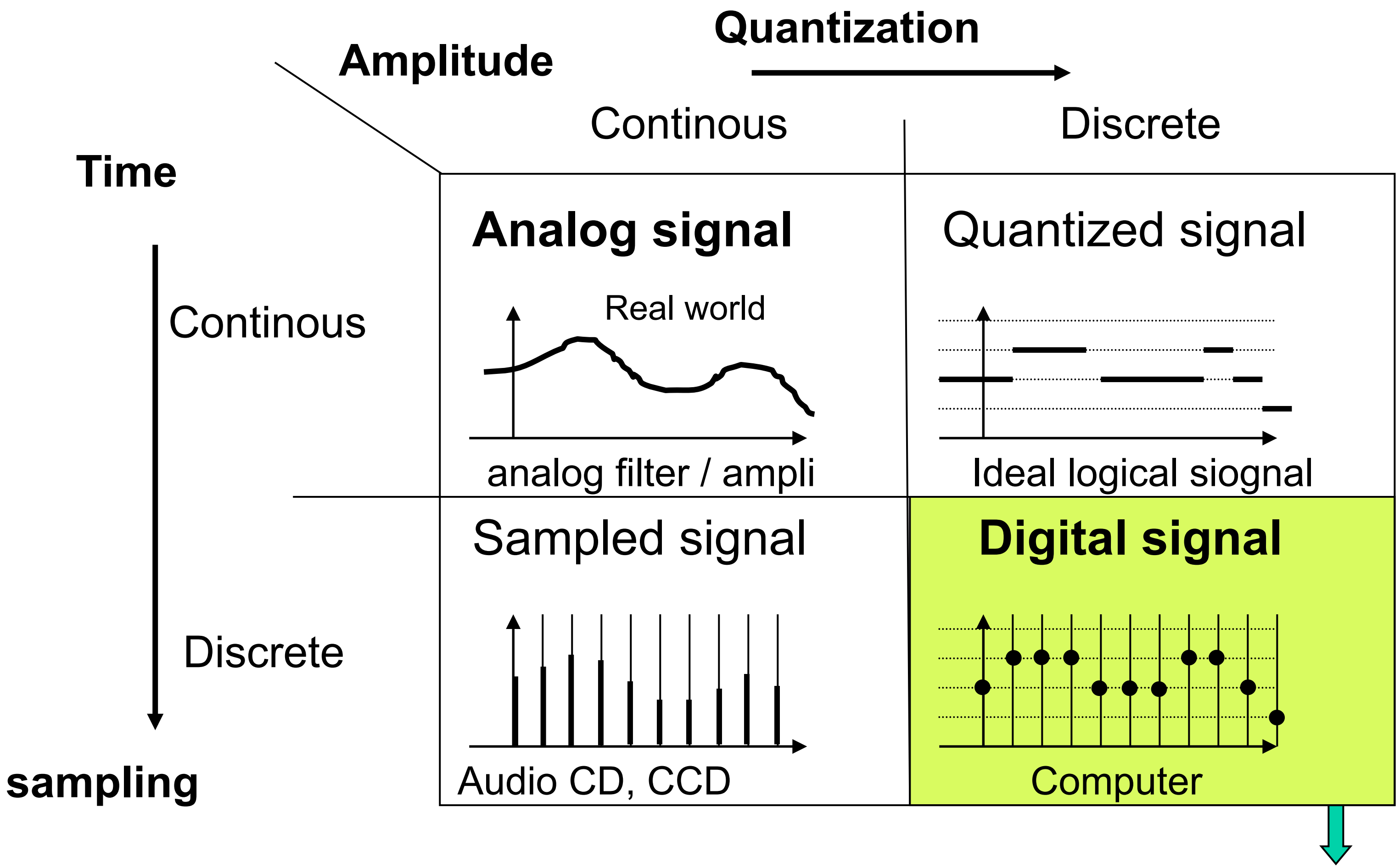
Use deployed low-resource IoT node to enhance acoustic services





PLAY/STORE RECEIVED
AUDIO DATA

Review of digital audio

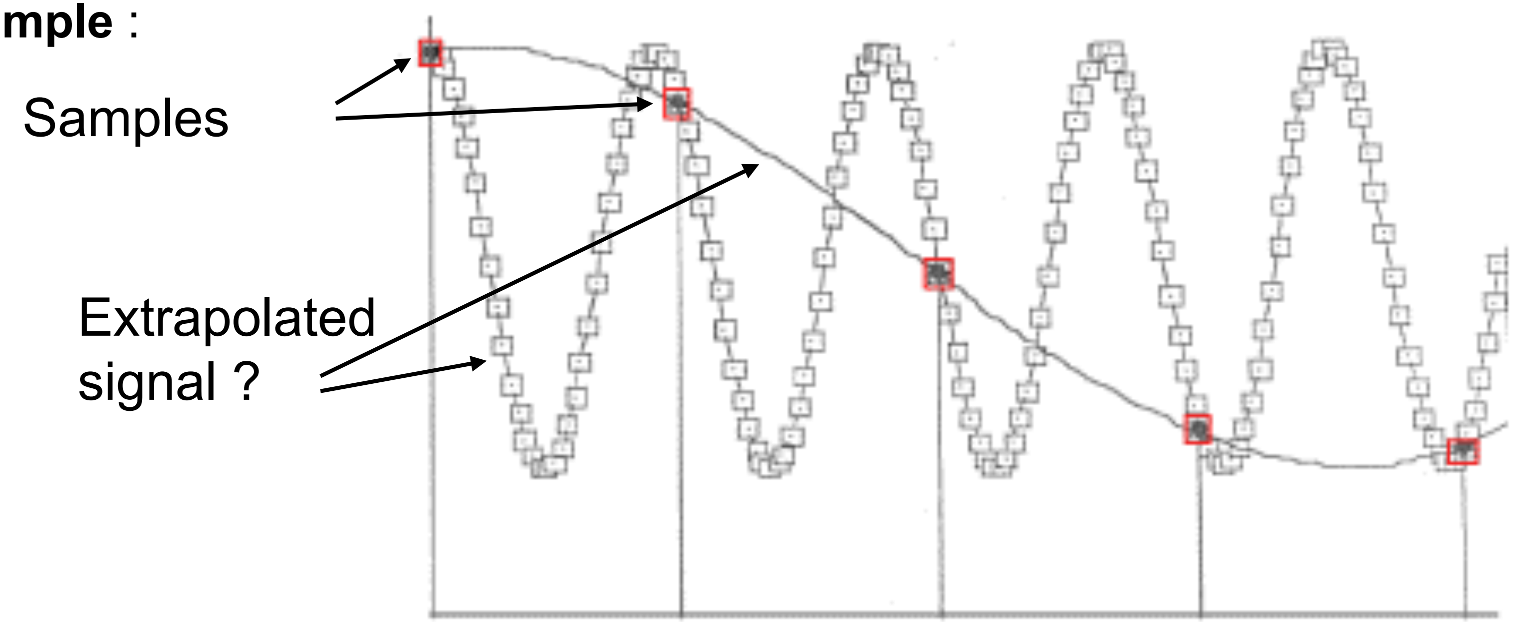


Only in this case can we associate an integer value to the signal

Sampling: Shannon's theorem

Shannon's theorem: Fe > 2 x Fmax(Signal)

Example :



An incorrectly sampled signal will not be reconstituted

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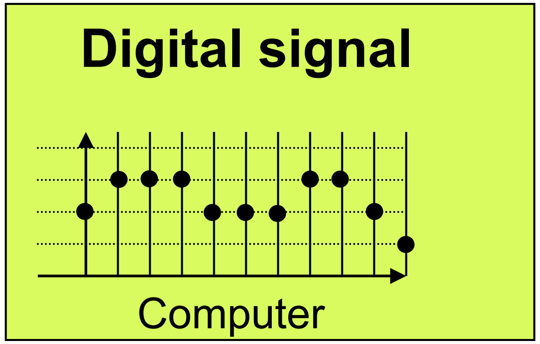
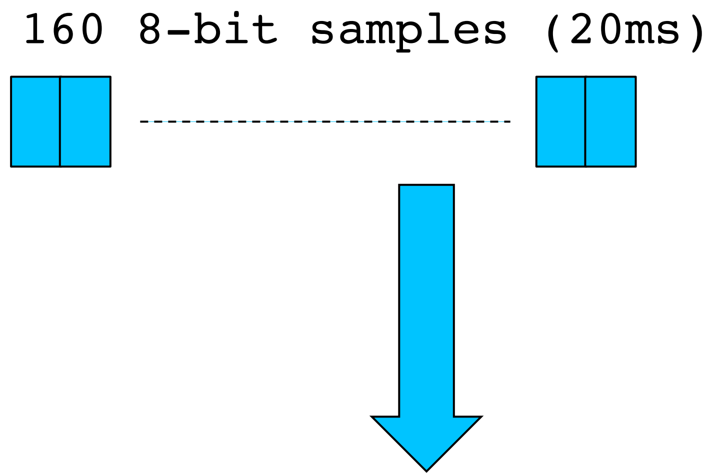
Narrow-band audio

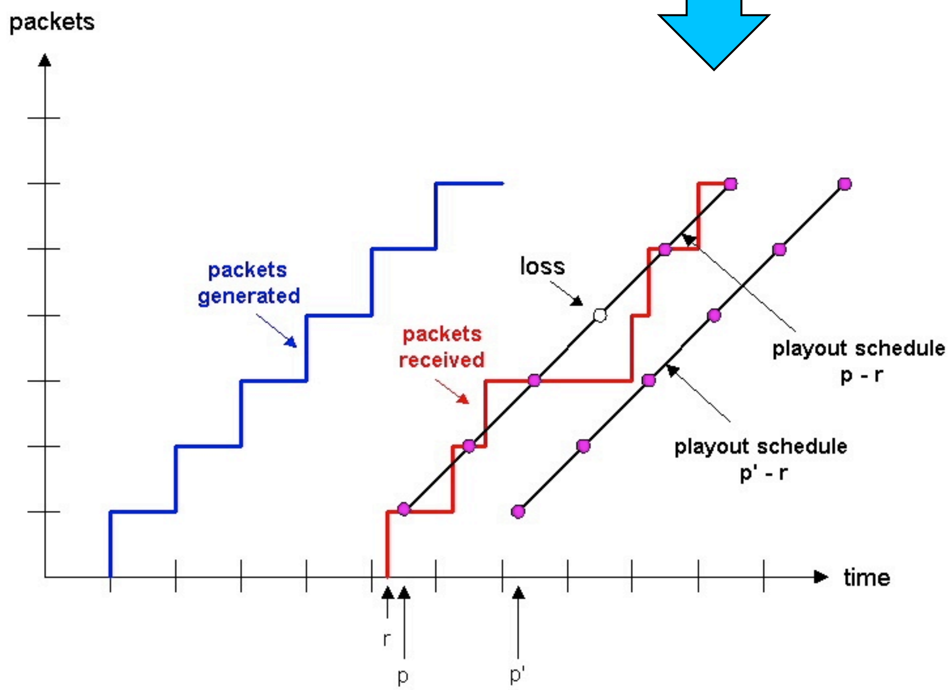
- Sampling rate up to 8kHz
- 1 sample every 1/8000s (125us)
- Sample coded on 8 bits
- Raw throughput of 64kbps
- So-called Pulse Code Modulation (PCM) used in most wired telephony systems
- With 4kHz sampling rate, can reduce to 32kbps

From Xavier Appé, modified by C. Pham for educational purpose only

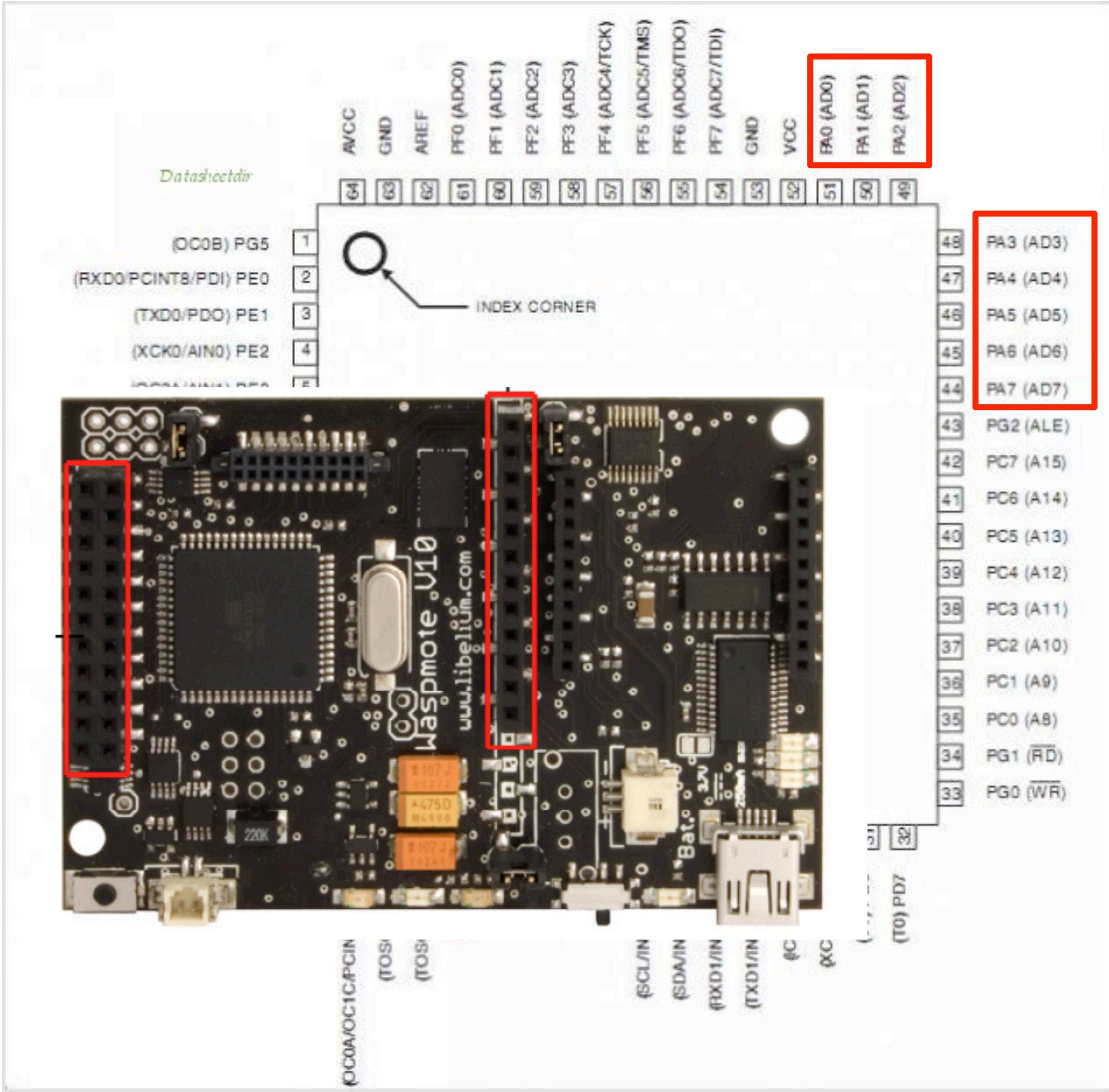
Audio streaming principle







ucontroller vs microprocessor



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

0 is for 0V
1014 is for 3.3V

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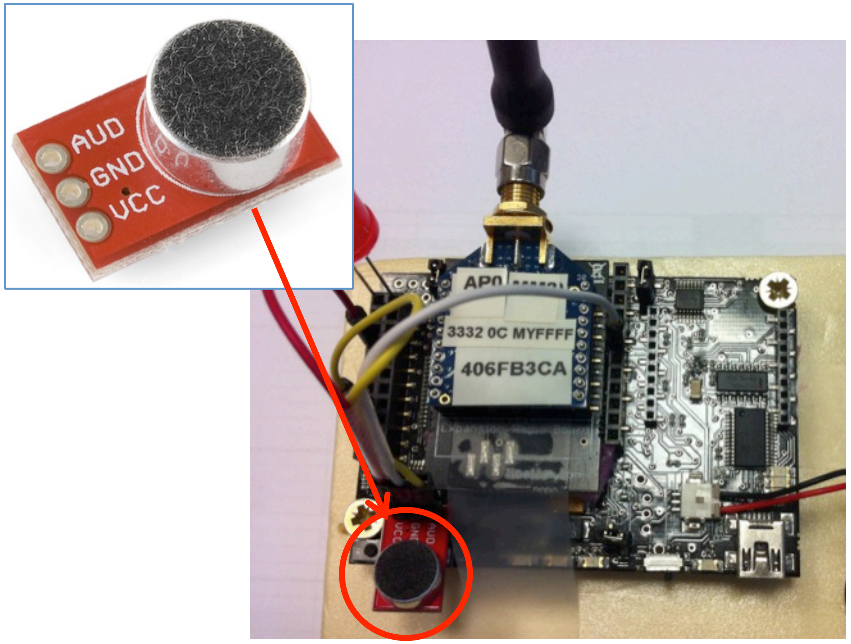
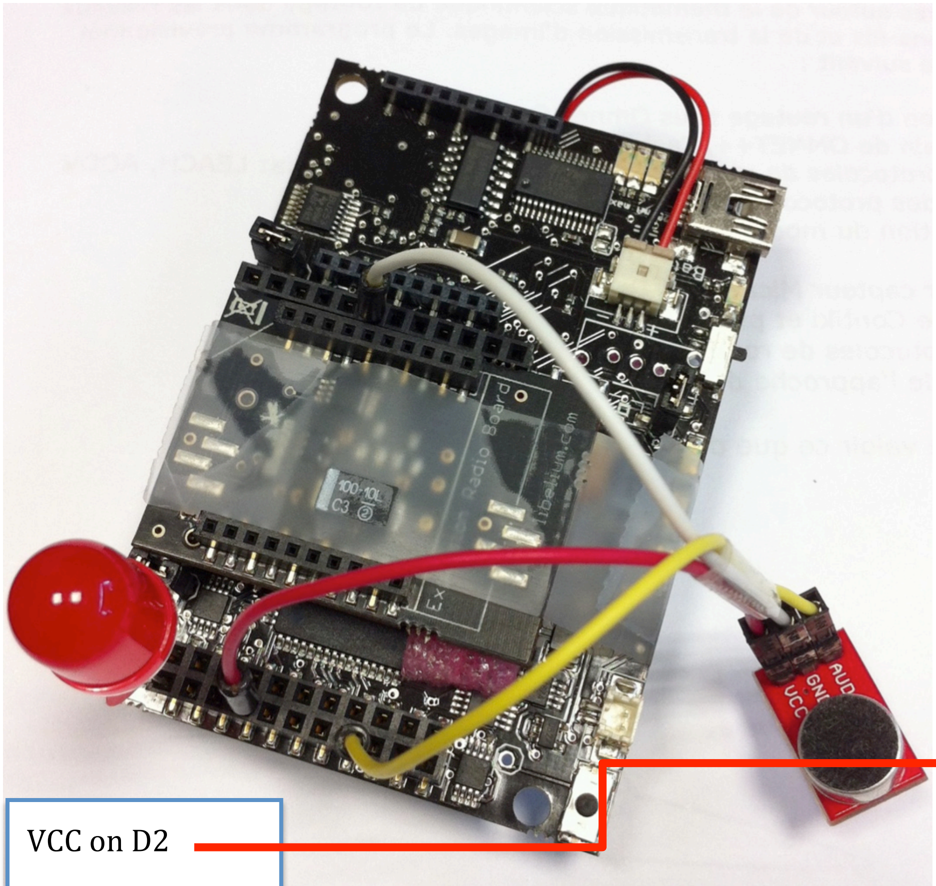
Practical audio

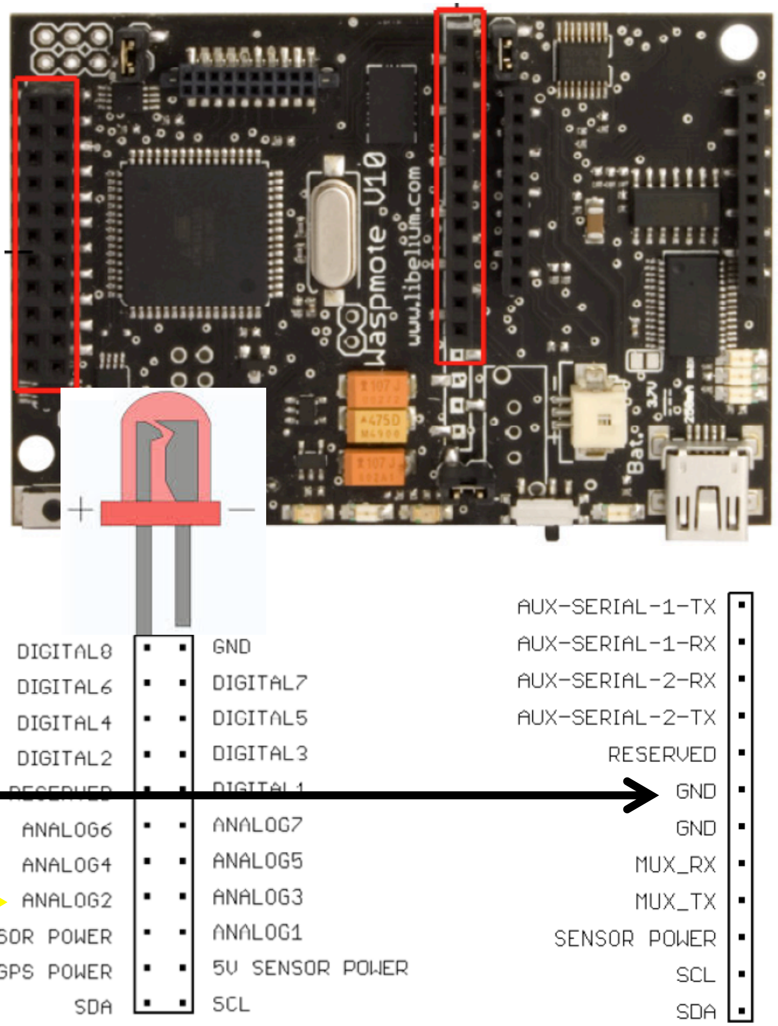
- Electret mic with amplifier on ADC input pin
- Convert from 10-bit to 8-bit sample
- 8Khz sampling gives 64000bps
- 4Khz sampling gives 32000bps



100 8-bit samples (12.5ms or 25ms)

Details of pin connection





VCC on D2

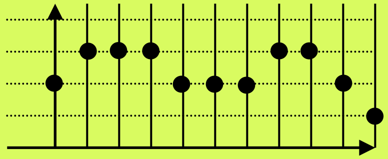
AUDIO on A2

GND on GND

Simple program

```
#define TIMING_SAMPLING 125 // 8000Hz
#define CAPTURE_DURATION 15000000UL // in us 15s
#define SAMPLE_COUNT_CAPTURE CAPTURE_DURATION/TIMING_SAMPLING

void setup() {
  Timer1.initialize(TIMING_SAMPLING);
}

void callback () {

  sampleCount++;

  if (sampleCount < SAMPLE_COUNT_CAPTURE) {

    val = analogRead(ANALOG2) ; // read analog value
    val8bit = ((val >> 2) ) ; // convert into 8 bit

    // write on UART1
    serialWrite(val8bit,1);
  } else {

    stopCapture=true;

    Timer1.detachInterrupt();
  }
}

void loop() {

       // we have to go to sleep
       if ( (millis() - lastWakeupTime > 15000 || stopCapture) && capturingAudio) {
              capturingAudio = false;
              stopCapture = false;
       }

       // we have to wake up
       if (millis() - lastSleepTime > 15000 && !capturingAudio) {
              sampleCount=0L;
              lastWakeupTime = millis();
              capturingAudio = true;
              Timer1.attachInterrupt(callback);
    }
}
```

Digital signal

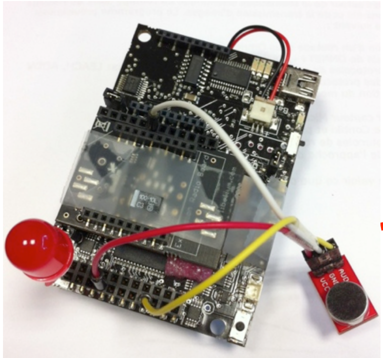


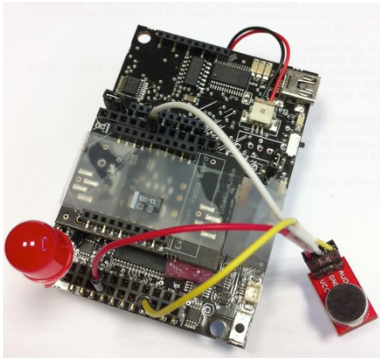
Computer

Get digital value of sound pressure level, i.e. raw audio

Or any other way to put the sample into a transmission buffer

Use deployed low-resource IoT node to enhance acoustic services

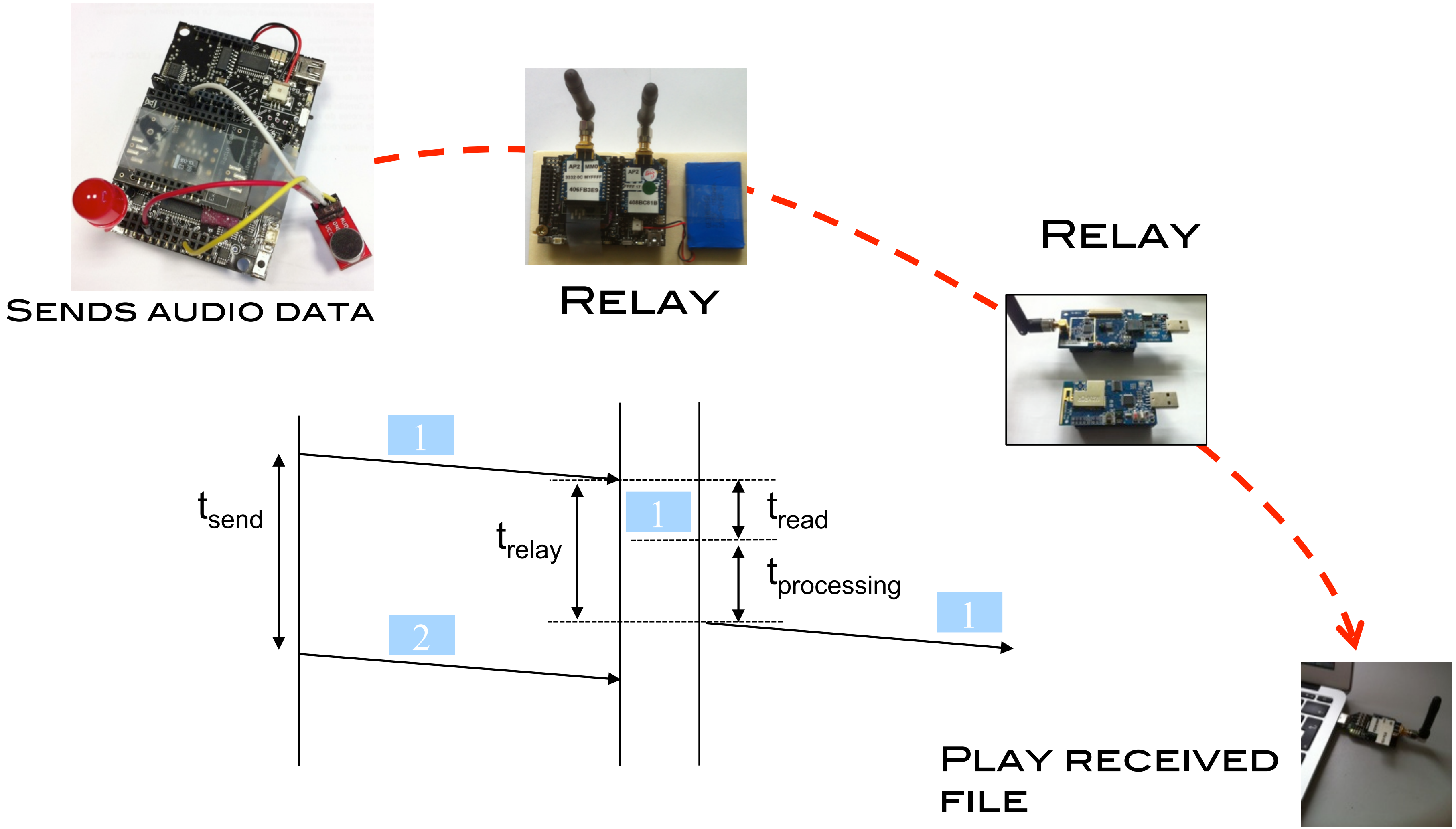




To what extend digital audio traffic can be supported by low-resource IoT nodes?

Play/store received Audio data

Multi-hop audio streaming



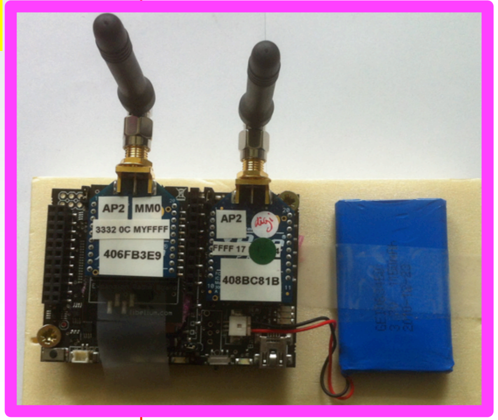
Communication performances

- 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?

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

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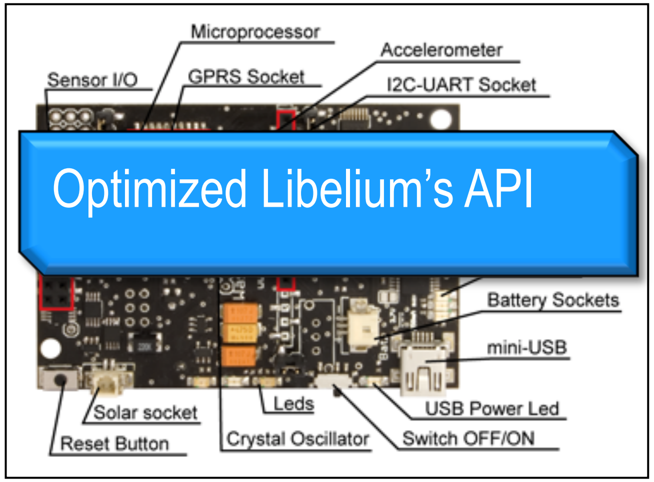
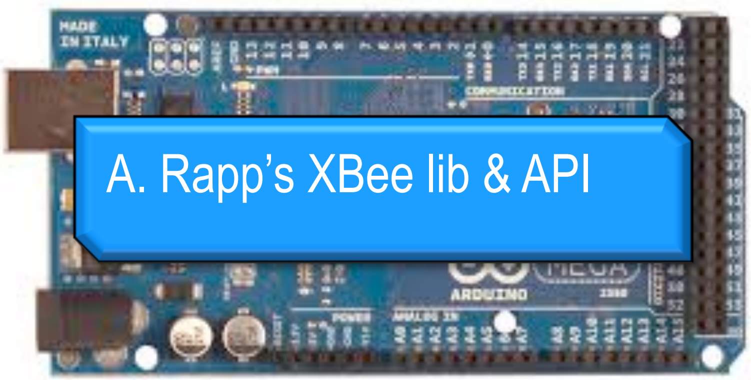
Sensor's HW&SW

Libelium WaspMote



Optimized Libelium's API



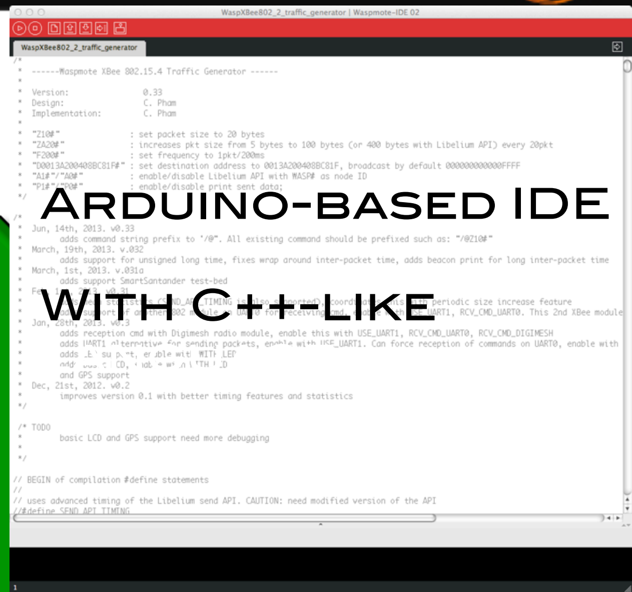
A. Rapp's XBee lib & API

Arduino Mega2560

UART-based connection to micro-controller

Default speed is usually 38400 bauds

Higher baud rate are possible but…

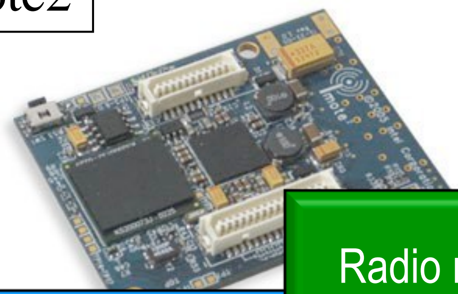


Arduino-based IDE with C++-like

XBee 802.15.4

« Academic » sensors

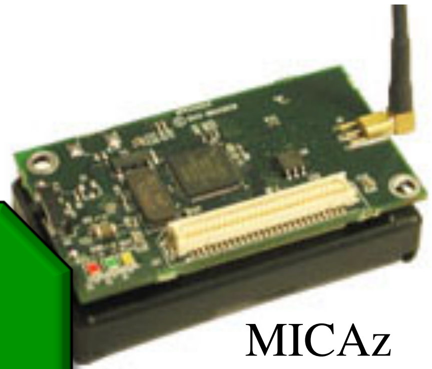
iMote2



13-416MHz PXA27
Wireless MMX DSP
256kB SRAM, 32M
32MB SDRAM
CC2420 radio

Radio module CC2420 is connected through SPI bus

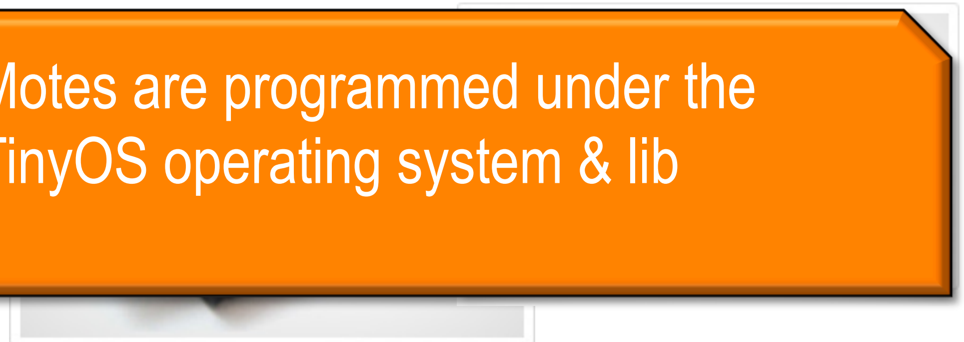
SPI speed is in the order of several hundredth kbps



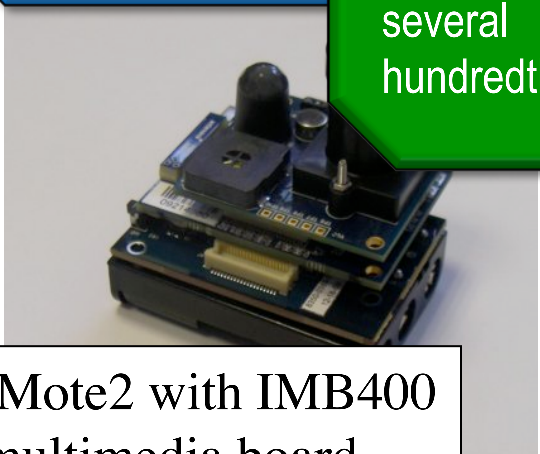
MICAz

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

Motes are programmed under the TinyOS operating system & lib



AdvanticSys CM5000 & CM3000
TelosB-like mote

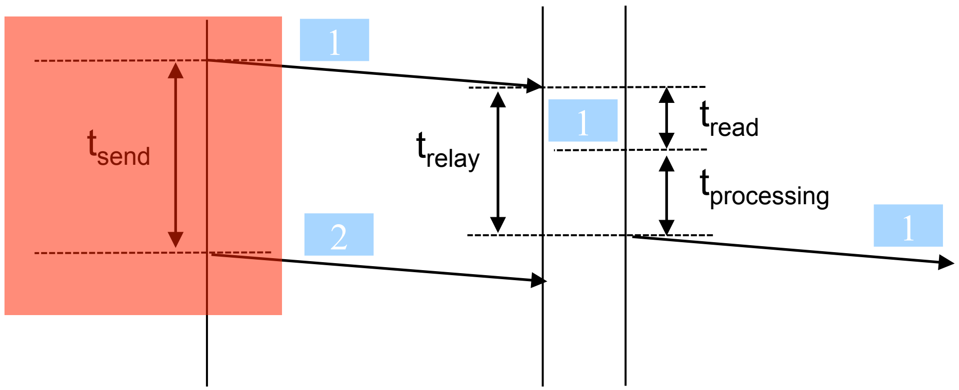


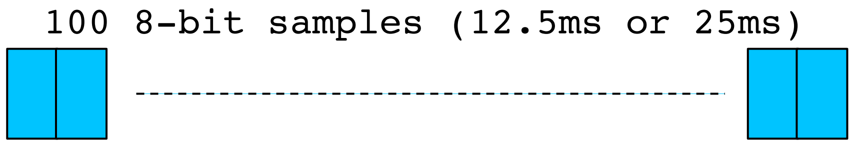
iMote2 with IMB400 multimedia board

TelosB

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

Sending performances





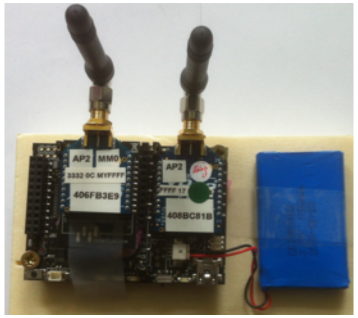
TRAFFIC GENERATOR

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

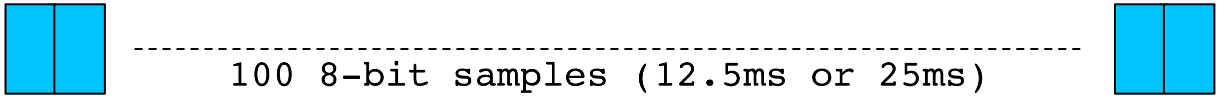
Measure the time in various part of API `send()` when possible.

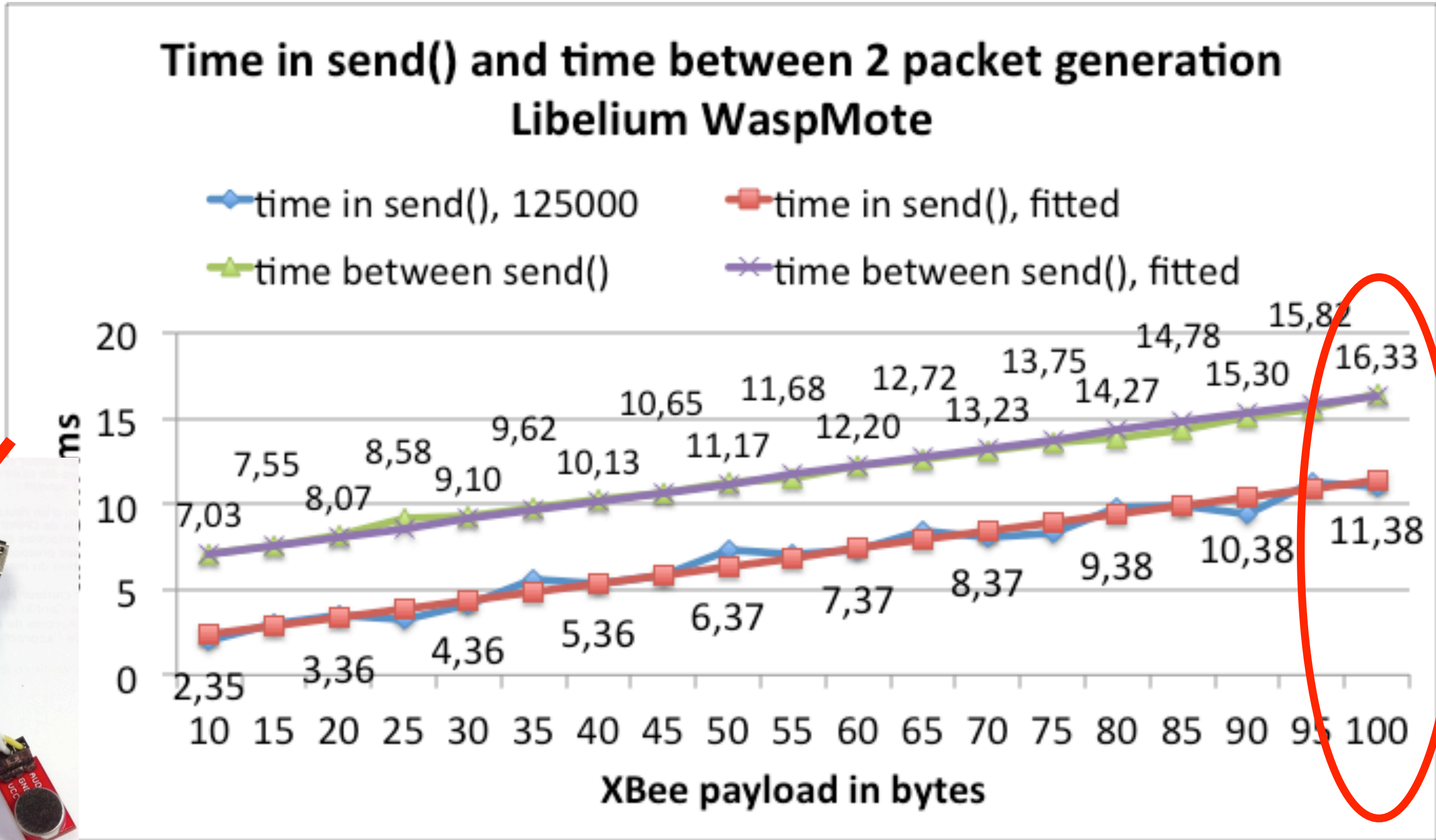
« Time in send() » is T2-T1
« Time between 2 pkt generation » is T0-L0
Time resolution is millisecond
Minimum data manipulation

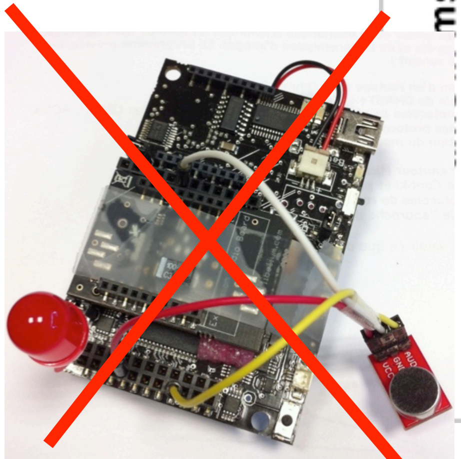
IoT node sending performance



LIBELIUM WASPMOTE

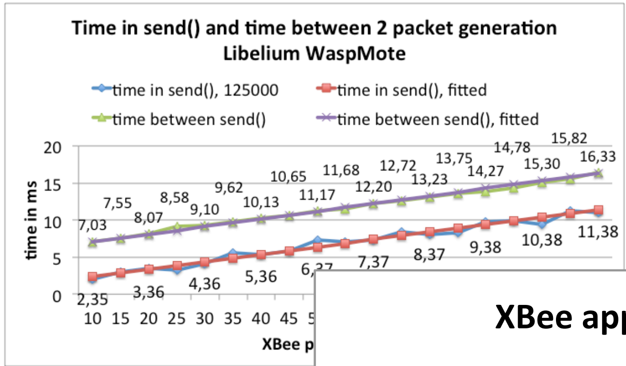


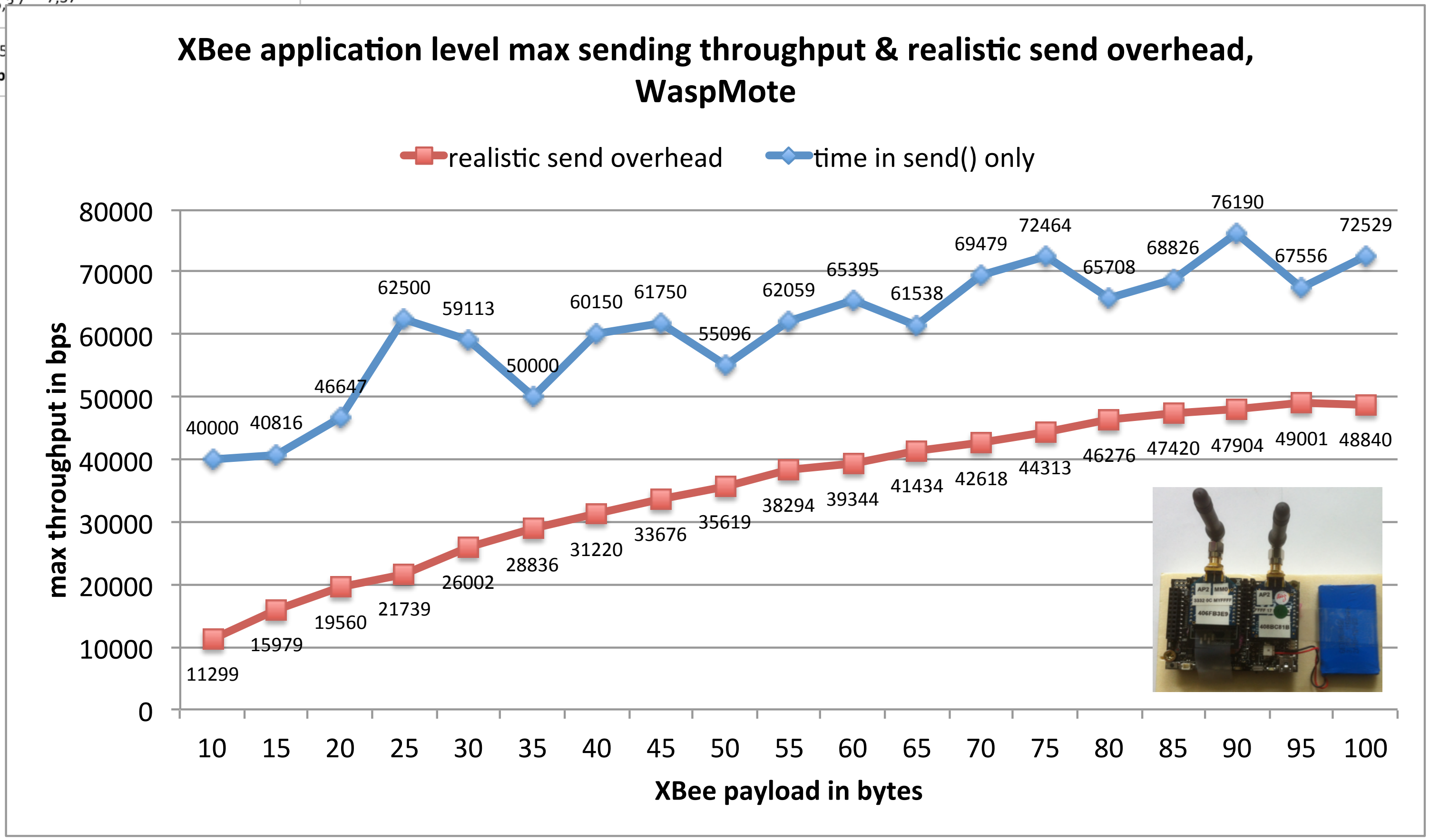




No capture and transmission at the same time if using only mote ucontroller!

Maximum app. Level throughput





First solution: use XBee ucontroller

- XBee 802.15.4 radio module has an embedded ucontroller that can perform framing tasks
- So called transparent mode or « serial line replacement » mode (AP0)
- Application provides payload, e.g. « hello », and XBee fills-in framing information
- Limitation is no dynamic destination address

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XBee and XBee gateways

IEEE 802.15.4 MAC frame format

Octets: 2	1	0/2	0/2/8	0/2	0/2/8	0/5/6/10/14	variable	2
Frame Control CC61	Sequence Number 58	Destination PAN 3332	Destination Address 0013A200 40922078	Source PAN 3332	Source Address 0013A200 4086D834	Auxiliary Security Header	Frame Payload HELLO	FCS 2B32
		Addressing fields						
MHR							MAC Payload	MFR

HELLO

64-bit 0x0013A2004086D834
16-bit 0x0010
PANID 0x3332

View as a
serial port
/dev/ttyUSB0

Some hardware give access to
Link-layer information

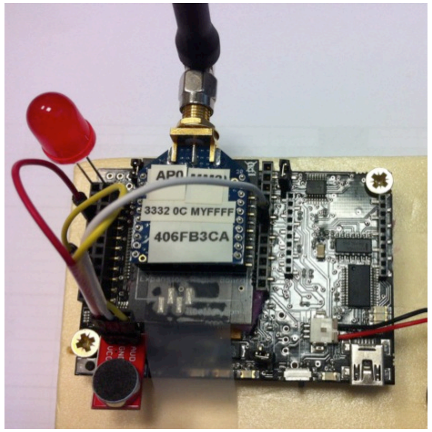
CC61 | 58 | 3332 | 0013A200 40722098 | 3332 | 0013A200 4086D834 | HELLO | 2B32

HELLO

Transparent mode
Or Serial line
replacement mode

HELLO

Example with XBee & Xbee gw AP0



```
void loop() {
    val = analogRead(ANALOG2) ; // read analog value
    val8bit = ((val >> 2) ) ; // convert into 8 bit

    // write on UART1, need an XBee module
    // with AP mode 0

    serialWrite(val8bit,1);
}
```

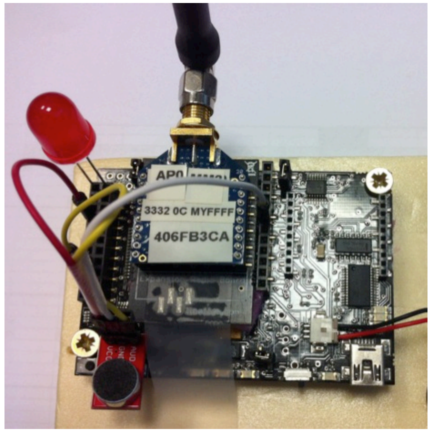
XBee radio in AP0 mode

With XBee GW also in AP0 mode

Use python script to read serial port /dev/ttyUSB0

```
> python SerialToStdout | play --buffer 50 -t raw –r 8000 -u -1 –
```

Example with XBee & Xbee gw AP0




```
void loop() {
     val = analogRead(ANALOG2) ; // read analog value
     val8bit = ((val >> 2) ) ; // convert into 8 bit

     // write on UART1, need an XBee module
     // with AP mode 0
```

XBee radio in AP0

Can support up to 8kHz raw audio, but:

1/ quickly saturates the radio medium, i.e. one 100-byte frame every 12.5ms

2/ only 1-hop communication

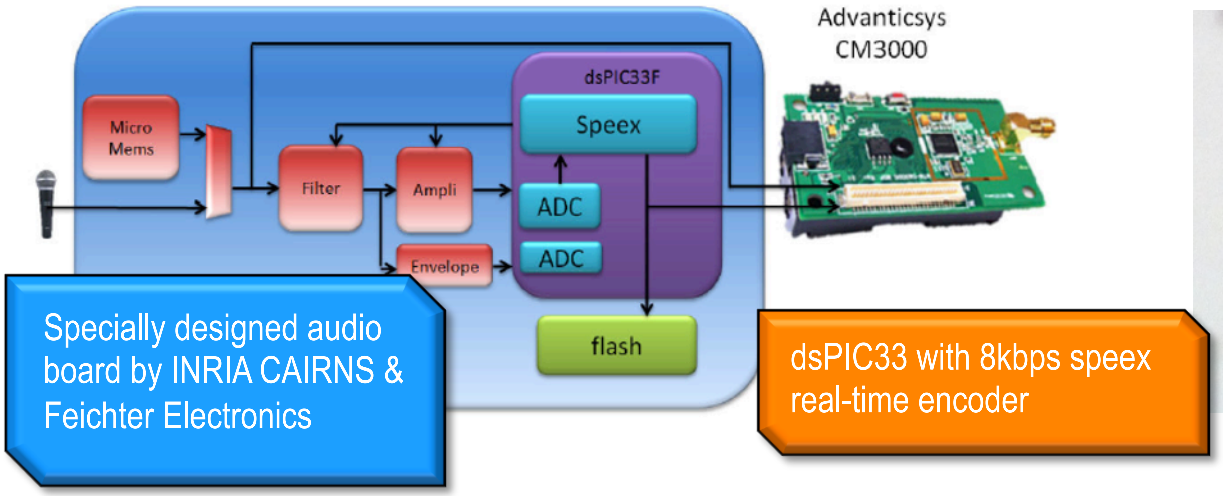
W also in AP0 mode

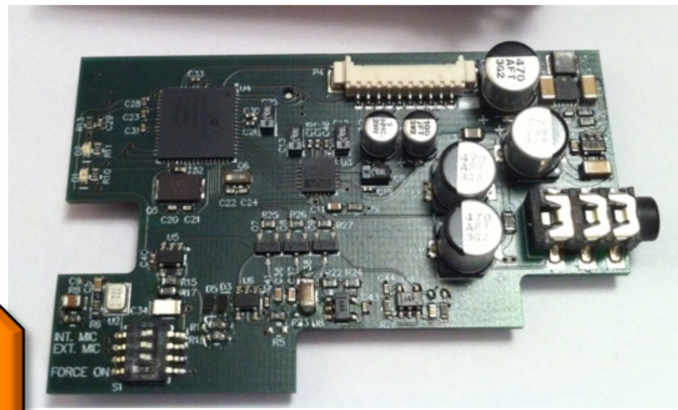
Use python script to read serial port /dev/ttyUSB0

```
> python SerialToStdout | play --buffer 50 -t raw –r 8000 -u -1 –
```

2nd solution: dev. of audio board

- Use dedicated audio board for sampling/storing/encoding at 8kbps



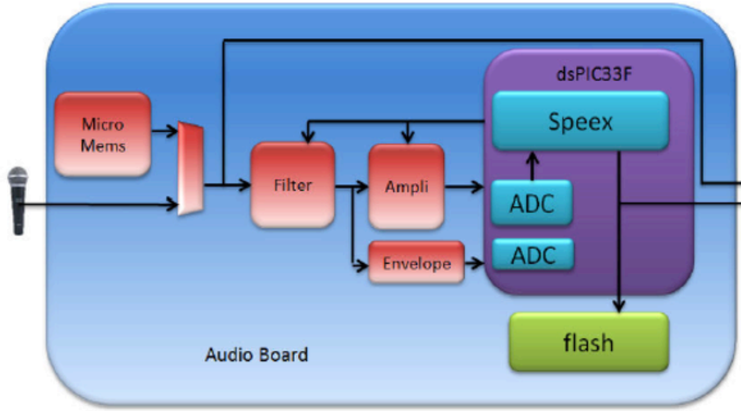


- Allows for multi-hop, encoded audio streaming scenarios

Audio board principle

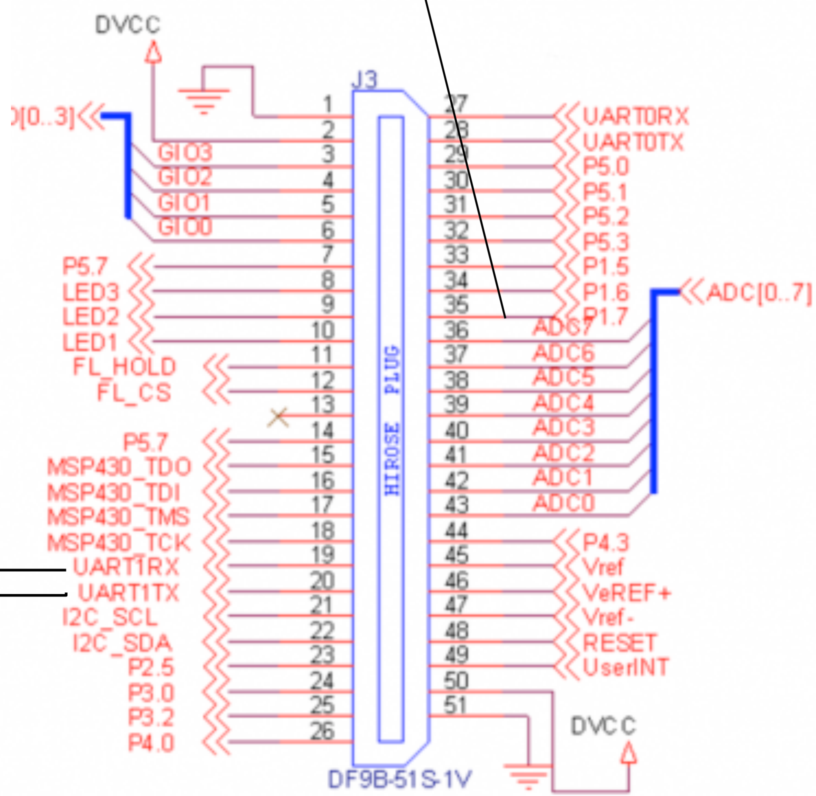
- The audio board captures 160 bytes (20ms) of raw audio and uses speex codec at 8kbps to produce 20 bytes to encoded audio data
- It sends the encoded audio data through an UART line to the host micro-controller
- The host micro-controller receives the encoded data and sends them wirelessly to the next hop
- The last hop is a base station that will forward the encoded audio into a speex audio decoder
- Output of the speex audio decoder is in raw format that can be feed into a player (`play`)

Audio board on TelosB

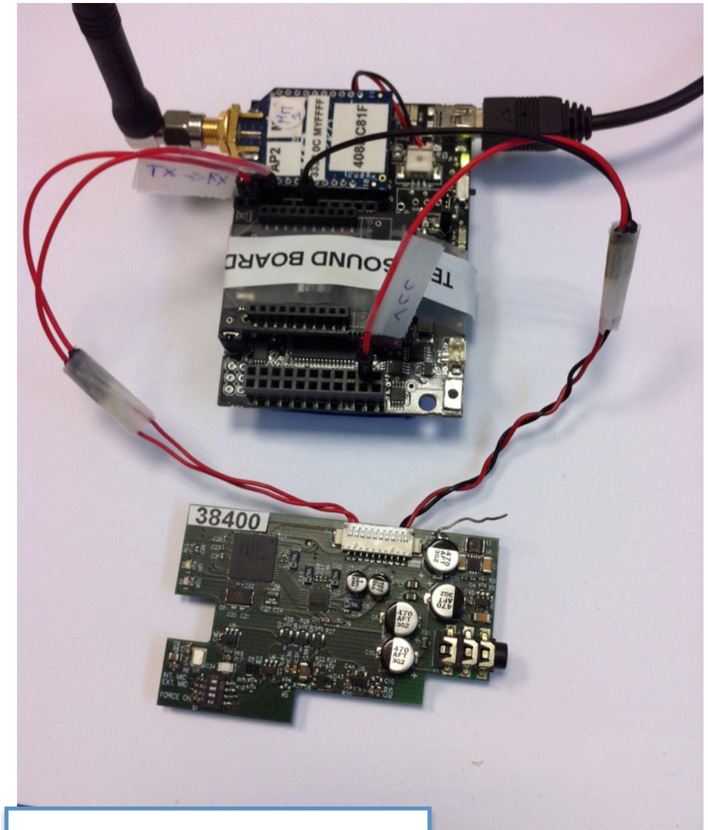


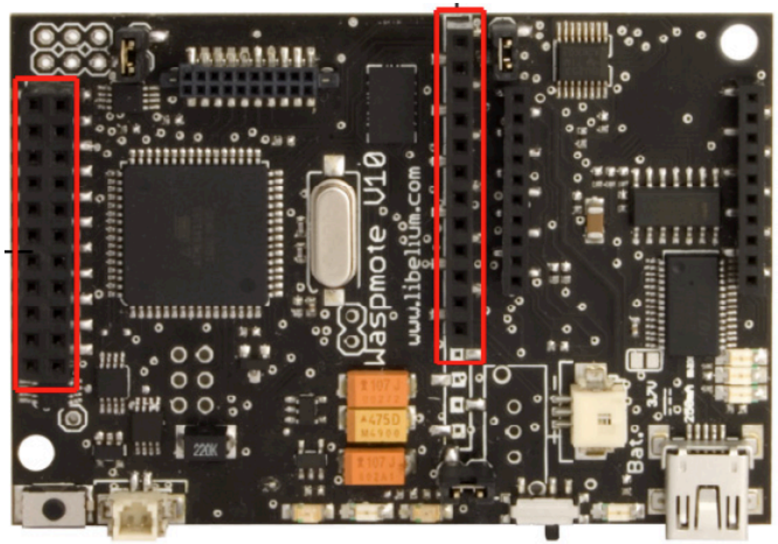
Initial development on AdvantiCsys TelosB mote. Encoded audio data transferts are realized with UART (serial) communication so easy to connect to other sensor boards.

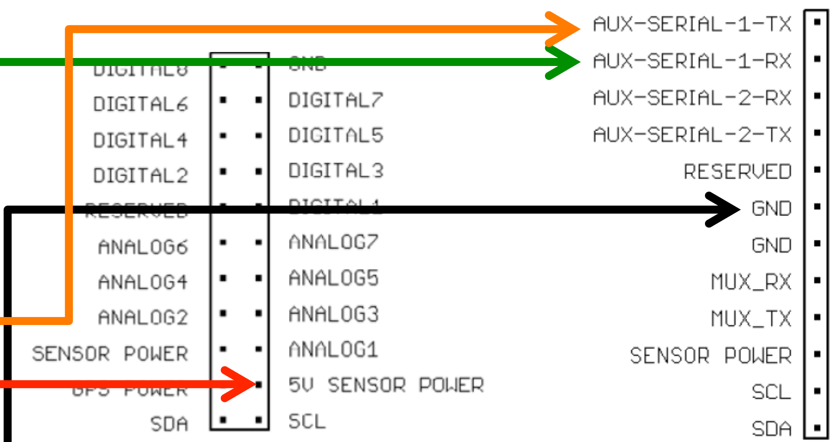
P1.7 can be used to power on/off the audio board



Audio board on WaspMote







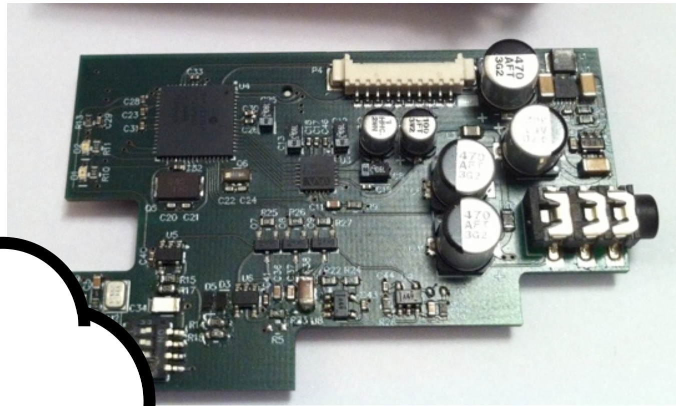
TX on AUX-SERIAL-1-RX

(RX on AUX-SERIAL-1-TX)

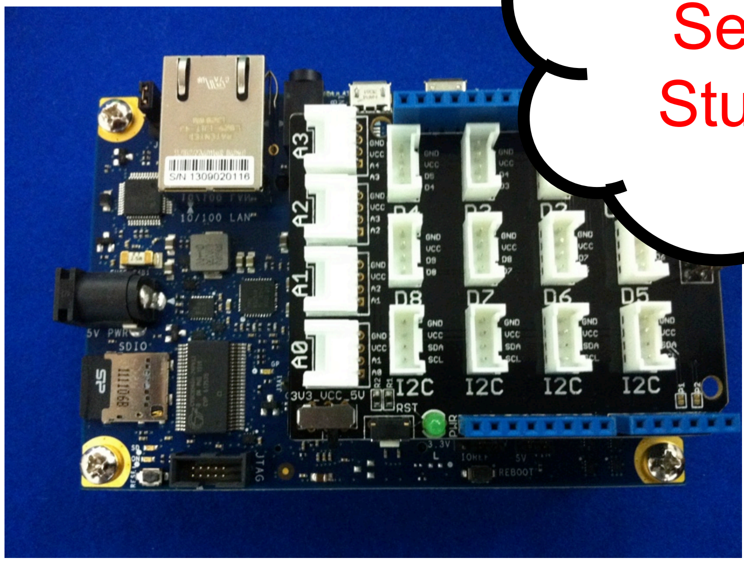
VCC on 5V

GND on GND

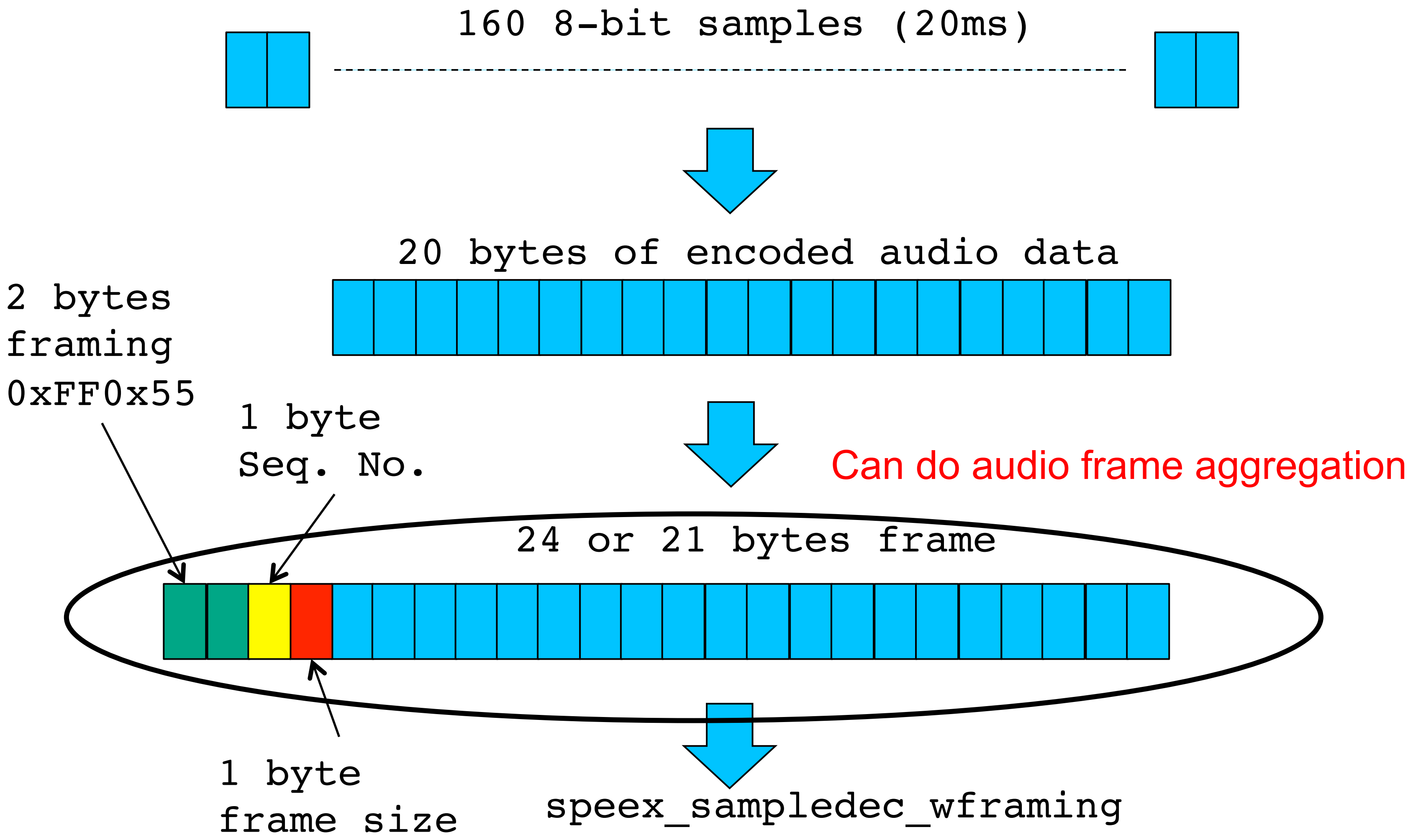
Audio board on Intel's Galileo



Senzation's
Sensational
Student team



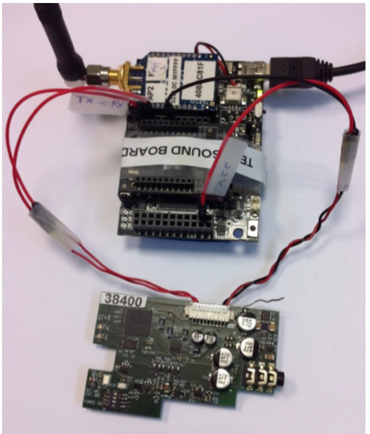
speex at 8kbps



Summary of audio constraints

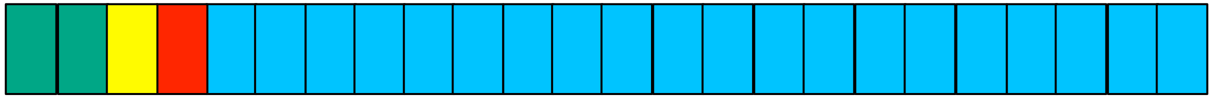
Codec	Minimum sending rate
Raw 4KHz 8KHz	 100 bytes every 25ms 100 bytes every 12.5ms
Speex 8000bps A1 A2 A3 A4	 24 bytes every 20ms 48 bytes every 40ms 72 bytes every 60ms 96 bytes every 80ms

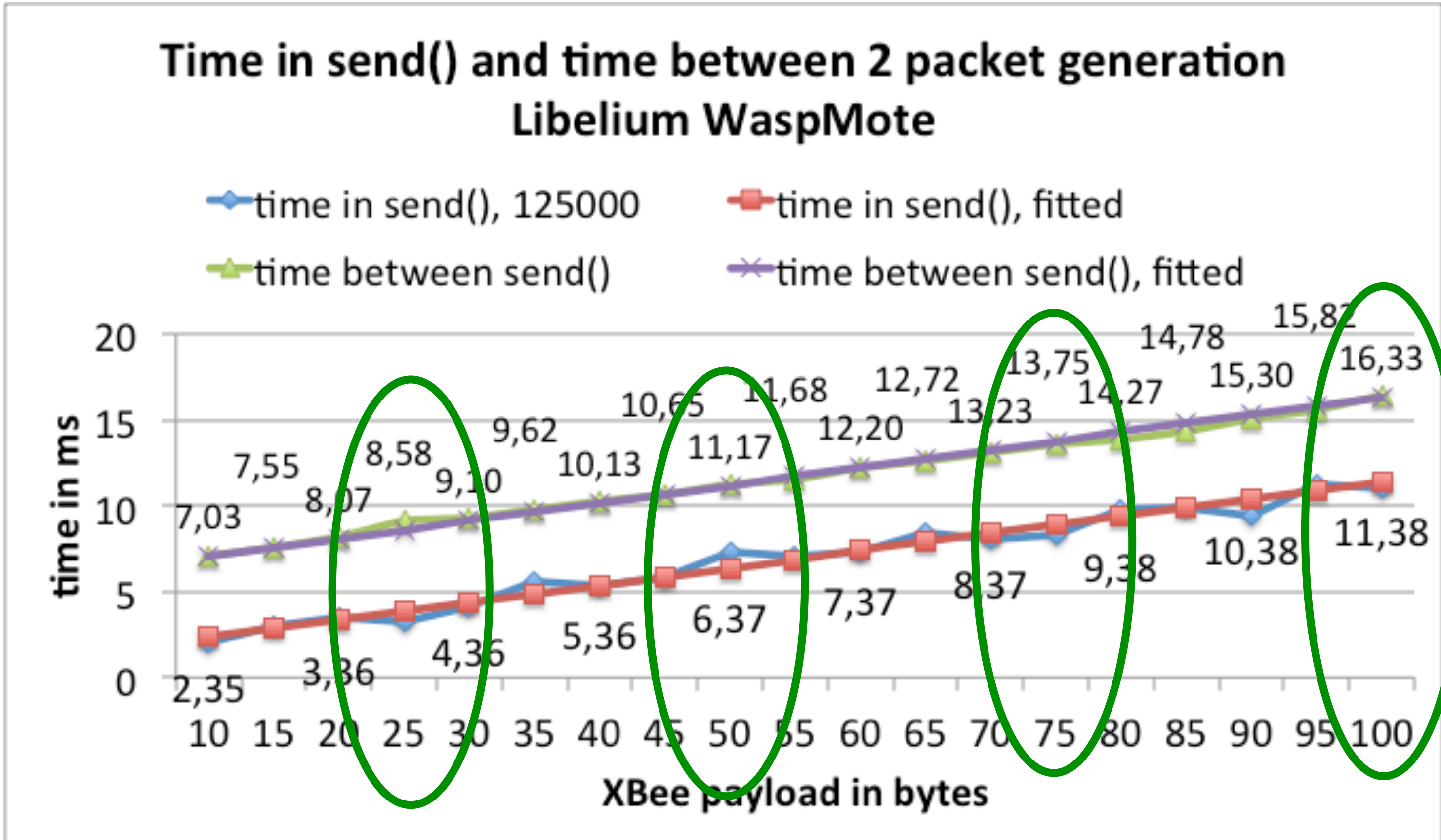
IoT node sending performance



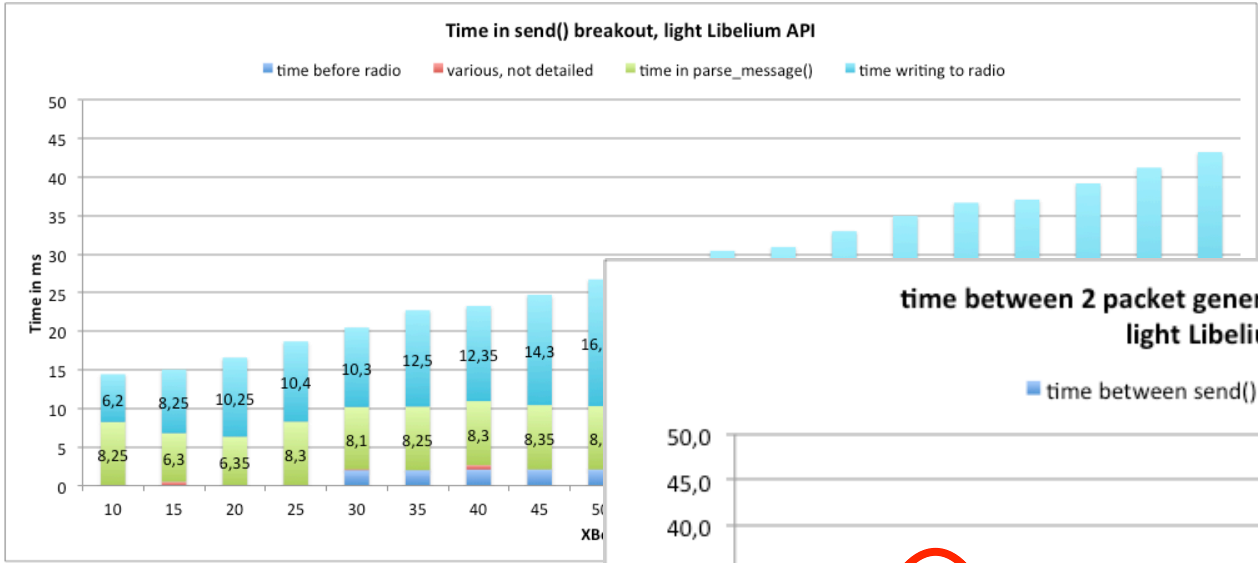
Libelium WaspMote

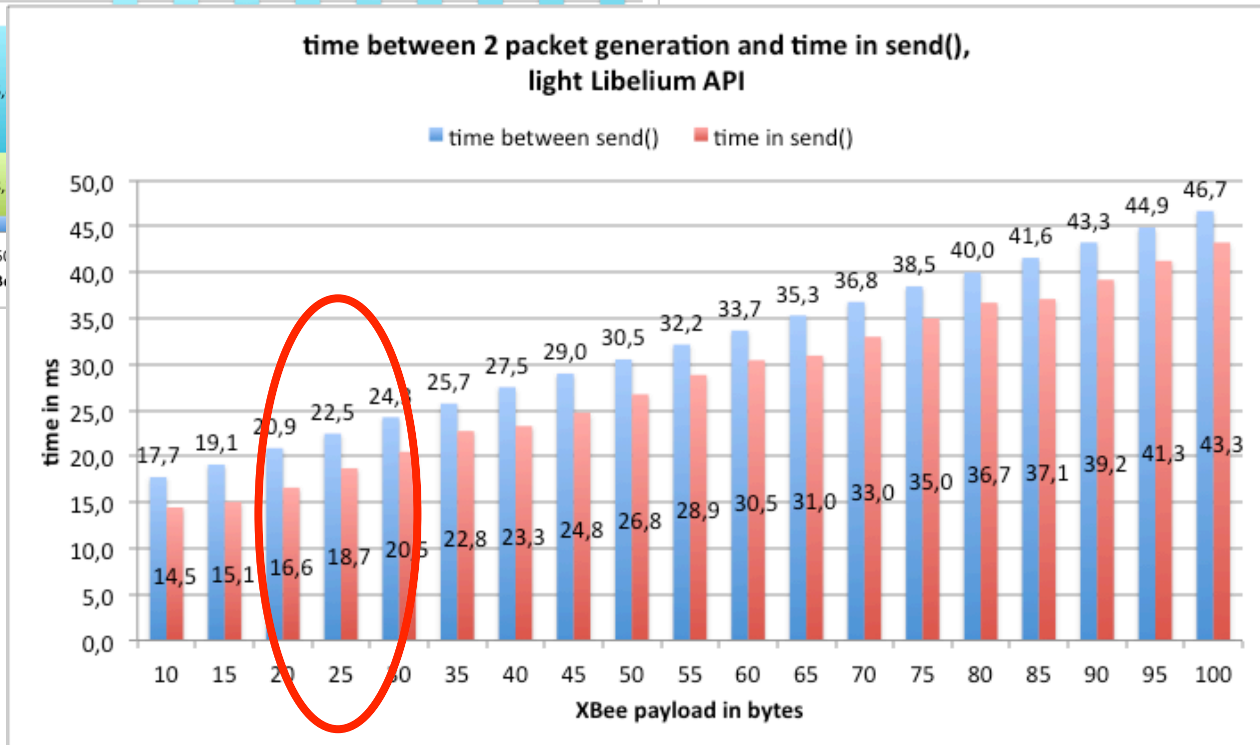
24 bytes every 20ms



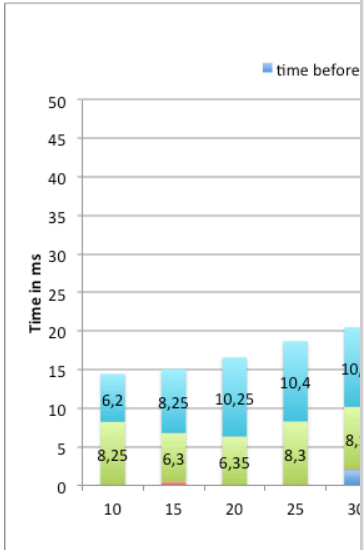


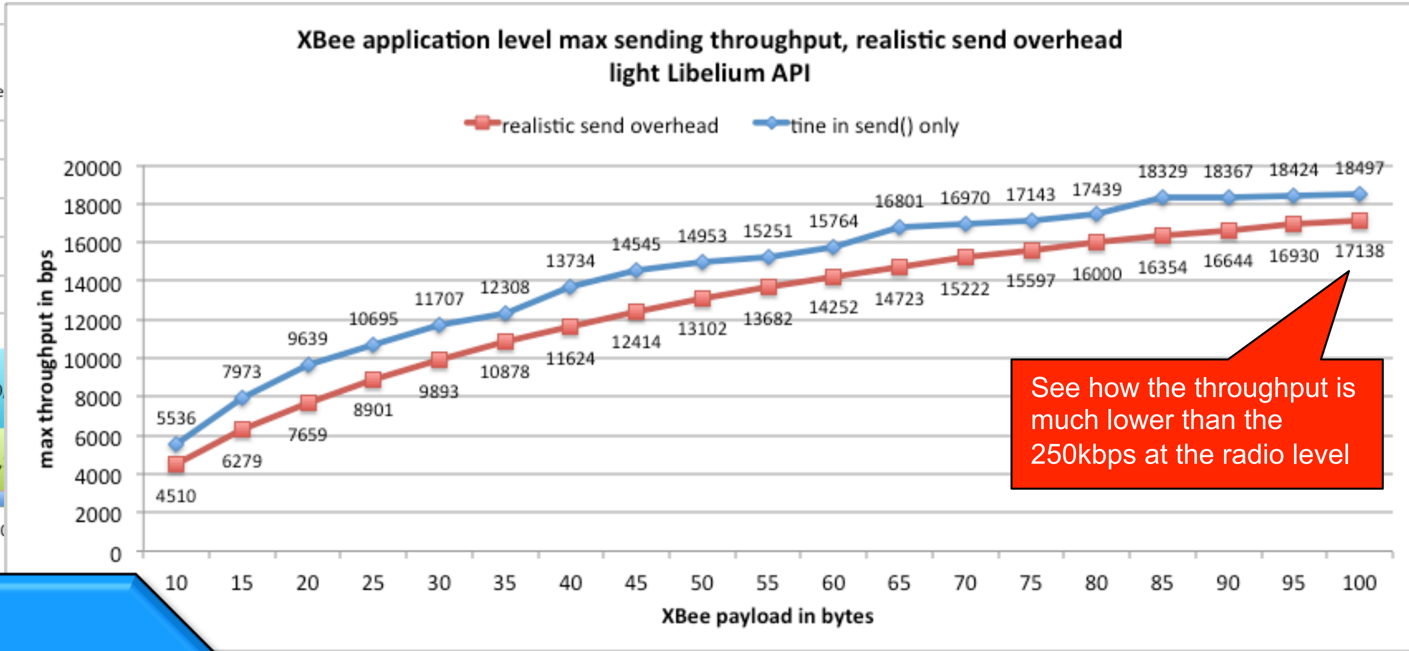
Off-the-shelves performance

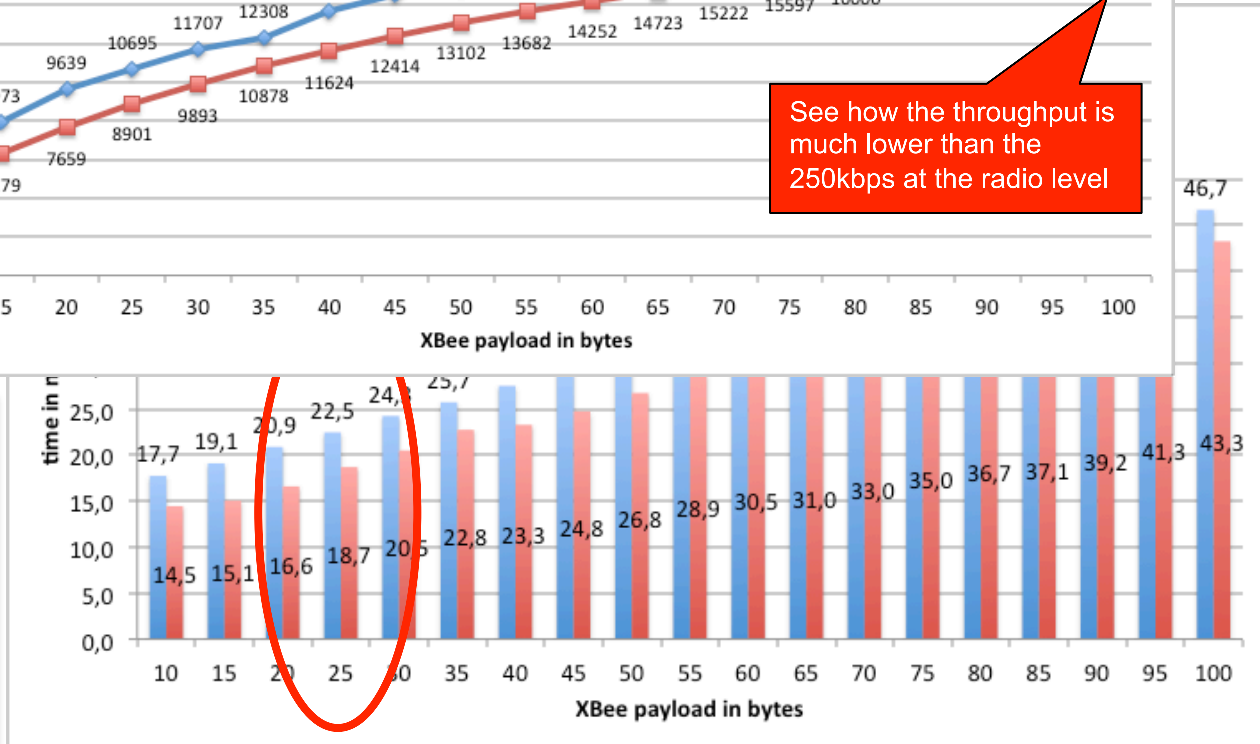




Off-the-shelves performance



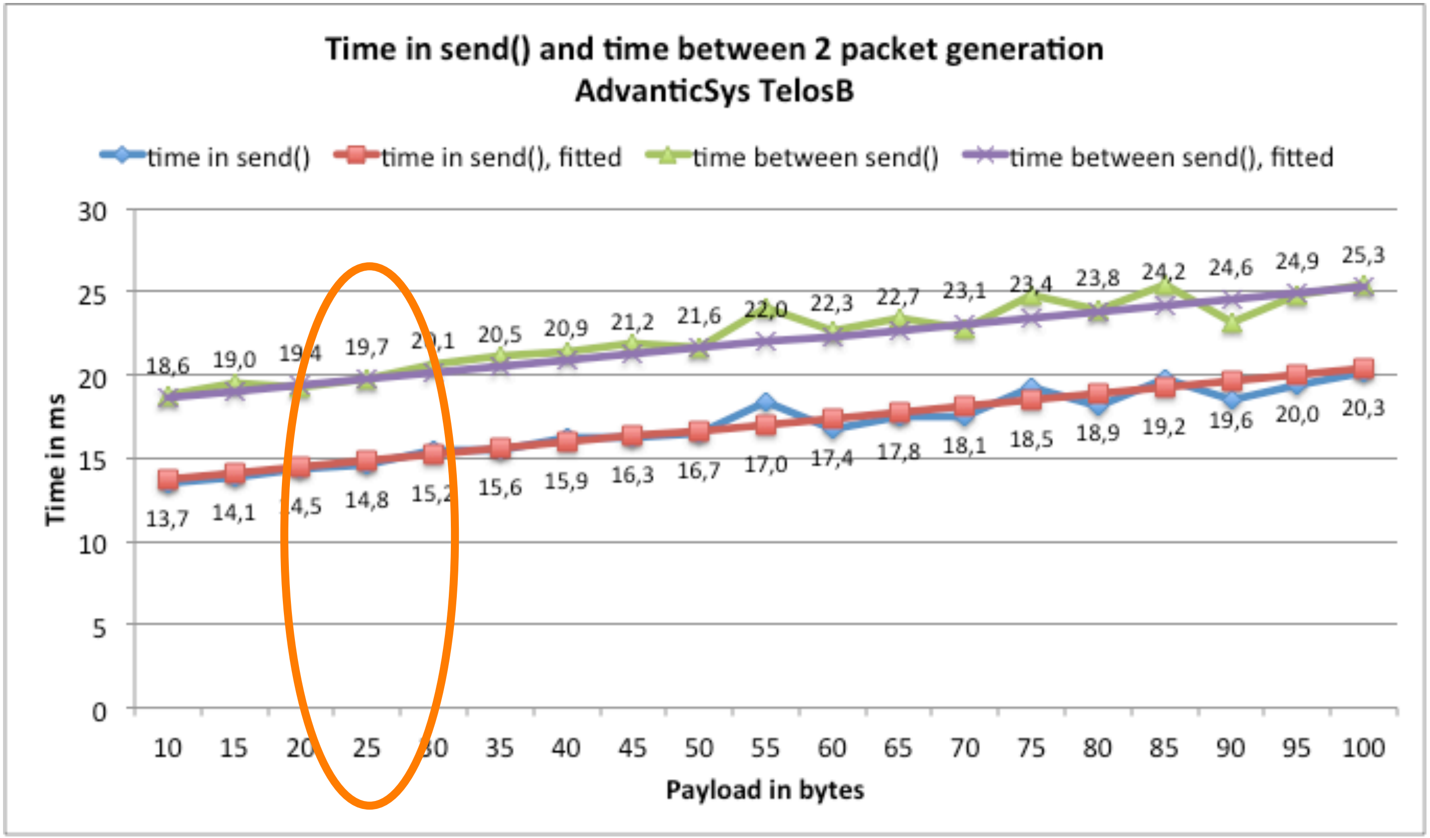




Need to increase communication speed between XBee radio and host ucontroller

Need to optimize the API

IoT node sending performance



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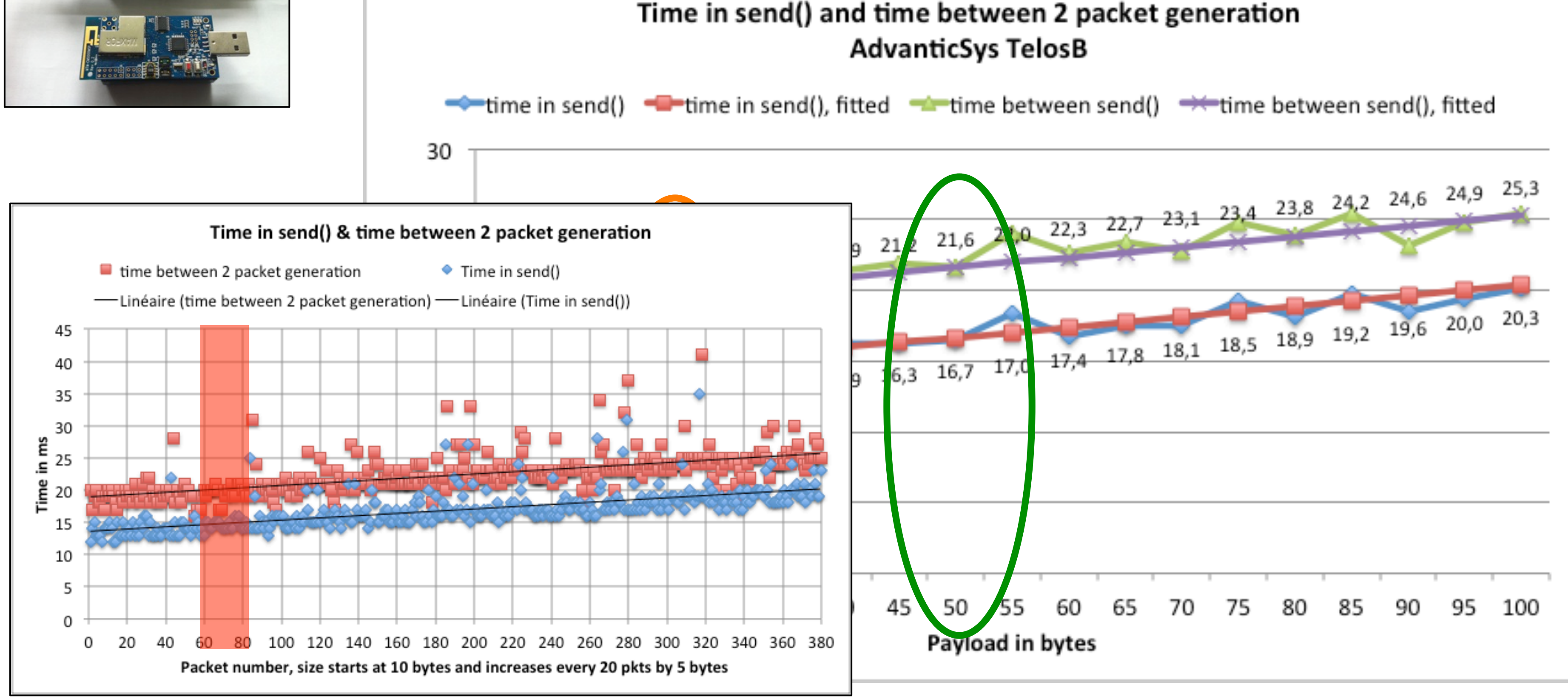
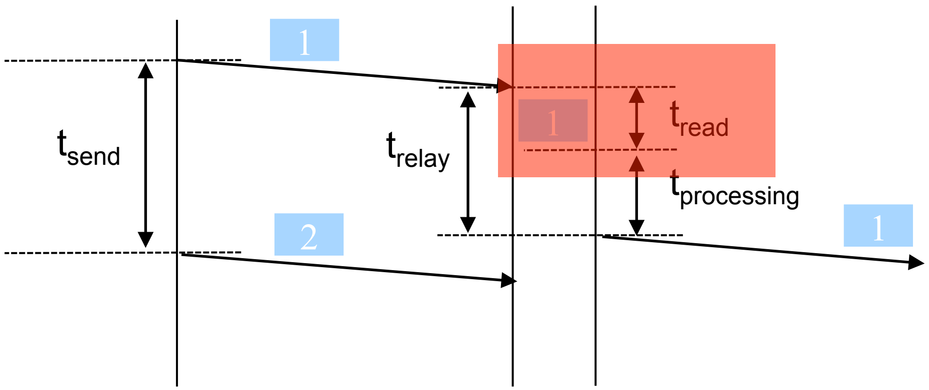
IoT node sending performance



Better with A2 agregation

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

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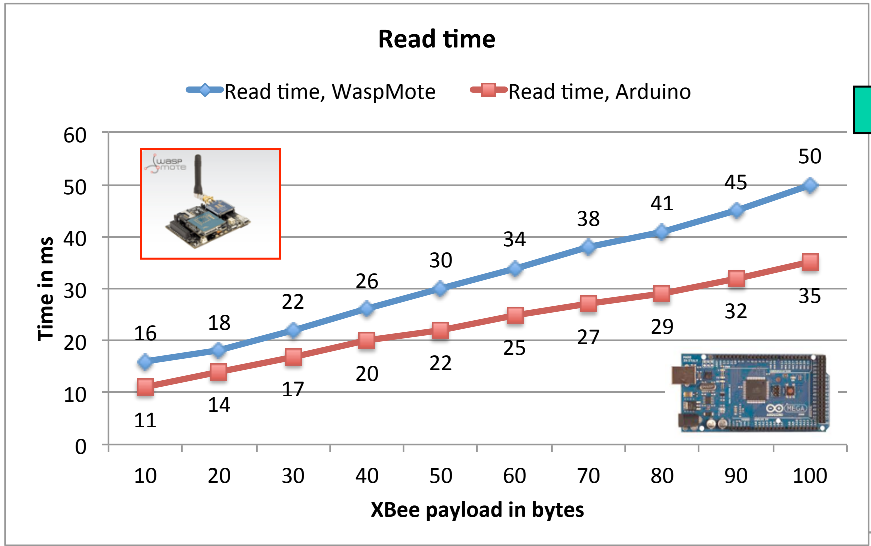
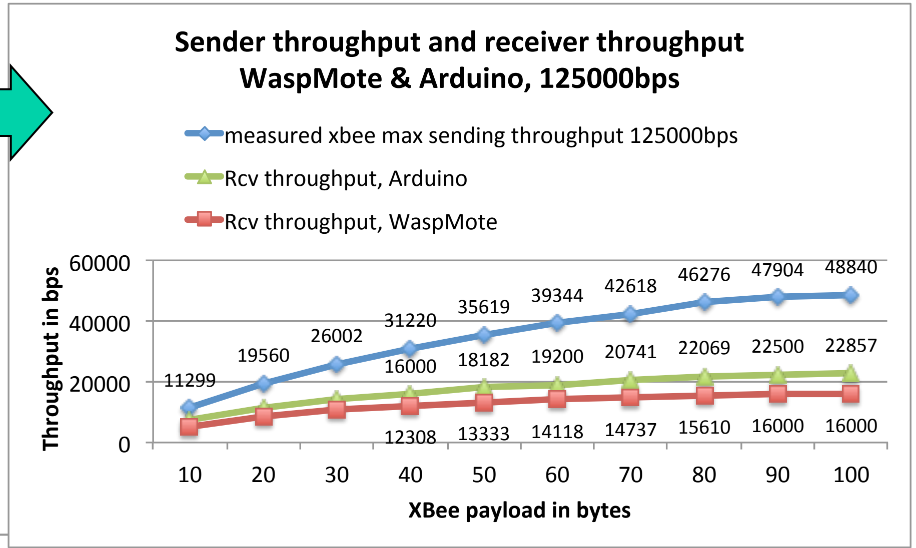
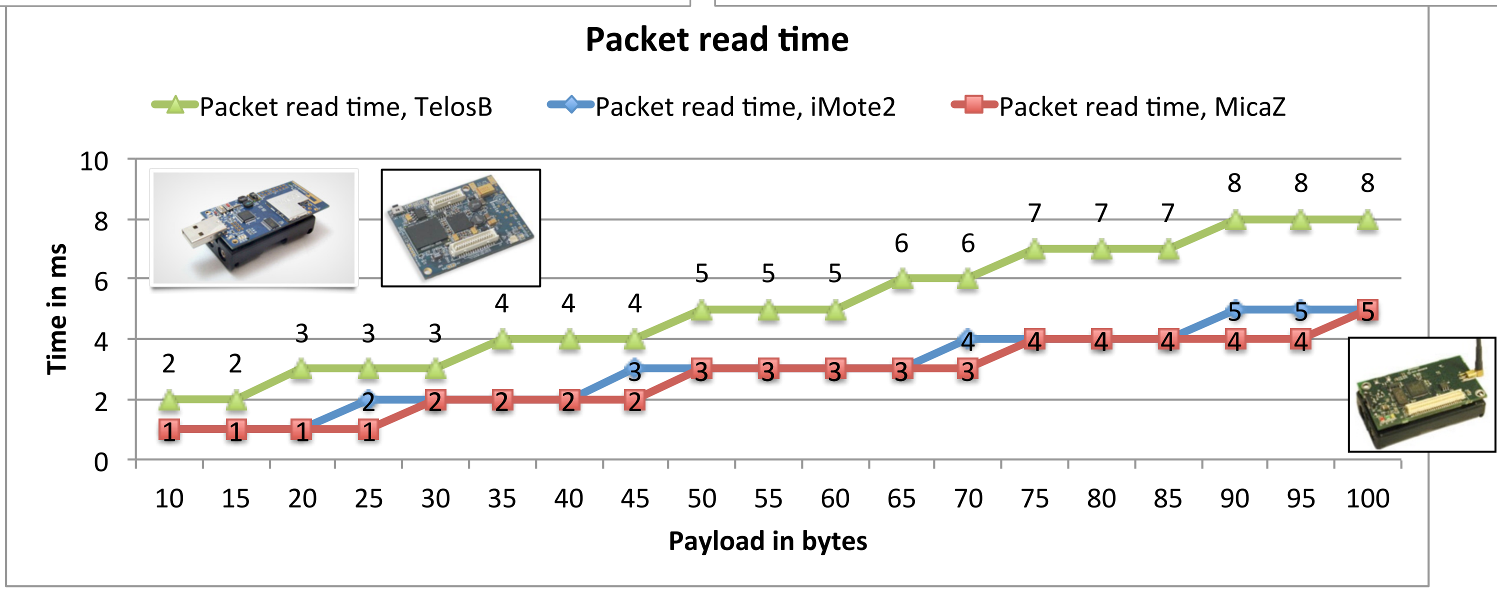
EAR-IT

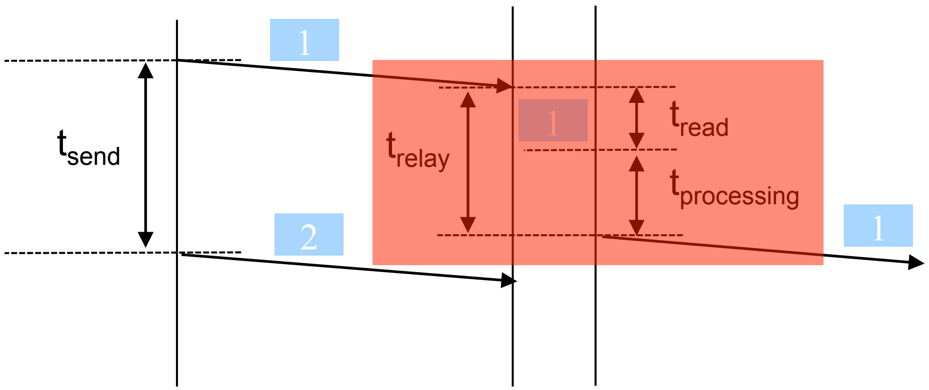
T_{READ} for various motes







Relay performances

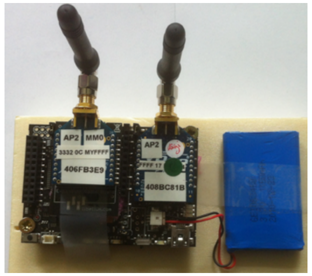


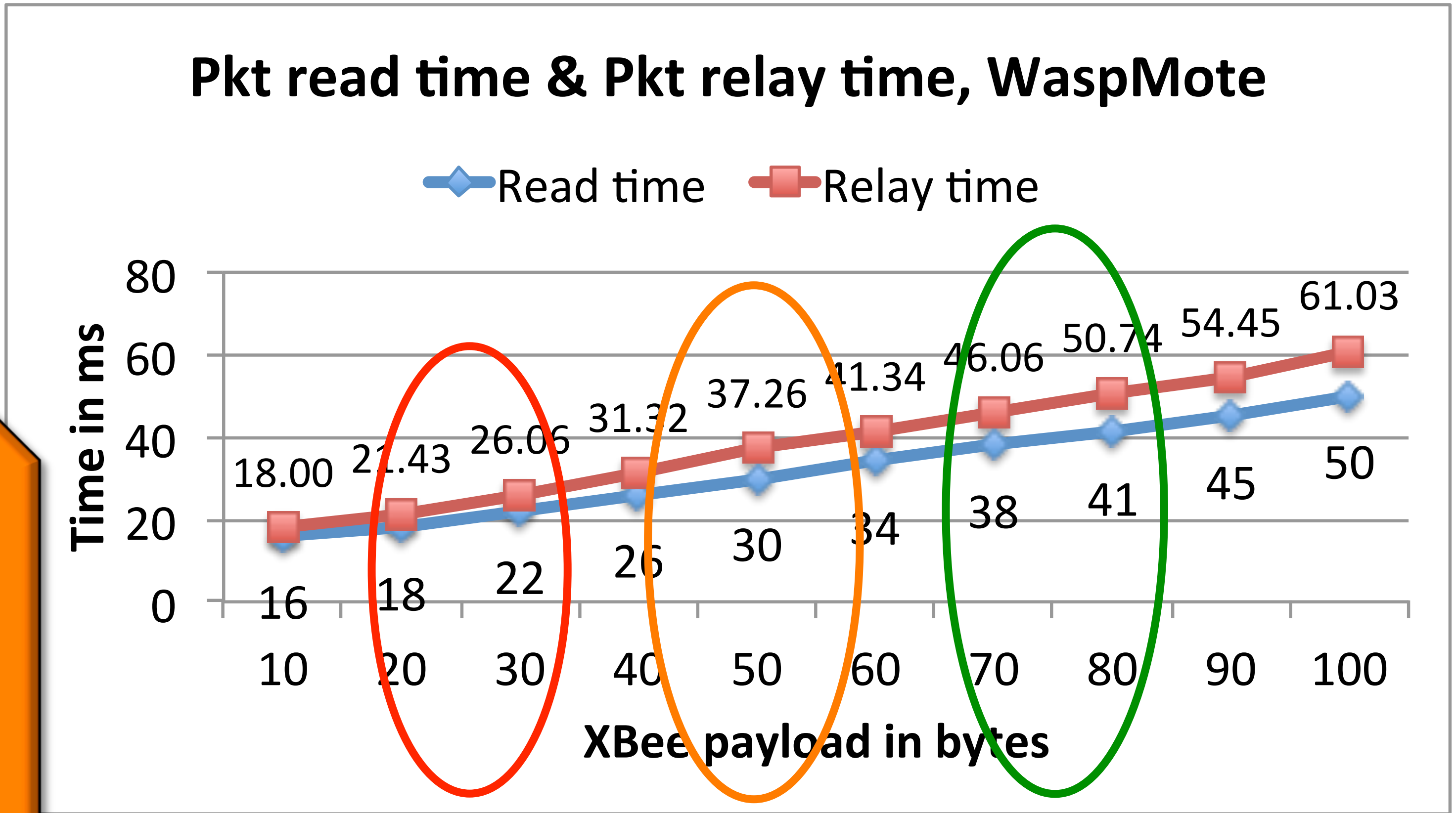
- Relaying are usually done at application-level (even OS level is considered app-level for the mote)
- Relaying means:

  Read the packet in memory

  Send the packet to next hop

Relay node performances

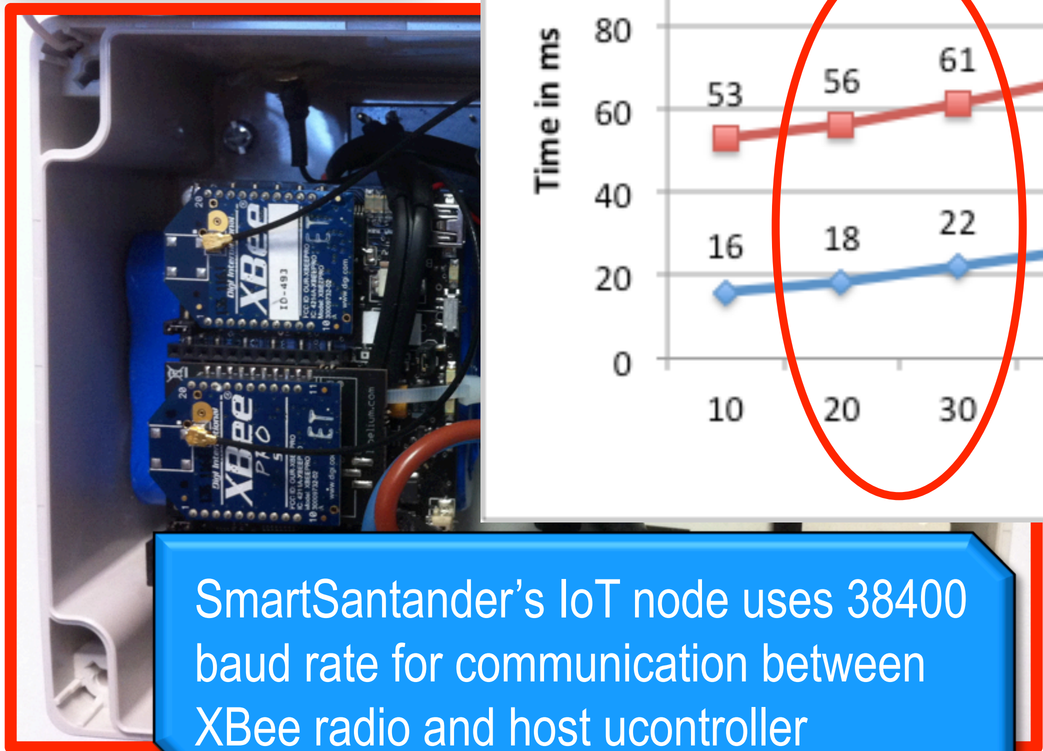


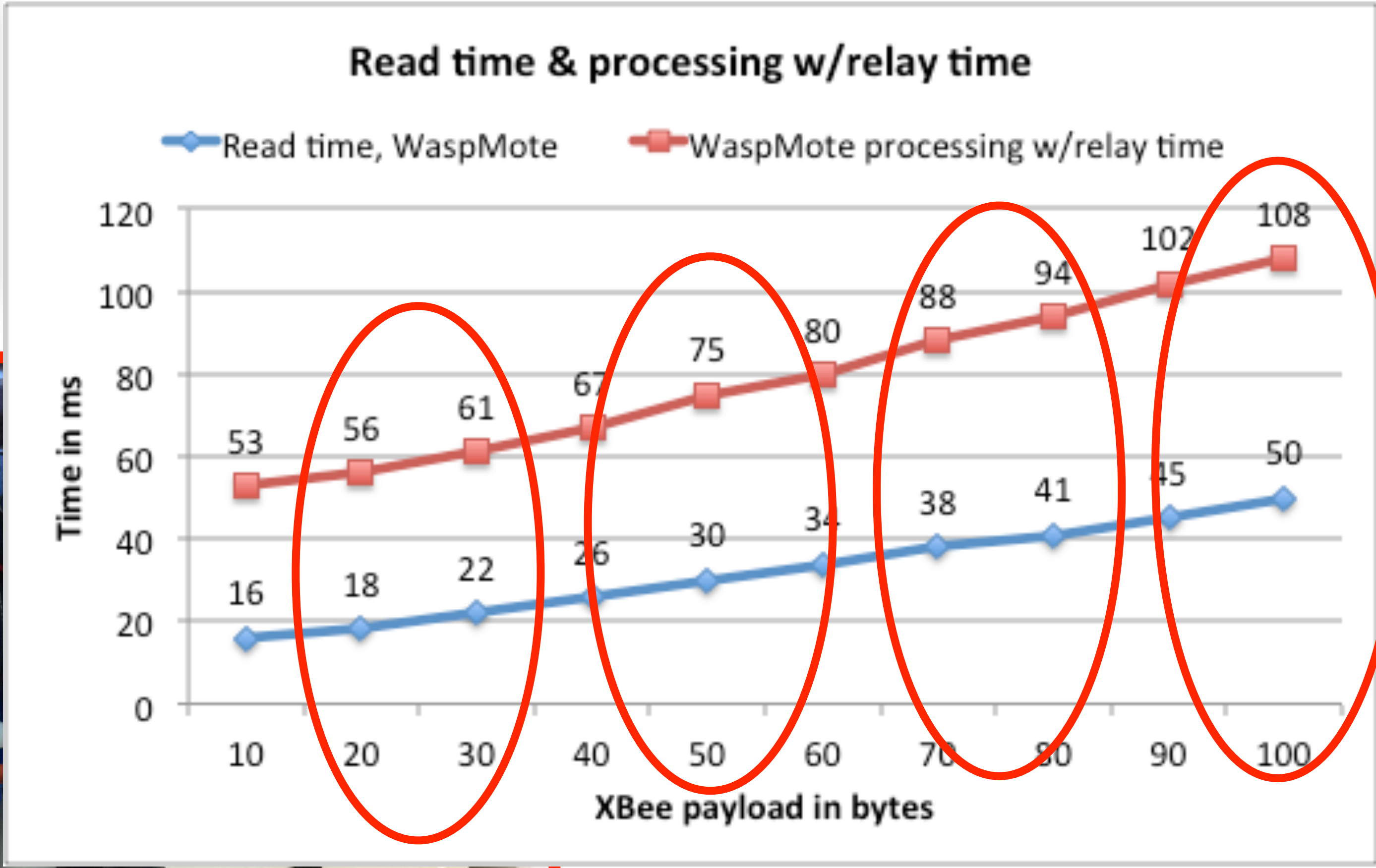


SPEEX codec at 8kbps requires to be able to relay a 25-byte packet every 20ms

Needs A3 agregation

Santander's limitations

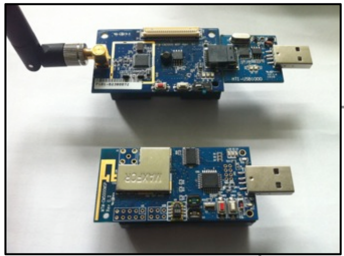


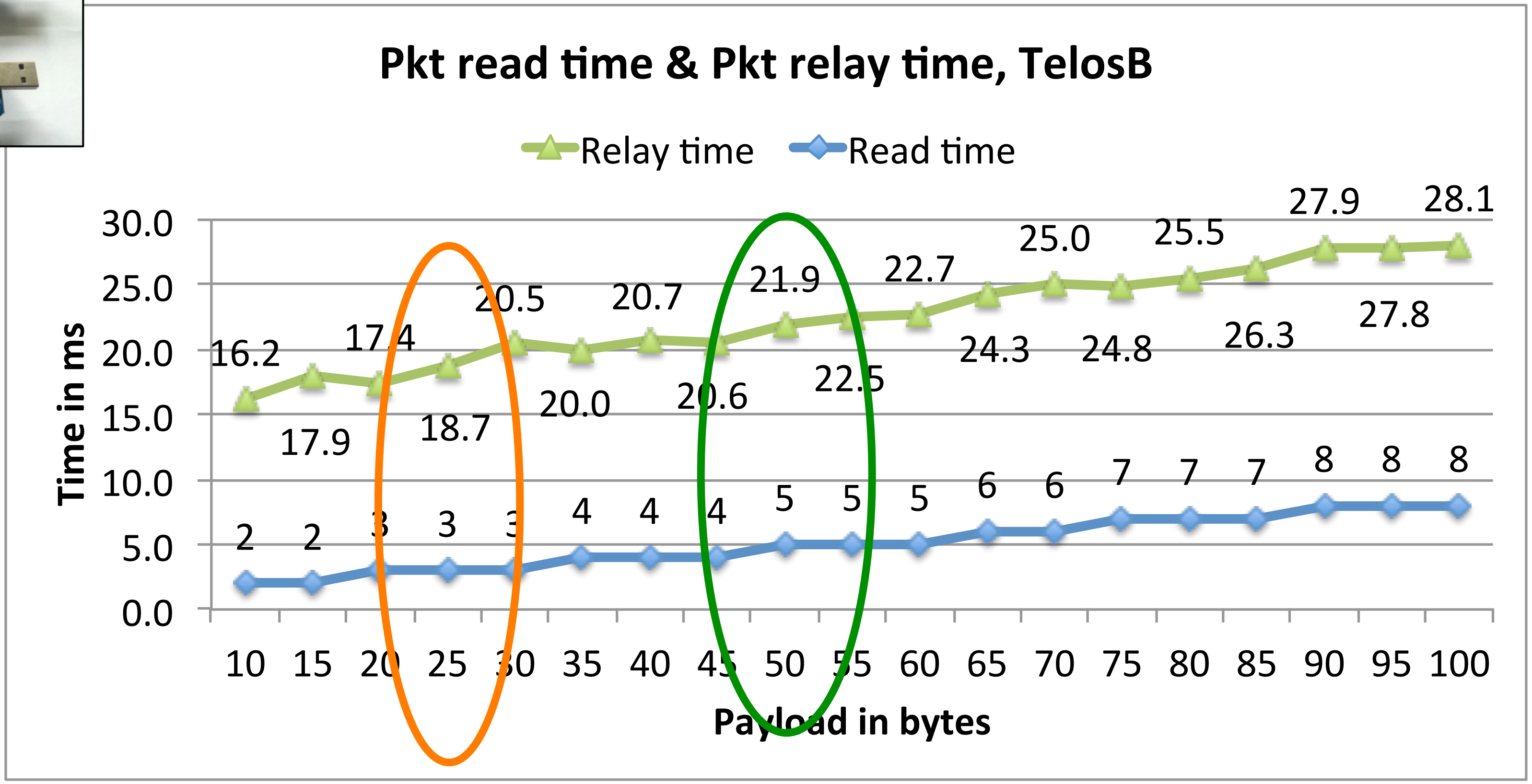


SmartSantander's IoT node uses 38400 baud rate for communication between XBee radio and host ucontroller

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

Relay node performances



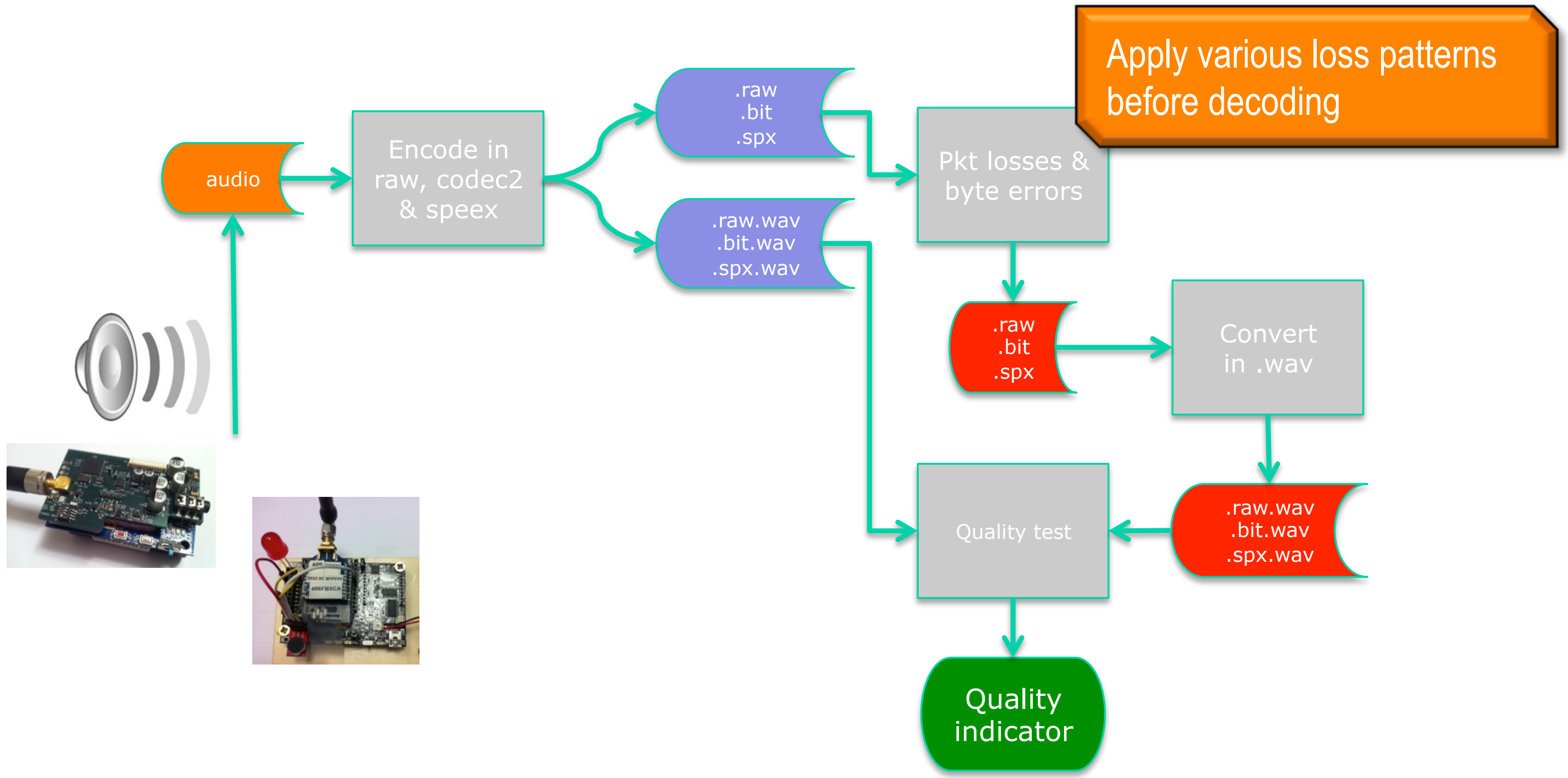


Needs A2 agregation

Summary on performances

- Looking at app-level performances, taking into account OS&API overheads (read, write)
- In multi-hop communication, relay time can dramatically reduce the E2E performances
- Dedicated audio board leverage some performance limits
- Audio frame aggregation can be used to adapt to IoT node limits

Sensitivity of codecs



Audio quality: PESQ & MOS (1)

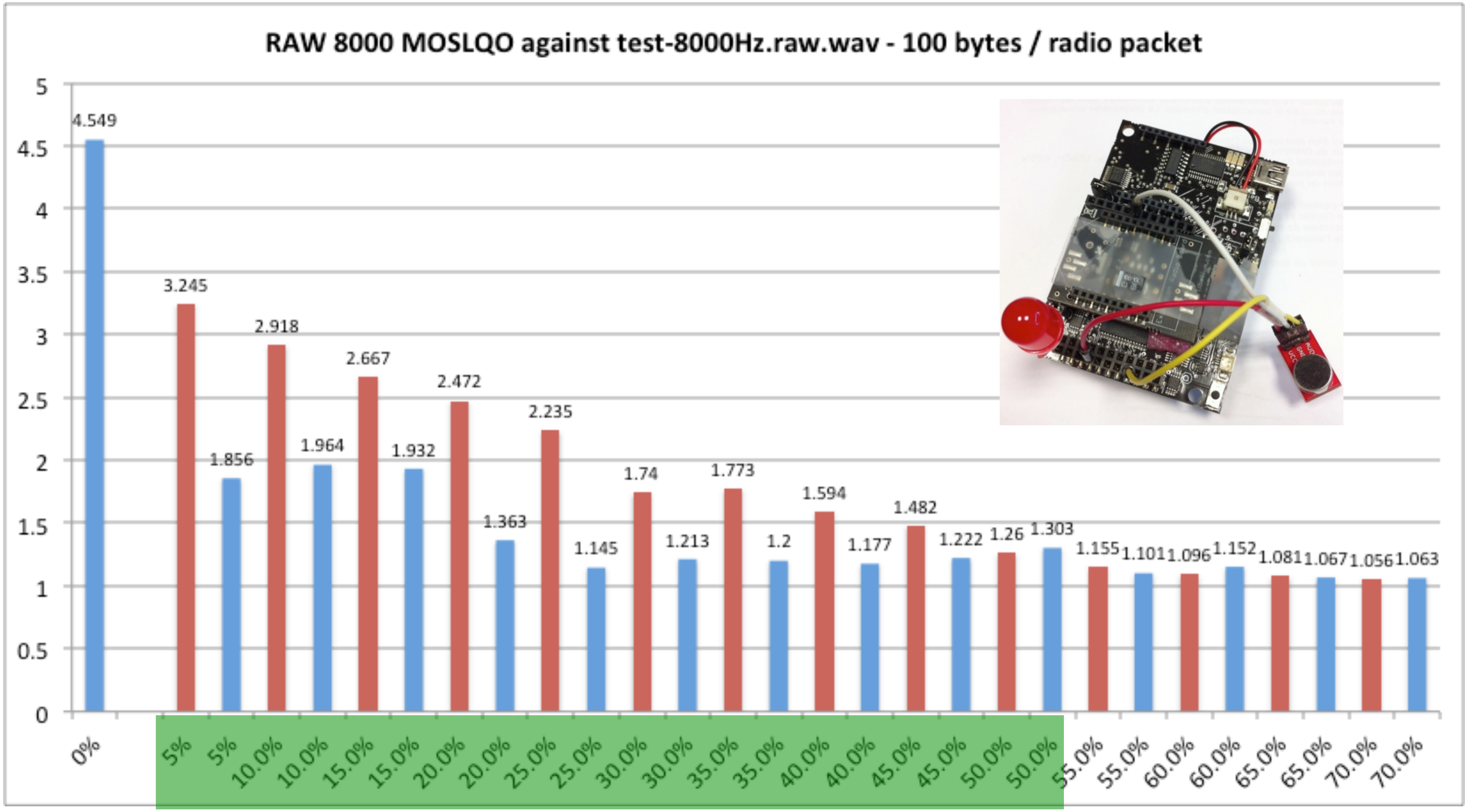
- ITU-T P.862 Perceptual evaluation of speech quality (PESQ): An objective method for end-to-end speech quality assessment of narrow-band telephone networks and speech codecs.
- We can use ITU-T PESQ tool to determine the MOS value for loss-free encoded audio (codec2, speex, …). MOS-LQO values greater than 2.6 are considered good.

Audio quality: PESQ & MOS (2)

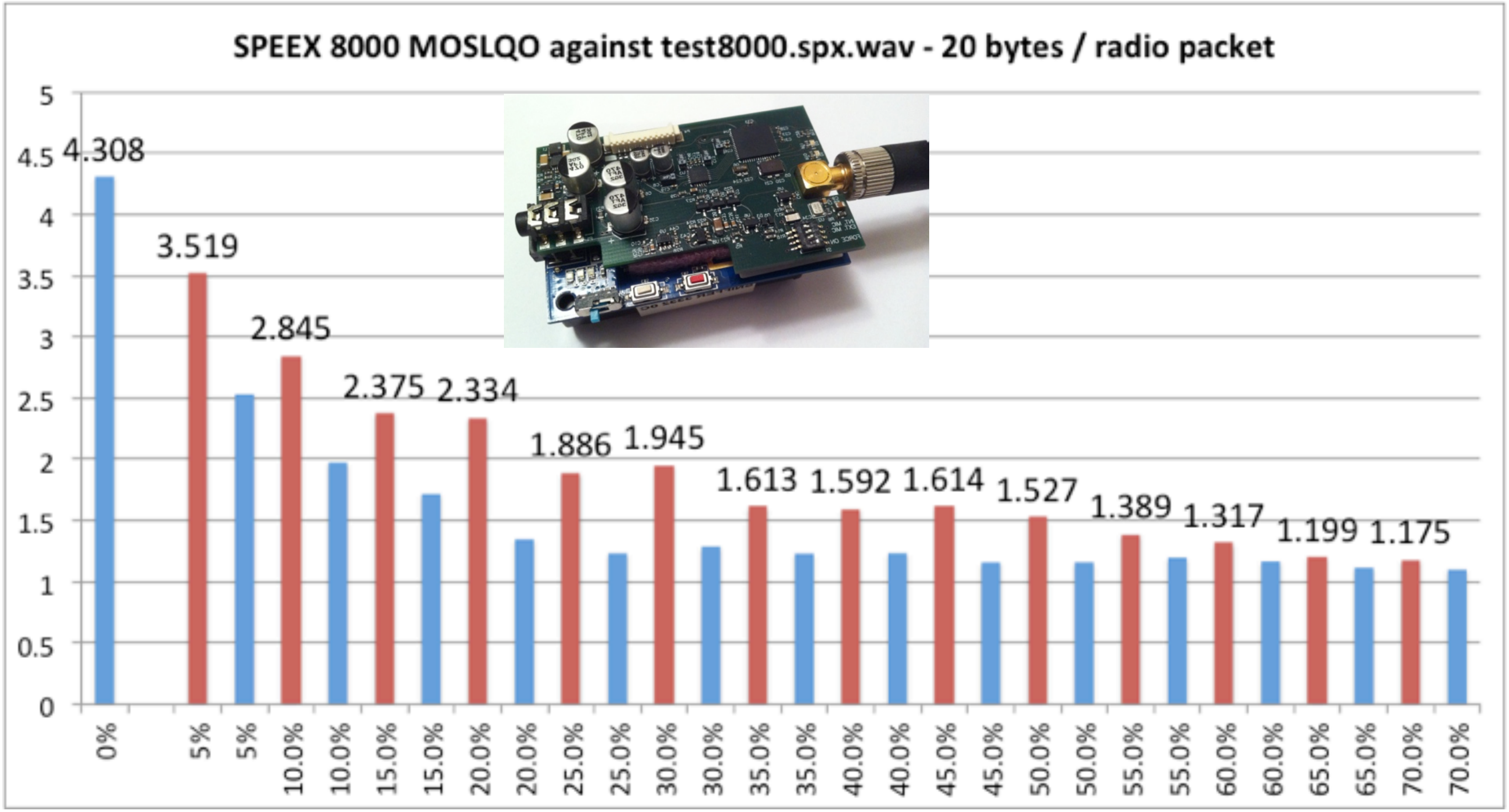
- 5=Excellent, 4=Good, 3=Fair, 2=Poor, 1=Bad

REFERENCE	DEGRADED	PESQMOS	MOSLQO	SAMPLE_FREQ
test.wav	test.wav	4.500	4.549	8000
test.wav	test4000Hz.raw.wav	0.769	1.115	4000
test.wav	test8000Hz.raw.wav	4.5	4.549	8000
test.wav	test2150.spx.wav	2.757	2.472	8000
test.wav	test5950.spx.wav	3.428	3.454	8000
test.wav	test8000.spx.wav	3.652	3.757	8000
test.wav	test11000.spx.wav	3.941	4.093	8000
test.wav	test13000.spx.wav	3.941	4.093	8000
test.wav	test15000.spx.wav	4.085	4.235	8000

Test8000.raw



Test8000.spx, 20B/pkt (A1)



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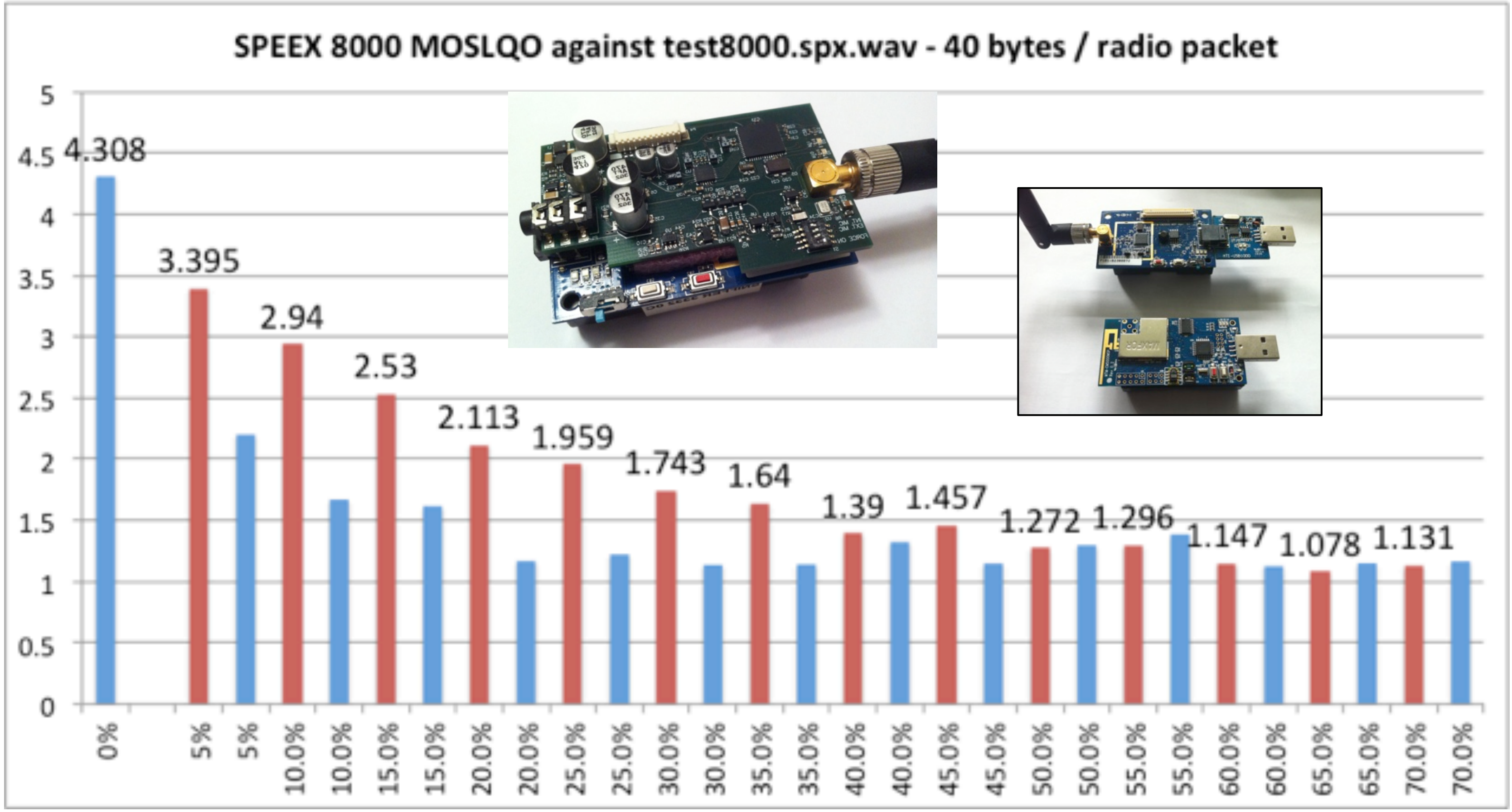
EAR-IT

Test800.spx, 40B/pkt (A2)



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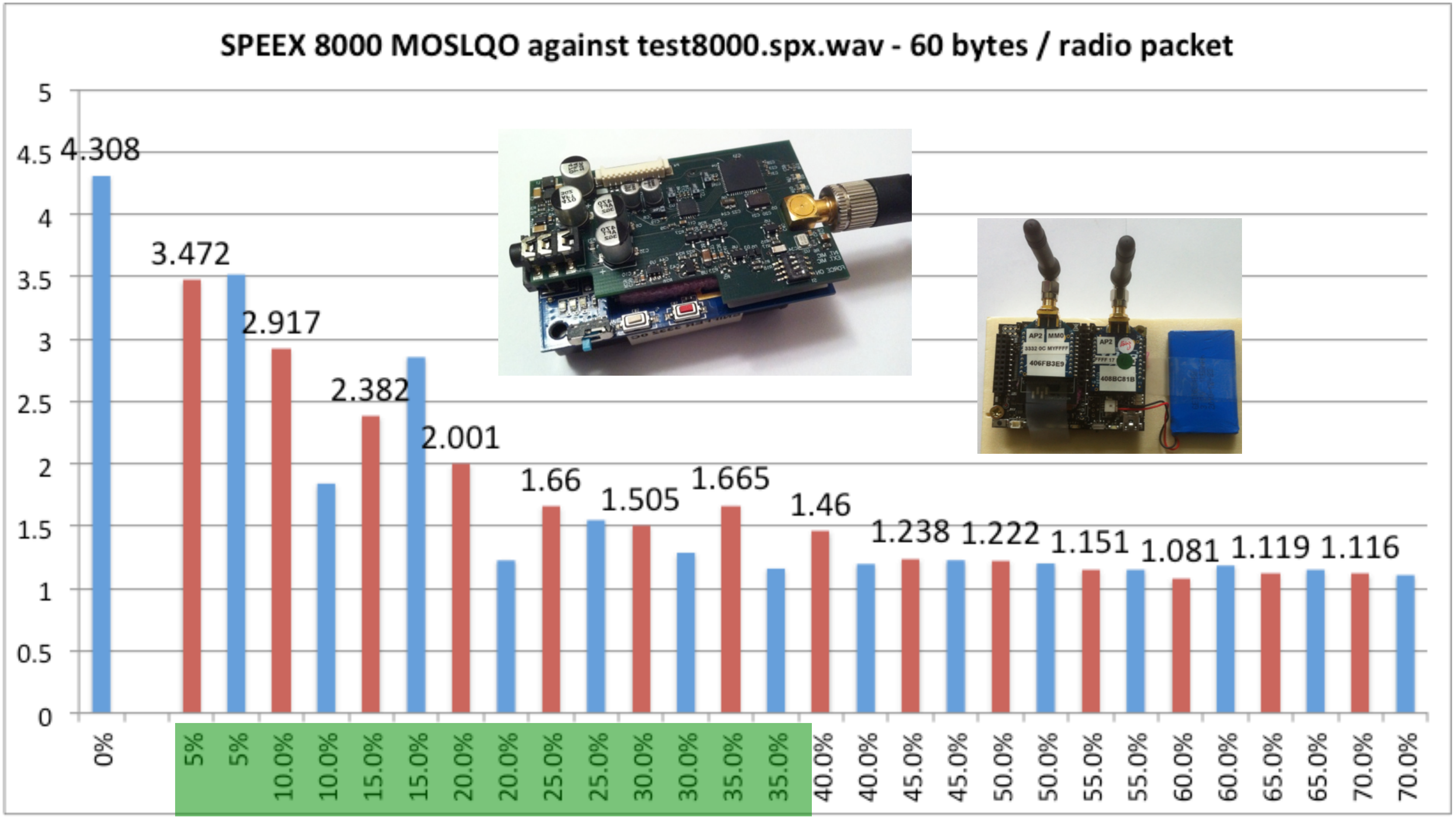
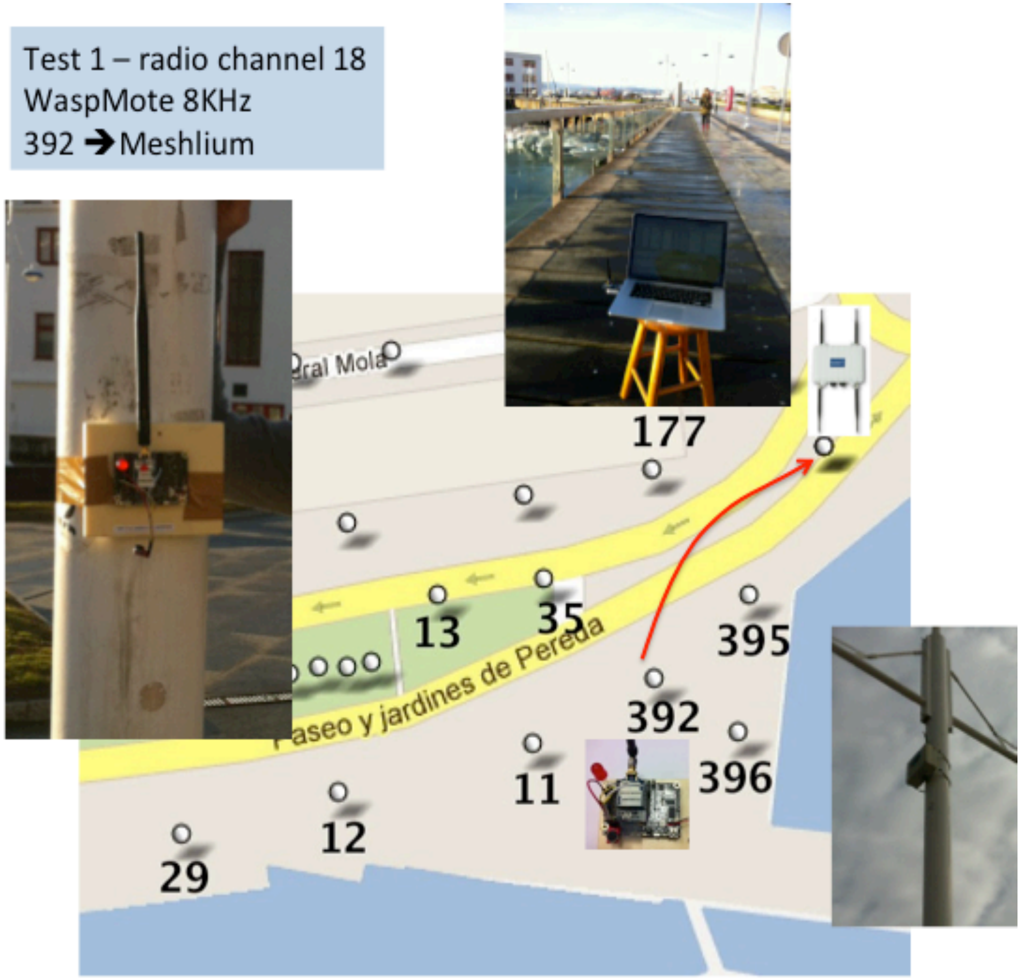
EAR-IT

Test800.spx, 60B/pkt (A3)



1-hop audio in LoS

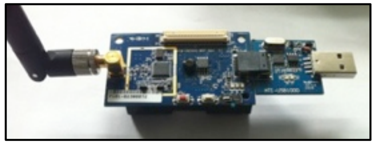
Test 1 – radio channel 18
WaspMote 8KHz
392 → Meshlium

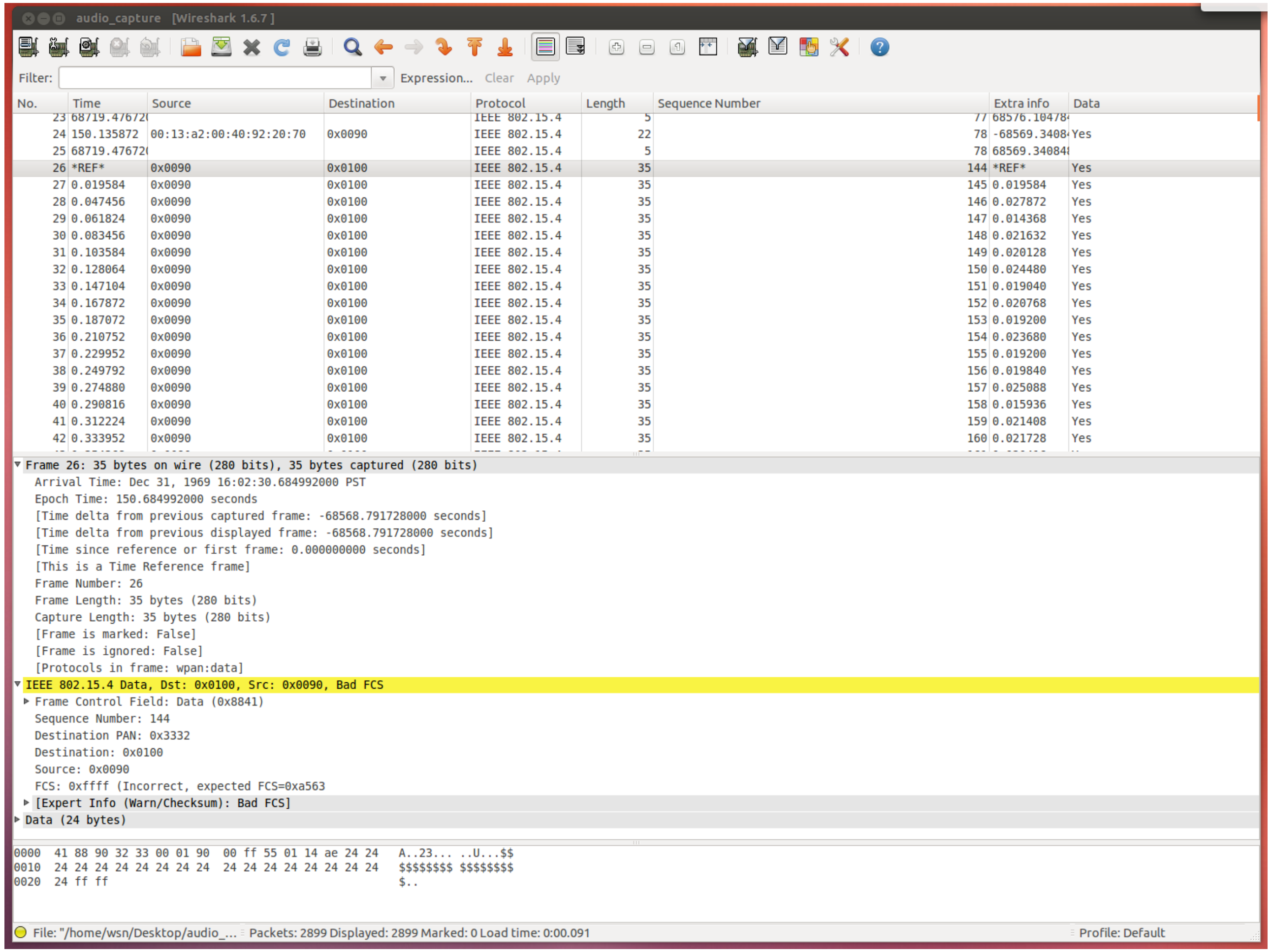


Frame analysis

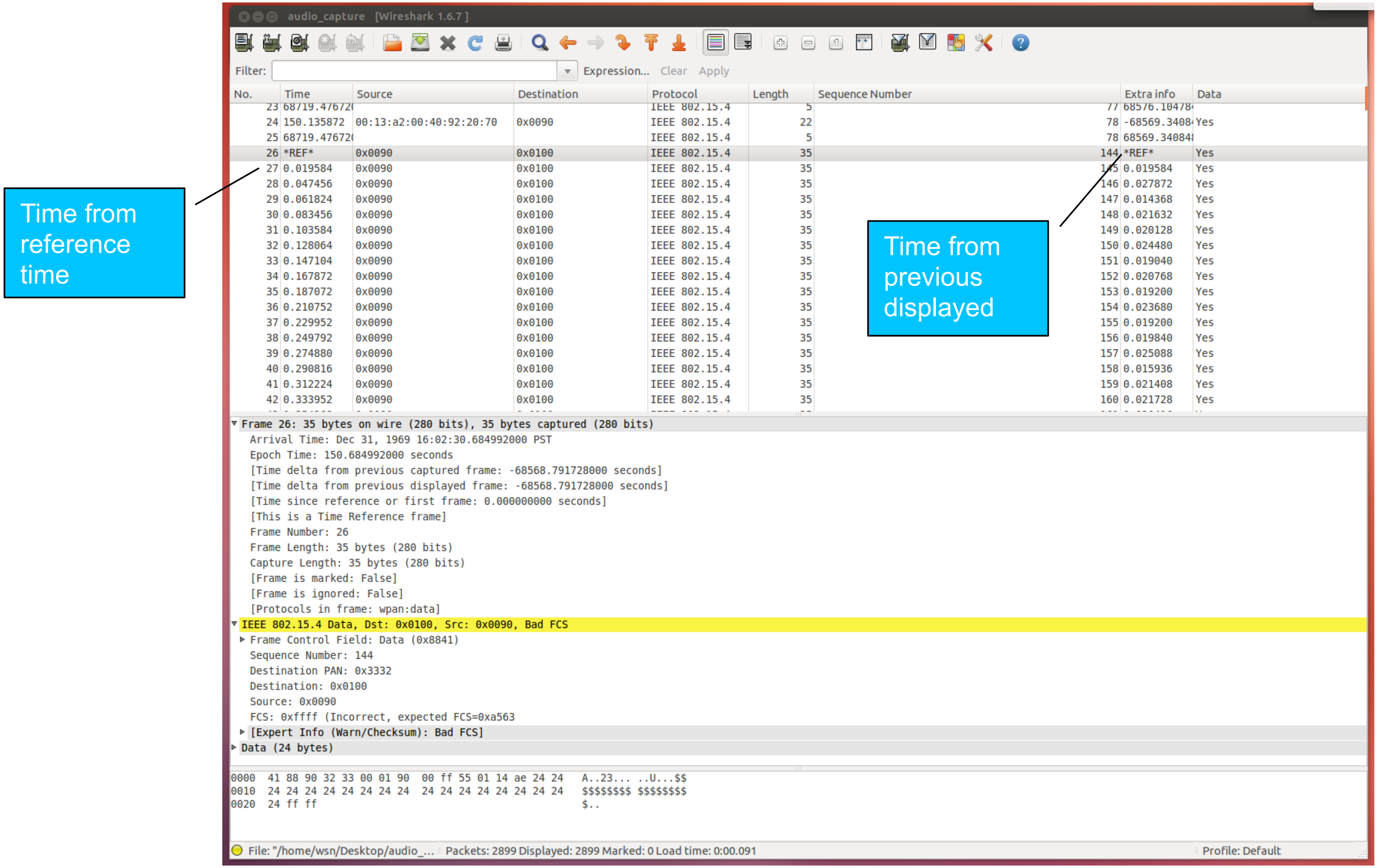
- Use `wireshark` as frame analysis tool
- AdvanticSys TelosB mote as promiscuous sniffer mote, connected to `wireshark` to display captured frames
- Frame reception time can be visualized for statistic collection
  - Transmission latencies
  - Frame jitter

wireshark frame capture





Example: latency 1-hop



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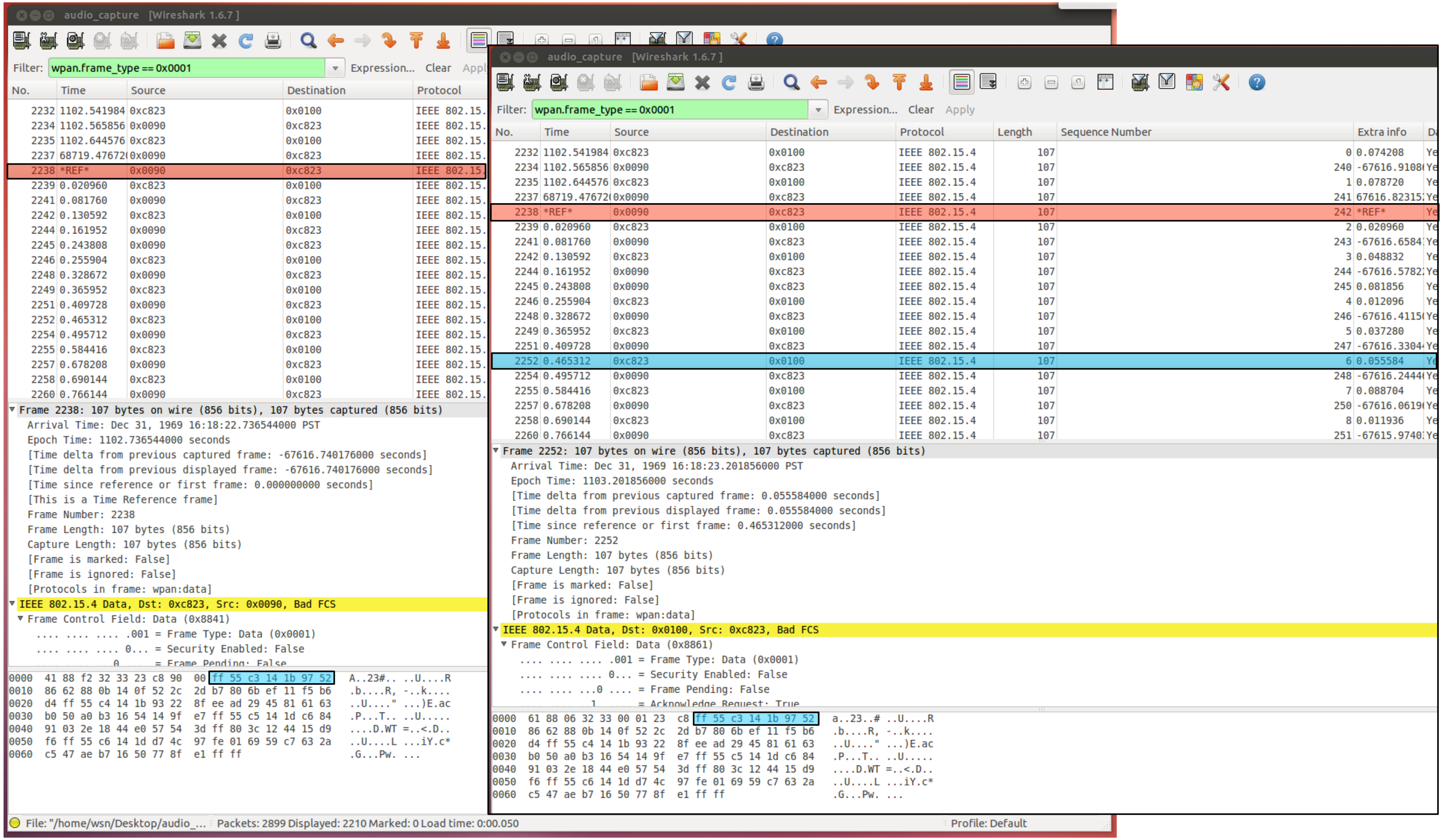
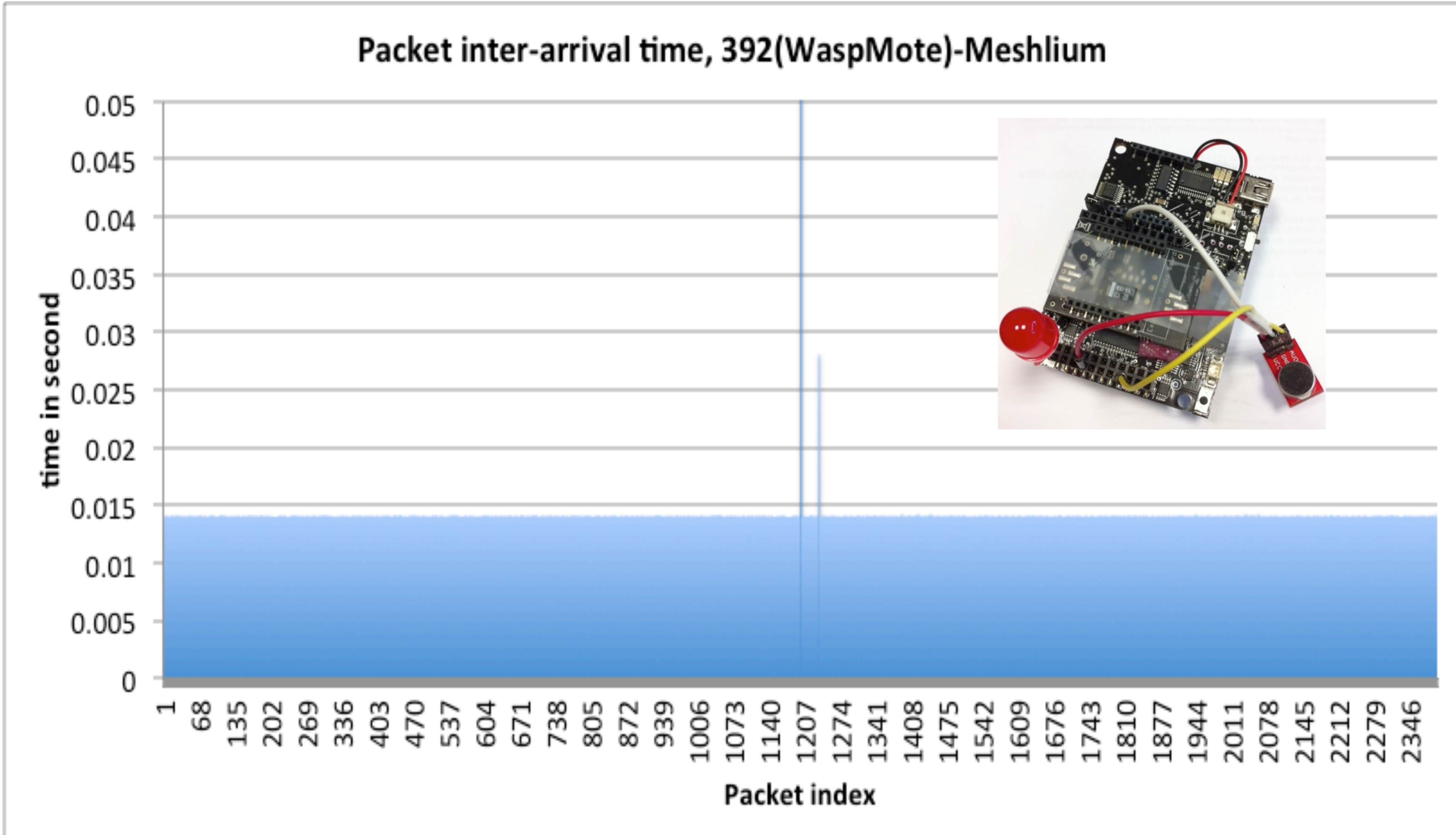
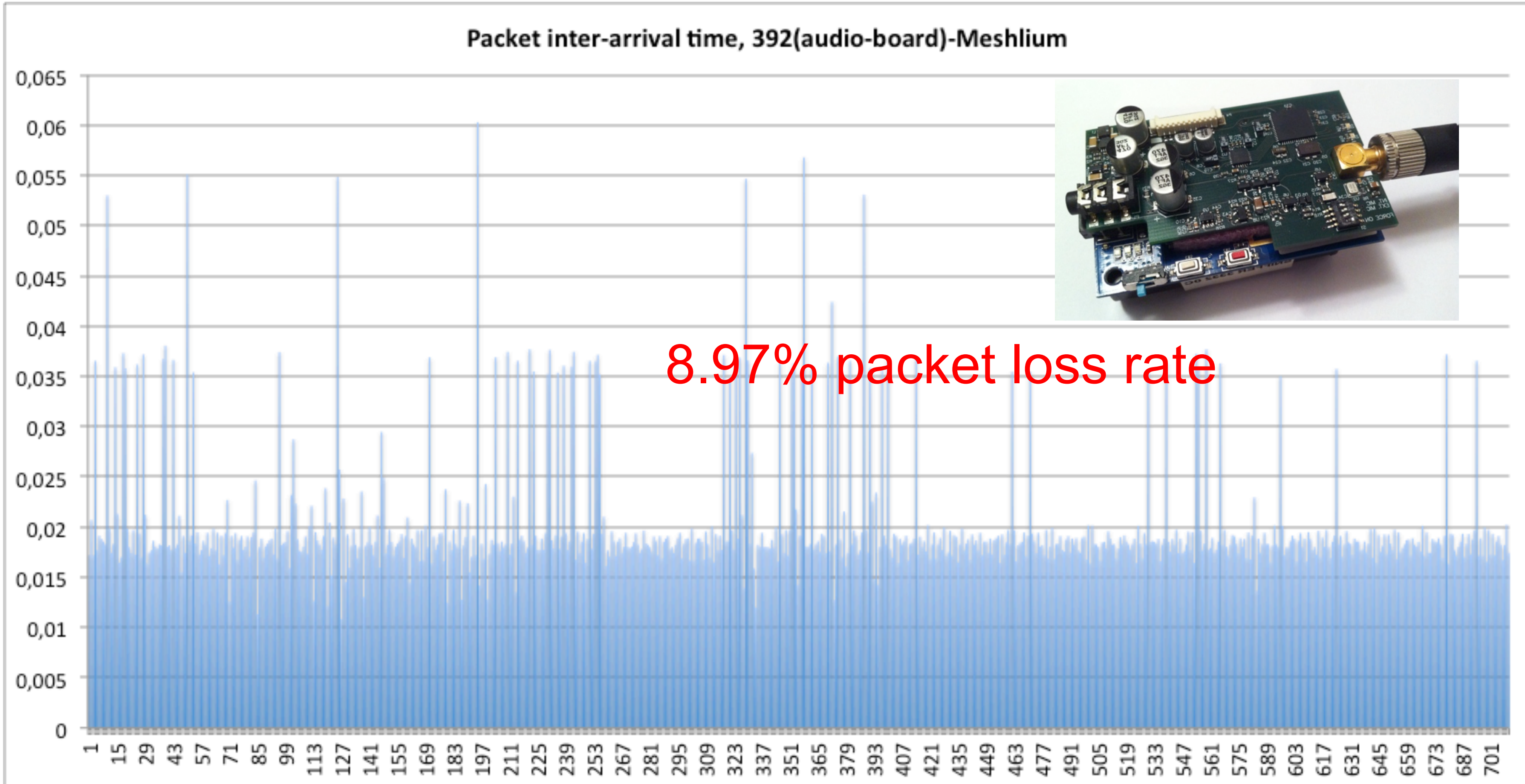
Example: latency 2-hop



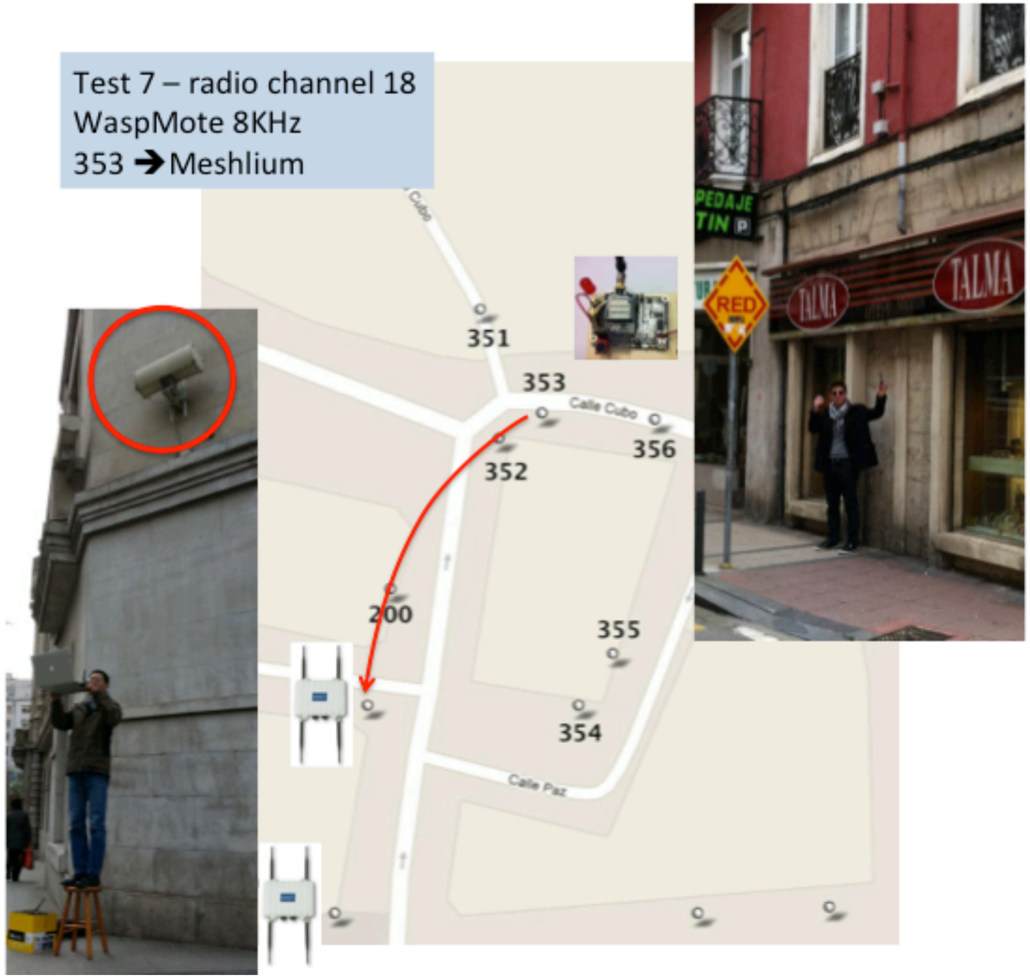
1-hop WaspMote audio



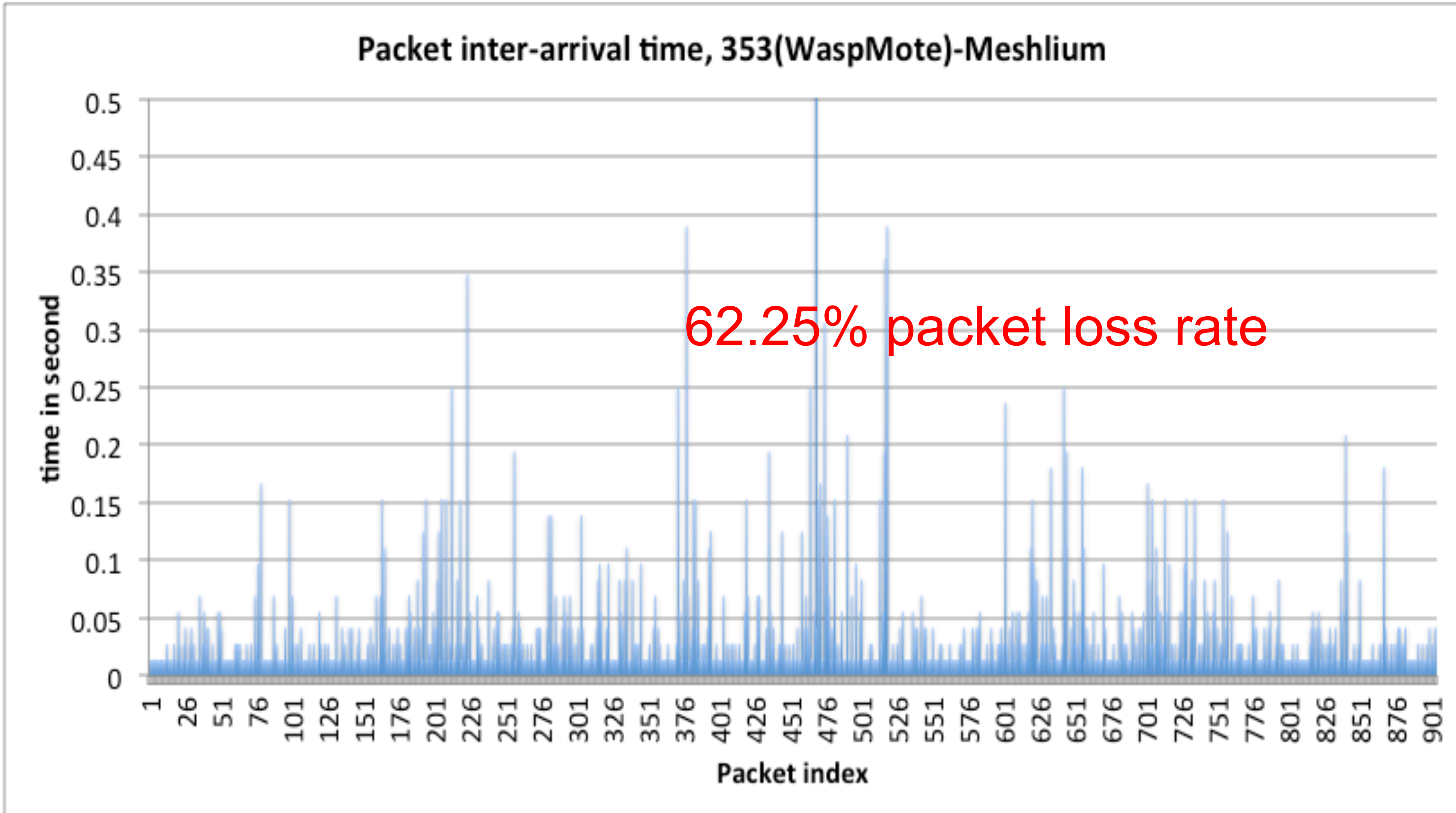
1-hop Advanticsys audio board



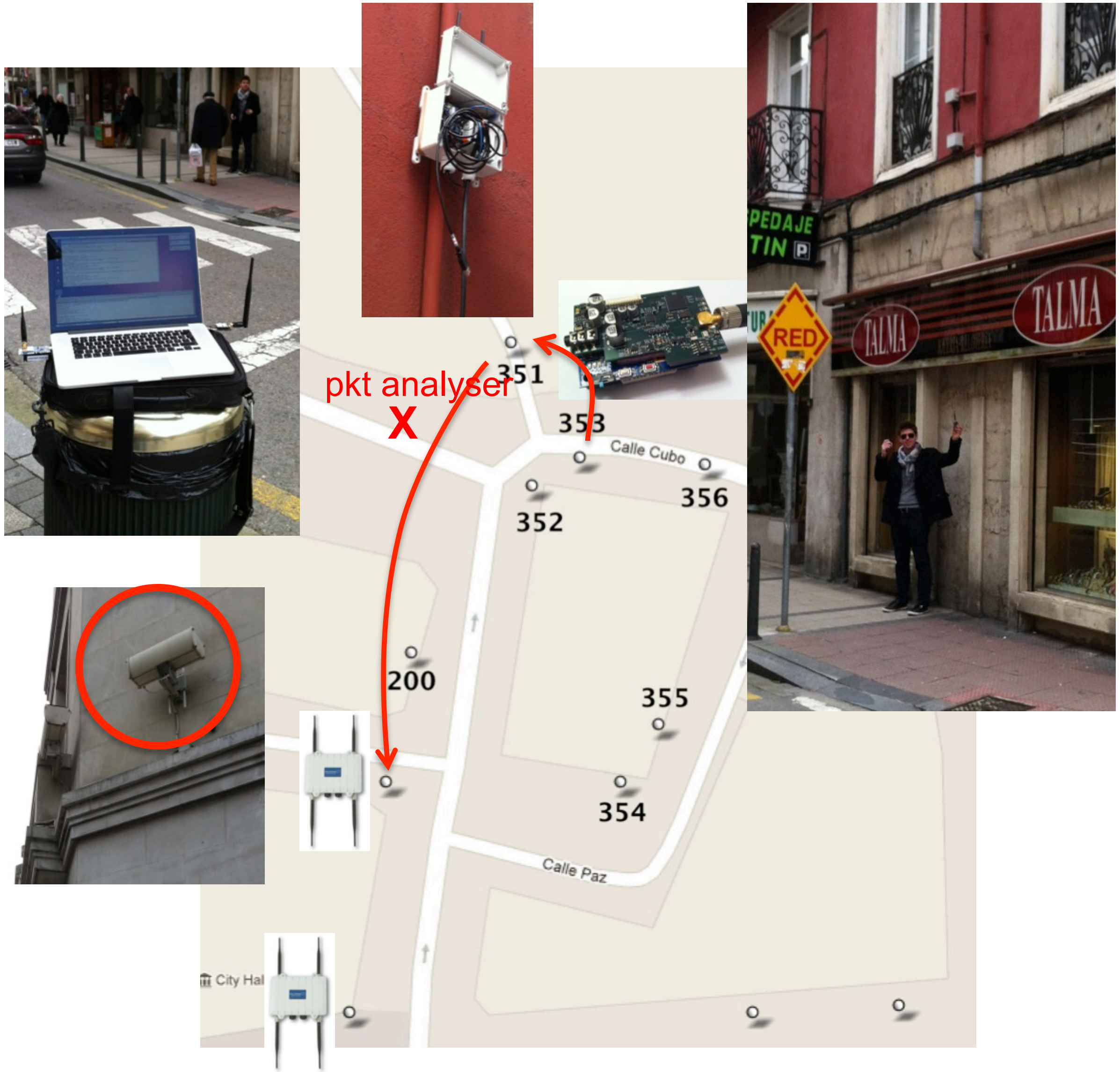
1-hop audio in non LoS



1-hop WaspMote audio



2-hop in non LOS



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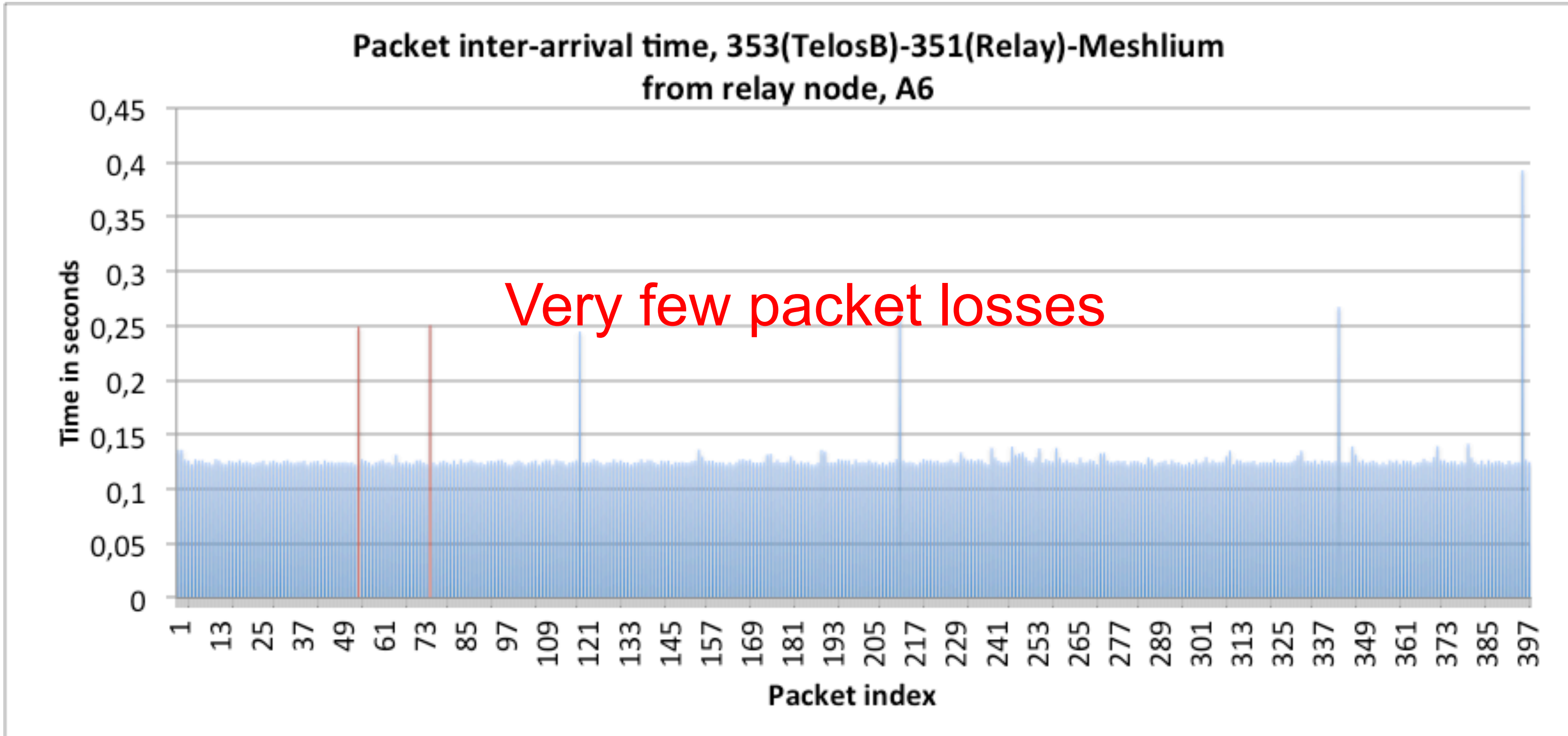
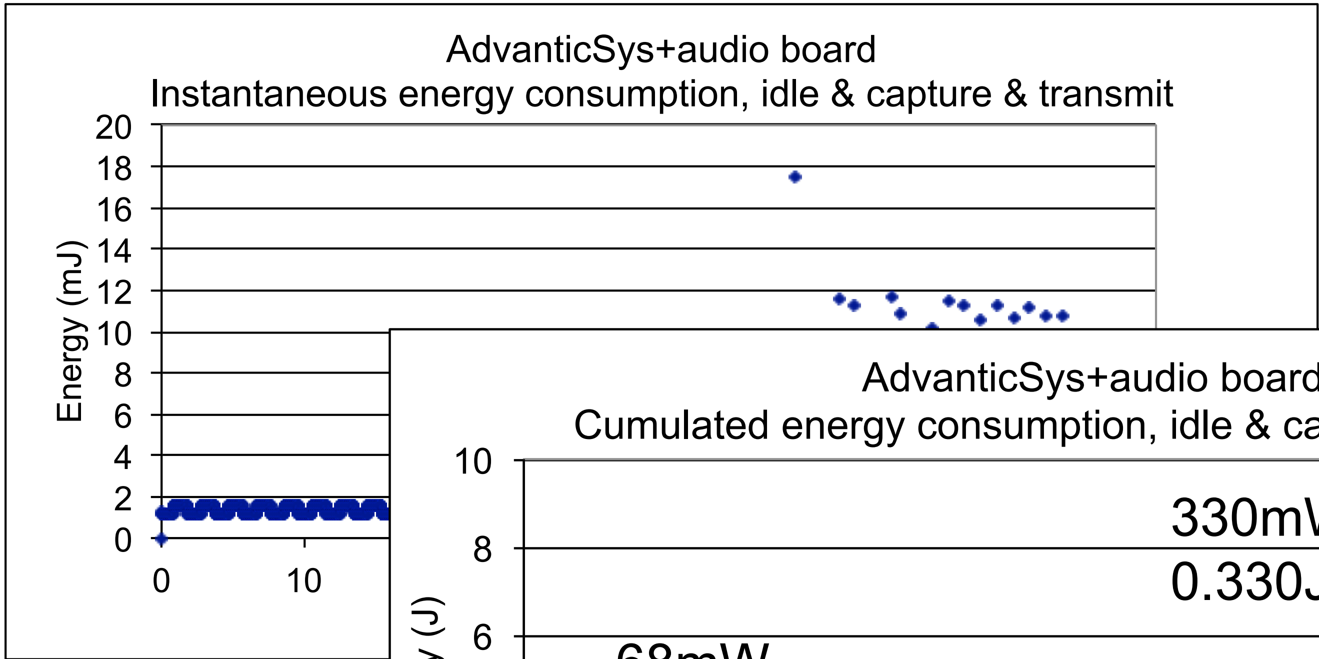
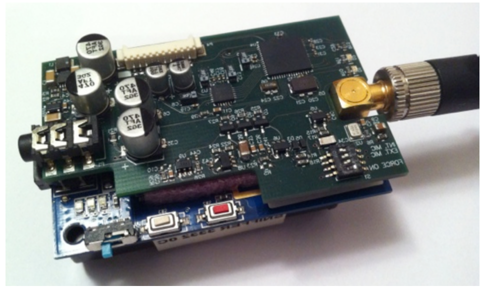
2-hop TelosB audio board

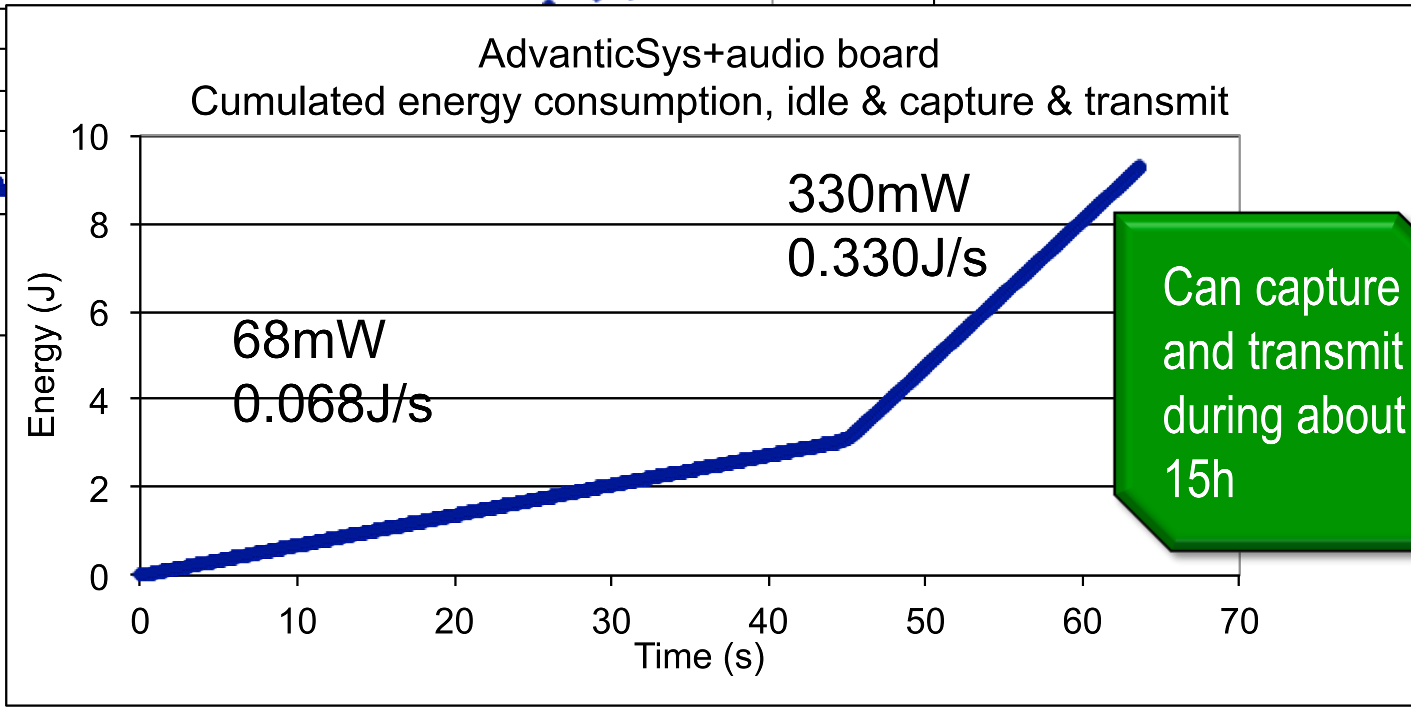


Usage of encoded audio allows for multi-hop transmission, improving greatly the transmission quality

Energy consumption



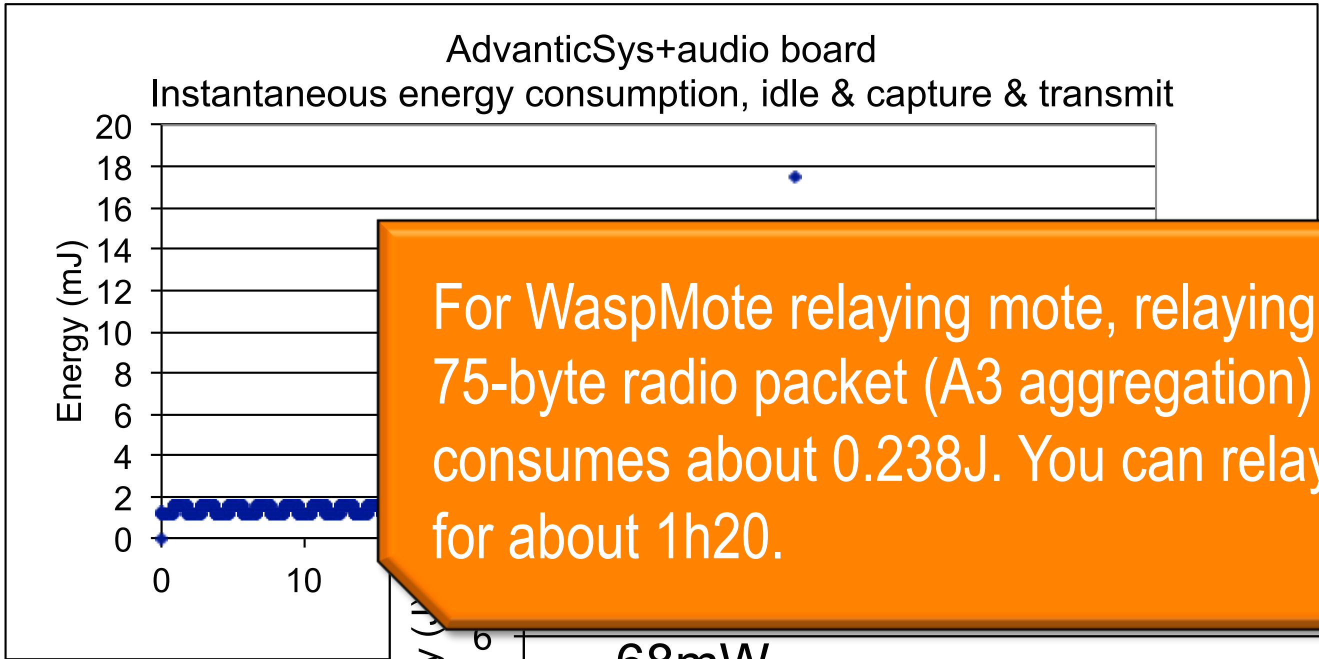


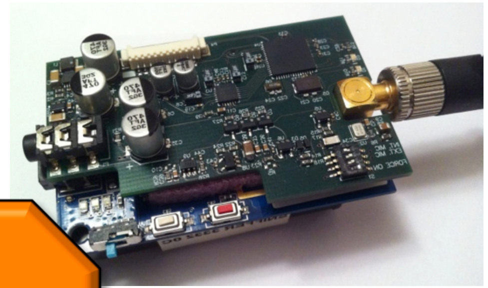


Can capture and transmit during about 15h

18720 JOULES

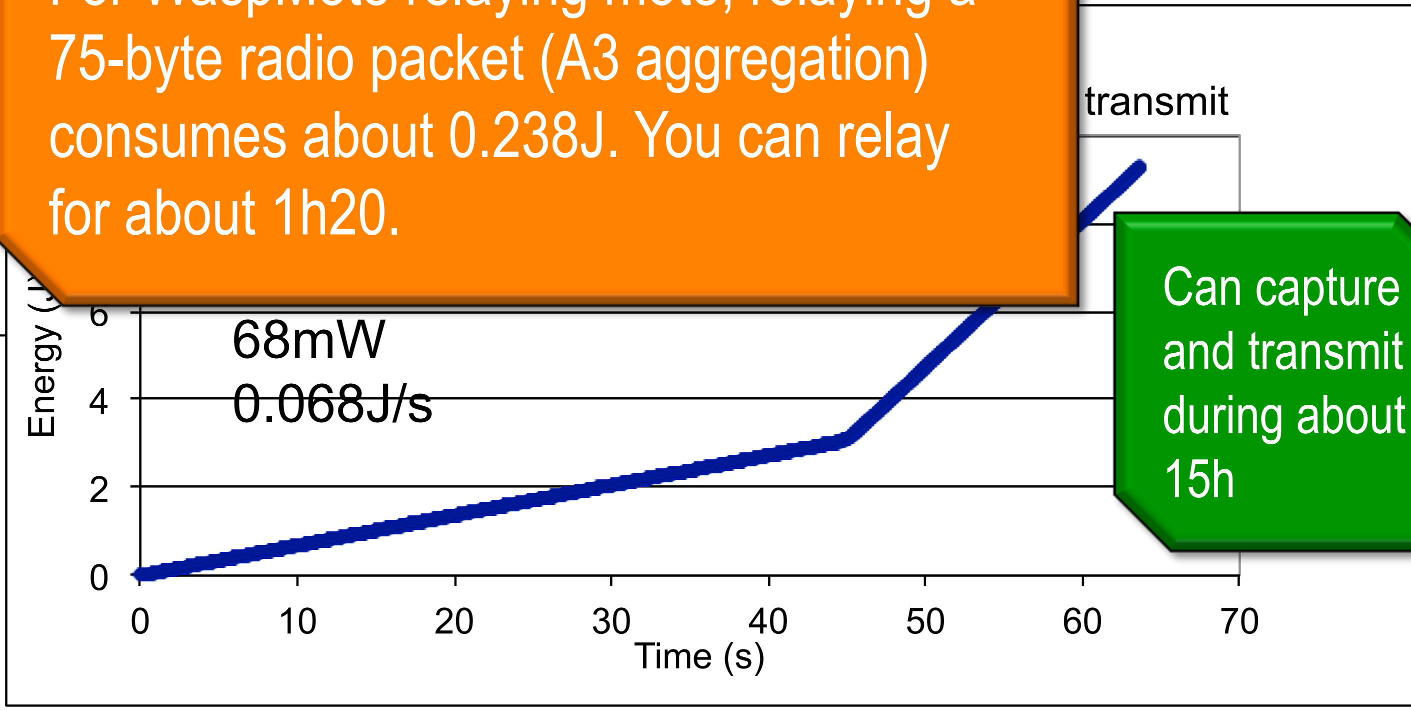
Energy consumption





For WaspMote relaying mote, relaying a 75-byte radio packet (A3 aggregation) consumes about 0.238J. You can relay for about 1h20.

18720 JOULES



Can capture and transmit during about 15h

Conclusions

- Low-resource devices (sensor, IoT, …) are currently deployed in a number of projects, especially in SmartCities context
- Benchmarking such test-beds is of prime importance for understanding the infrastructure limitations
- The EAR-IT project focuses on acoustic data, deployed on large scale test-beds, with very innovative applications
- We shown main performance issues as well as quality and usability indicators for streaming acoustic data
- Synthetic workload and in-situ tests have been performed to quantify the test-bed capacity and to propose adequate mechanism to provide near real-time acoustic data
- Same methodology can be applied to other test-beds, see the proposed methodology and tools: http://www.ear-it.eu/audio-benchmarking

Additional references

1. 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, 2014, DOI information: 10.1016/j.jnca.2014.08.002.

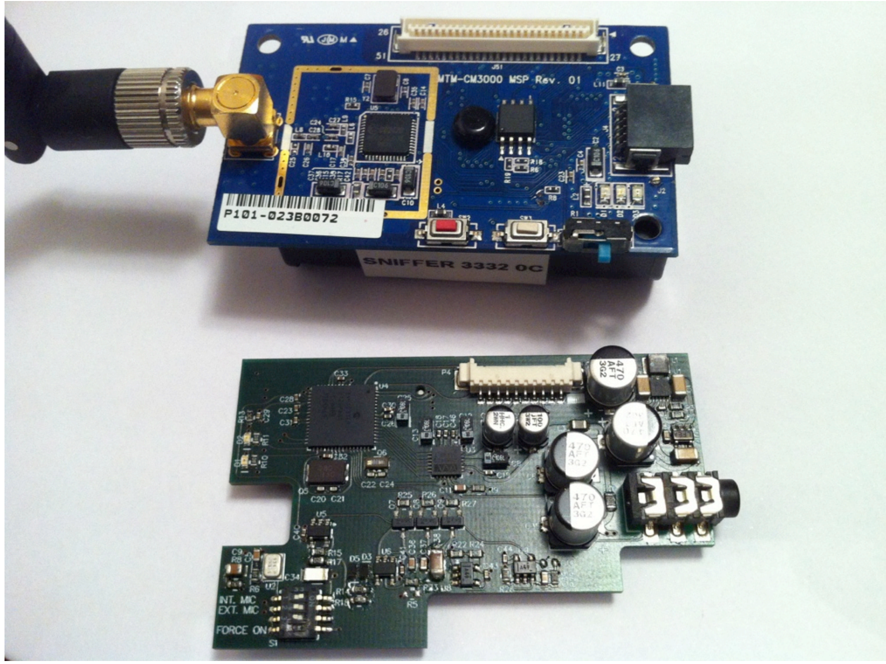
2. C. Pham, P. Cousin, A. Carer, "Real-time On-Demand Multi-Hop Audio Streaming with Low-Resource Sensor Motes", Proceedings of IEEE SenseApp, in conjunction with LCN 2014, Edmonton, Canada, September 2014.

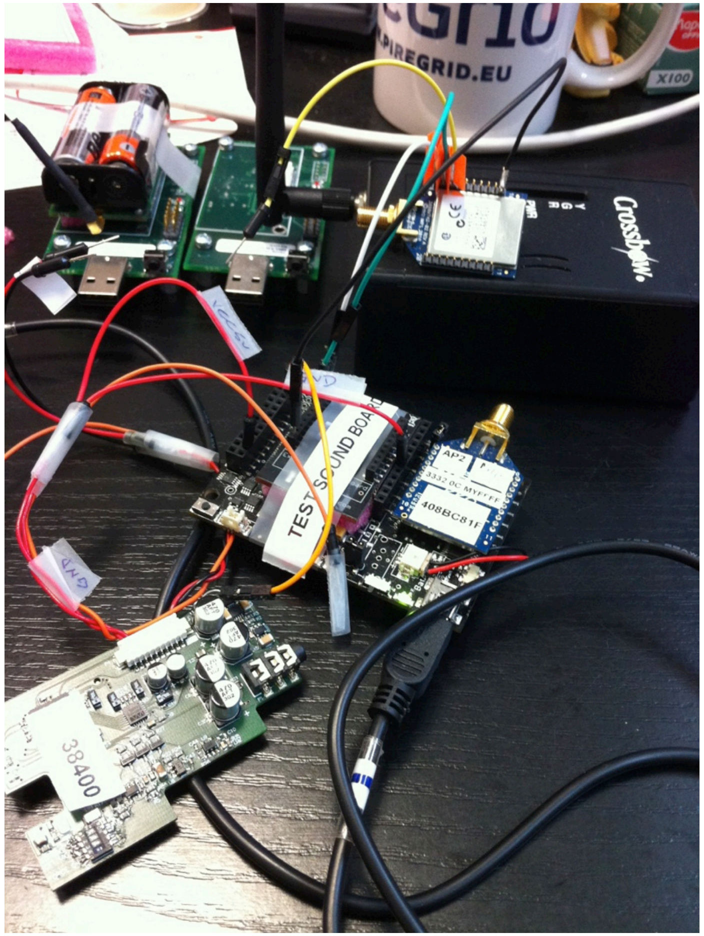
3. C. Pham and P. Cousin, "Benchmarking low-resource device test-beds for real-time acoustic data", Proceedings of the 9th International Conference on Testbeds and Research Infrastructures for the Development of Networks & Communities (TridentCom'2014) , Guangzhou, China, May 5-7, 2014.

4. 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.

5. 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.

Developped audio board





Do not hesitate to contact us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Thank you for your attention.
Questions ?