



*the sounds of smart environment*



## ***WP1.3 Methodology and tools for measurements and benchmarking on the use of acoustic sensors***

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SmartSensingStars

# Objectives of WP1.3

- Present **methodology and tools** for measurements and benchmarking for a number of performance indicators
- Describe the **benchmark** campaigns in Santander's SmartSantander and Geneva's HobNet test-beds for NETWORK indicators
- Present energy consumption **measures** for ENERGY indicators

- Presentation of the benchmarking methodology, procedure and tools
- Review of minimum NETWORK & AUDIO requirements
- Presentation of benchmark campaigns for NETWORK & AUDIO indicators
- Presentation of ENERGY indicators
- Conclusions

# Benchmark methodology (1)

1. Determine IoT node performance, lab tests
  - Upper bounds performances for sending and receiving
  - Upper bounds performances for relaying

**Have been realized in WP1.1  
and WP1.2**

2. Determine sensitivity of codec against packet losses, with various packet size, lab tests
  - audio benchmarking, apply controlled packet error rates
  - MOS-LQO computation



# Benchmark methodology (2)

3. Verify **sending time** and **pkt jitter** at audio source
4. Determine **latencies** and **jitter** in multi-hop
  - Controlled transmission of packetized/encoded audio
  - Measure latencies and jitter at intermediate nodes
5. Determine channel condition in selected areas
  - 1-hop **packet loss rates**
6. Determine **energy consumption**
  - When idle, When capturing and sending audio, When relaying
7. Develop and provide benchmark **tools**

# Indicators

- NETWORK indicators
  - Packet jitter at the source
  - Packet relaying time at relay nodes
  - Packet relaying jitter at relay nodes
- AUDIO indicators
  - Packet loss rates at 1-hop
  - Packet loss rates at 2-hop
- ENERGY indicators
  - Energy consumption at the audio source
  - Energy consumption at the relay nodes

# Frame analysis tool

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

# Example: latency 1-hop



Time from  
reference  
time

audio\_capture [Wireshark 1.6.7]

Filter: Expression... Clear Apply

| No. | Time        | Source                  | Destination | Protocol      | Length | Sequence Number | Extra info     | Data |
|-----|-------------|-------------------------|-------------|---------------|--------|-----------------|----------------|------|
| 23  | 68719.47672 |                         |             | IEEE 802.15.4 | 5      |                 | 77 68576.10478 |      |
| 24  | 150.135872  | 00:13:a2:00:40:92:20:70 | 0x0090      | IEEE 802.15.4 | 22     |                 | 78 -68569.3408 | Yes  |
| 25  | 68719.47672 |                         |             | IEEE 802.15.4 | 5      |                 | 78 68569.34084 |      |
| 26  | *REF*       | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 144 *REF*      | Yes  |
| 27  | 0.019584    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 145 0.019584   | Yes  |
| 28  | 0.047456    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 146 0.027872   | Yes  |
| 29  | 0.061824    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 147 0.014368   | Yes  |
| 30  | 0.083456    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 148 0.021632   | Yes  |
| 31  | 0.103584    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 149 0.020128   | Yes  |
| 32  | 0.128064    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 150 0.024480   | Yes  |
| 33  | 0.147104    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 151 0.019040   | Yes  |
| 34  | 0.167872    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 152 0.020768   | Yes  |
| 35  | 0.187072    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 153 0.019200   | Yes  |
| 36  | 0.210752    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 154 0.023680   | Yes  |
| 37  | 0.229952    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 155 0.019200   | Yes  |
| 38  | 0.249792    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 156 0.019840   | Yes  |
| 39  | 0.274880    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 157 0.025088   | Yes  |
| 40  | 0.290816    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 158 0.015936   | Yes  |
| 41  | 0.312224    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 159 0.021408   | Yes  |
| 42  | 0.333952    | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 160 0.021728   | Yes  |

▼ Frame 26: 35 bytes on wire (280 bits), 35 bytes captured (280 bits)  
 Arrival Time: Dec 31, 1969 16:02:30.684992000 PST  
 Epoch Time: 150.684992000 seconds  
 [Time delta from previous captured frame: -68568.791728000 seconds]  
 [Time delta from previous displayed frame: -68568.791728000 seconds]  
 [Time since reference or first frame: 0.000000000 seconds]  
 [This is a Time Reference frame]  
 Frame Number: 26  
 Frame Length: 35 bytes (280 bits)  
 Capture Length: 35 bytes (280 bits)  
 [Frame is marked: False]  
 [Frame is ignored: False]  
 [Protocols in frame: wlan:data]

▼ IEEE 802.15.4 Data, Dst: 0x0100, Src: 0x0090, Bad FCS  
 ► Frame Control Field: Data (0x8841)  
 Sequence Number: 144  
 Destination PAN: 0x3332  
 Destination: 0x0100  
 Source: 0x0090  
 FCS: 0xffff (Incorrect, expected FCS=0xa563)  
 ► [Expert Info (Warn/Checksum): Bad FCS]  
 ► Data (24 bytes)

```

0000  41 88 90 32 33 00 01 90  00 ff 55 01 14 ae 24 24  A..23... ..U...$
0010  24 24 24 24 24 24 24 24  24 24 24 24 24 24 24 24  $$$$$$ $$$$$$
0020  24 ff ff                                     $.
  
```

File: "/home/wsn/Desktop/audio\_... - Packets: 2899 Displayed: 2899 Marked: 0 Load time: 0:00.091 Profile: Default

Time from  
previous  
displayed



# Example: packet losses & jitter

audio\_capture [Wireshark 1.6.7]

Filter: Expression... Clear Apply

| No. | Time         | Source                  | Destination | Protocol      | Length | Sequence Number | Extra info      | Data |
|-----|--------------|-------------------------|-------------|---------------|--------|-----------------|-----------------|------|
| 23  | 68719.476721 |                         |             | IEEE 802.15.4 | 5      |                 | 77 68576.10478  |      |
| 24  | 150.135872   | 00:13:a2:00:40:92:20:70 | 0x0090      | IEEE 802.15.4 | 22     |                 | 78 -68569.34084 | Yes  |
| 25  | 68719.476721 |                         |             | IEEE 802.15.4 | 5      |                 | 78 68569.34084  |      |
| 26  | *REF*        | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 144 *REF*       | Yes  |
| 27  | 0.019584     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 145 0.019584    | Yes  |
| 28  | 0.047456     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 146 0.027872    | Yes  |
| 29  | 0.061824     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 147 0.014368    | Yes  |
| 30  | 0.083456     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 148 0.021632    | Yes  |
| 31  | 0.103584     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 149 0.020128    | Yes  |
| 32  | 0.128064     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 150 0.024480    | Yes  |
| 33  | 0.147104     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 151 0.019040    | Yes  |
| 34  | 0.167872     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 152 0.020768    | Yes  |
| 35  | 0.187072     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 153 0.019200    | Yes  |
| 36  | 0.210752     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 154 0.023680    | Yes  |
| 37  | 0.229952     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 155 0.019200    | Yes  |
| 38  | 0.249792     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 156 0.019840    | Yes  |
| 39  | 0.274880     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 157 0.025088    | Yes  |
| 40  | 0.290816     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 158 0.015936    | Yes  |
| 41  | 0.312224     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 159 0.021408    | Yes  |
| 42  | 0.333952     | 0x0090                  | 0x0100      | IEEE 802.15.4 | 35     |                 | 160 0.021728    | Yes  |

▼ Frame 26: 35 bytes on wire (280 bits), 35 bytes captured (280 bits)  
 Arrival Time: Dec 31, 1969 16:02:30.684992000 PST  
 Epoch Time: 150.684992000 seconds  
 [Time delta from previous captured frame: -68568.791728000 seconds]  
 [Time delta from previous displayed frame: -68568.791728000 seconds]  
 [Time since reference or first frame: 0.000000000 seconds]  
 [This is a Time Reference frame]  
 Frame Number: 26  
 Frame Length: 35 bytes (280 bits)  
 Capture Length: 35 bytes (280 bits)  
 [Frame is marked: False]  
 [Frame is ignored: False]  
 [Protocols in frame: wlan:data]

▼ IEEE 802.15.4 Data, Dst: 0x0100, Src: 0x0090, Bad FCS  
 ▶ Frame Control Field: Data (0x8841)  
 Sequence Number: 144  
 Destination PAN: 0x3332  
 Destination: 0x0100  
 Source: 0x0090  
 FCS: 0xffff (Incorrect, expected FCS=0xa563)  
 ▶ [Expert Info (Warn/Checksum): Bad FCS]  
 ▶ Data (24 bytes)

```

0000 41 88 90 32 33 00 01 90 00 ff 55 01 14 ae 24 24  A..23... ..U...$
0010 24 24 24 24 24 24 24 24 24 24 24 24 24 24 24  $$$$$$ $$$$$$$$
0020 24 ff ff                                          $..
  
```

File: "/home/wsn/Desktop/audio\_... Packets: 2899 Displayed: 2899 Marked: 0 Load time: 0:00.091 Profile: Default

Time from  
reference  
time

SN to detect  
packet  
losses

Time from  
previous  
displayed

Packet jitter  
can be  
determine  
from time  
sequence

# Example: relay latency

audio\_capture [Wireshark 1.6.7]

Filter: `wpan.Frame_Type == 0x0001` Expression... Clear Apply

| No.  | Time         | Source | Destination | Protocol      | Length | Sequence Number | Extra info      | Data |
|------|--------------|--------|-------------|---------------|--------|-----------------|-----------------|------|
| 2232 | 1102.541984  | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 0 0.074208      | Yes  |
| 2234 | 1102.565856  | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 240 -67616.9108 | Yes  |
| 2235 | 1102.644576  | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 1 0.078720      | Yes  |
| 2237 | 68719.476721 | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 241 67616.82315 | Yes  |
| 2238 | *REF*        | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 242 *REF*       | Yes  |
| 2239 | 0.020960     | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 2 0.020960      | Yes  |
| 2241 | 0.081760     | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 243 -67616.6584 | Yes  |
| 2242 | 0.130592     | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 3 0.048832      | Yes  |
| 2244 | 0.161952     | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 244 -67616.5782 | Yes  |
| 2245 | 0.243808     | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 245 0.081856    | Yes  |
| 2246 | 0.255104     | 0x0100 | 0xc823      | IEEE 802.15.4 | 107    |                 | 4 0.012096      | Yes  |
| 2248 | 0.328160     | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 246 -67616.4115 | Yes  |
| 2249 | 0.365120     | 0x0100 | 0xc823      | IEEE 802.15.4 | 107    |                 | 5 0.037280      | Yes  |
| 2251 | 0.409184     | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 247 -67616.3304 | Yes  |
| 2252 | 0.465312     | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 6 0.055584      | Yes  |
| 2254 | 0.495712     | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 248 -67616.2444 | Yes  |
| 2255 | 0.584416     | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 7 0.088704      | Yes  |
| 2257 | 0.678208     | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 250 -67616.0619 | Yes  |
| 2258 | 0.690144     | 0xc823 | 0x0100      | IEEE 802.15.4 | 107    |                 | 8 0.011936      | Yes  |
| 2260 | 0.766144     | 0x0090 | 0xc823      | IEEE 802.15.4 | 107    |                 | 251 -67615.9740 | Yes  |

Original frame

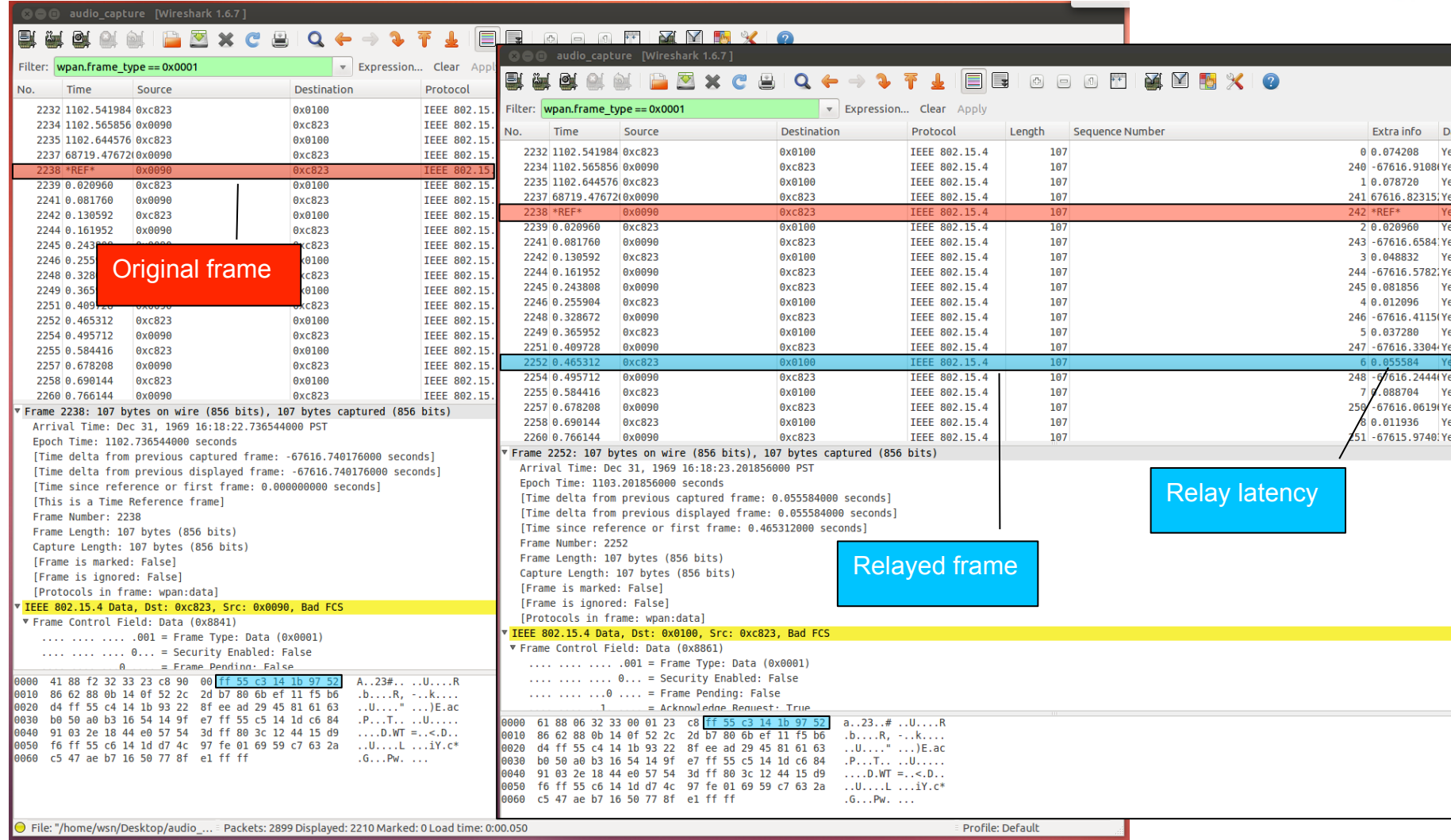
▼ Frame 2238: 107 bytes on wire (856 bits), 107 bytes captured (856 bits)  
 Arrival Time: Dec 31, 1969 16:18:22.736544000 PST  
 Epoch Time: 1102.736544000 seconds  
 [Time delta from previous captured frame: -67616.740176000 seconds]  
 [Time delta from previous displayed frame: -67616.740176000 seconds]  
 [Time since reference or first frame: 0.000000000 seconds]  
 [This is a Time Reference frame]  
 Frame Number: 2238  
 Frame Length: 107 bytes (856 bits)  
 Capture Length: 107 bytes (856 bits)  
 [Frame is marked: False]  
 [Frame is ignored: False]  
 [Protocols in frame: wpan:data]

▼ IEEE 802.15.4 Data, Dst: 0xc823, Src: 0x0090, Bad FCS  
 ▼ Frame Control Field: Data (0x8841)  
 .... .001 = Frame Type: Data (0x0001)  
 .... .0... = Security Enabled: False  
 0 = Frame Pending: False

0000 41 88 f2 32 33 23 c8 90 00 ff 55 c3 14 1b 97 52 A...23#...U...R  
 0010 86 62 88 0b 14 0f 52 2c 2d b7 80 6b ef 11 f5 b6 .b....R...k....  
 0020 d4 ff 55 c4 14 1b 93 22 8f ee ad 29 45 81 61 63 ..U..."...E.ac  
 0030 b0 50 a0 b3 16 54 14 9f e7 ff 55 c5 14 1d c6 84 .P...T...U....  
 0040 91 03 2e 18 44 e0 57 54 3d ff 80 3c 12 44 15 d9 ....D.WT=...<.D..  
 0050 f6 ff 55 c6 14 1d d7 4c 97 fe 01 69 59 c7 63 2a ..U...L...iY.c\*  
 0060 c5 47 ae b7 16 50 77 8f e1 ff ff .G...Pw. ...

File: "/home/wsn/Desktop/audio\_... Packets: 2899 Displayed: 2210 Marked: 0 Load time: 0:00.050 Profile: Default

# Example: relay latency



The image displays two Wireshark packet captures side-by-side, illustrating relay latency. The left capture shows an 'Original frame' (Frame 2238) and the right capture shows a 'Relayed frame' (Frame 2252). A blue box labeled 'Relay latency' indicates the time difference between the two frames.

**Original frame (Frame 2238):**

- Arrival Time: Dec 31, 1969 16:18:22.736544000 PST
- Epoch Time: 1102.736544000 seconds
- Frame Number: 2238
- Frame Length: 107 bytes (856 bits)
- Capture Length: 107 bytes (856 bits)
- IEEE 802.15.4 Data, Dst: 0xc823, Src: 0x0090, Bad FCS

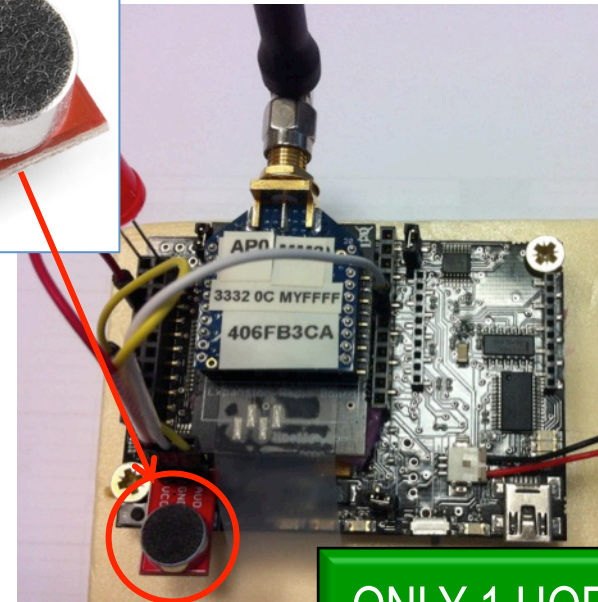
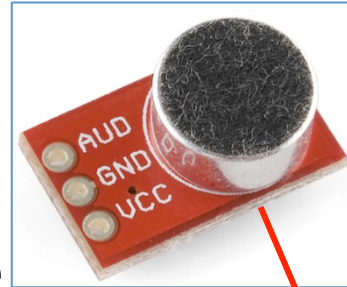
**Relayed frame (Frame 2252):**

- Arrival Time: Dec 31, 1969 16:18:23.201856000 PST
- Epoch Time: 1103.201856000 seconds
- Frame Number: 2252
- Frame Length: 107 bytes (856 bits)
- Capture Length: 107 bytes (856 bits)
- IEEE 802.15.4 Data, Dst: 0x0100, Src: 0xc823, Bad FCS

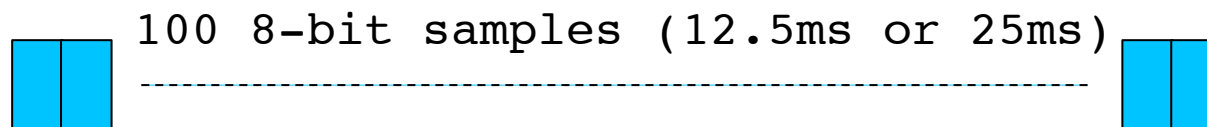
The time difference between the arrival of the original frame (22.736544000 seconds) and the relayed frame (23.201856000 seconds) is approximately 0.465312000 seconds, which is the relay latency.

# Raw audio IoT

- Electret mic with amplifier
- XBee in AP0 mode (transparent mode)
- 8-bit 4Khz sampling gives 32000bps
- 8Khz sampling gives 64000bps
- Periodic ON/OFF (15s)



ONLY 1 HOP!



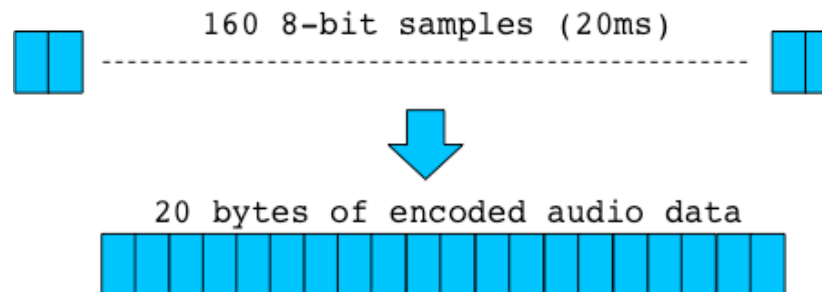
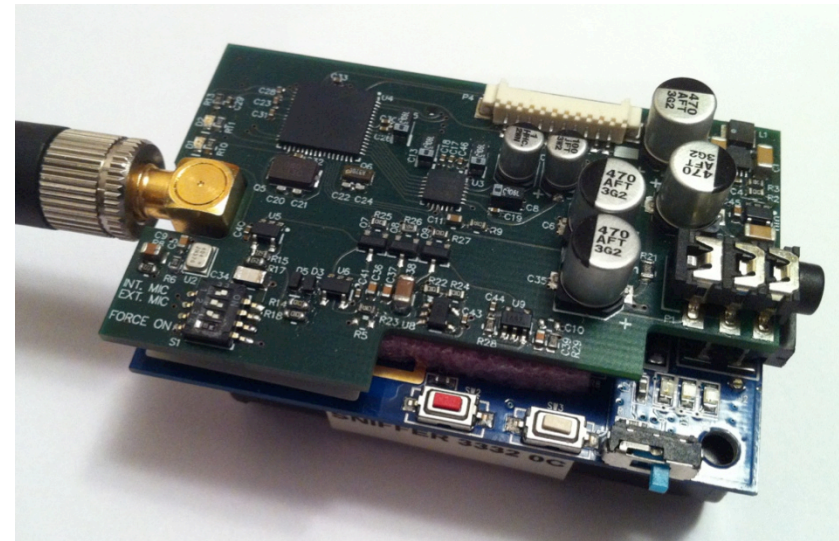
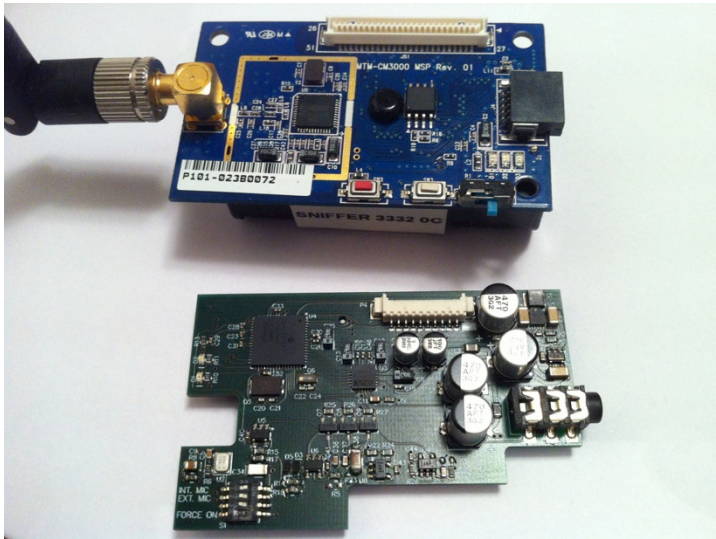
100 8-bit samples (12.5ms or 25ms)





# Compressed audio IoT

- Encode with Speex codec at 8kbps



- The audio source can be controlled wirelessly with text-based message
    - "@/A" for aggregation mode
    - "@/D" to set destination address
    - "@/C" to start/stop audio capture
- `A1/2/3/4` aggregate audio frames  
`D0013A2004086D828` set the 64-bit dest. mac addr  
`D0080` set the 16-bit dest. mac addr  
`C0/1` power off/on the audio board
- Use a 802.15.4 gateway to send control messages

# Review of minimum requirements

| Codec   | Minimum sending rate   |
|---|--|
| Raw<br>4KHz<br><br>8KHz   | 100 bytes every 25ms<br><br>100 bytes every 12.5ms   |
| Speex 8000bps<br>A1<br>A2<br>A3<br>A4   | 24 bytes every 20ms<br>48 bytes every 40ms<br>72 bytes every 60ms<br>96 bytes every 80ms                         |
| Codec2<br>2400bps<br>A1<br>.<br>.<br>An ( $1 \leq n \leq 11$ )<br>3200bps<br>A1<br>.<br>.<br>An ( $1 \leq n \leq 9$ ) | 9 bytes every 20ms<br>.<br>.<br>9*n bytes every n*20ms<br><br>11 bytes every 20ms<br><br>11*n bytes every n*20ms |

| Codec                                | Maximum packet loss rate for speech understanding |
|--------------------------------------|---|
| Raw 4KHz & 8KHz                      | 50%   |
| Speex 8000bps                        | 35%   |
| Codec2<br><br>2400bps<br><br>3200bps | <br><br>20%<br><br>30%                            |

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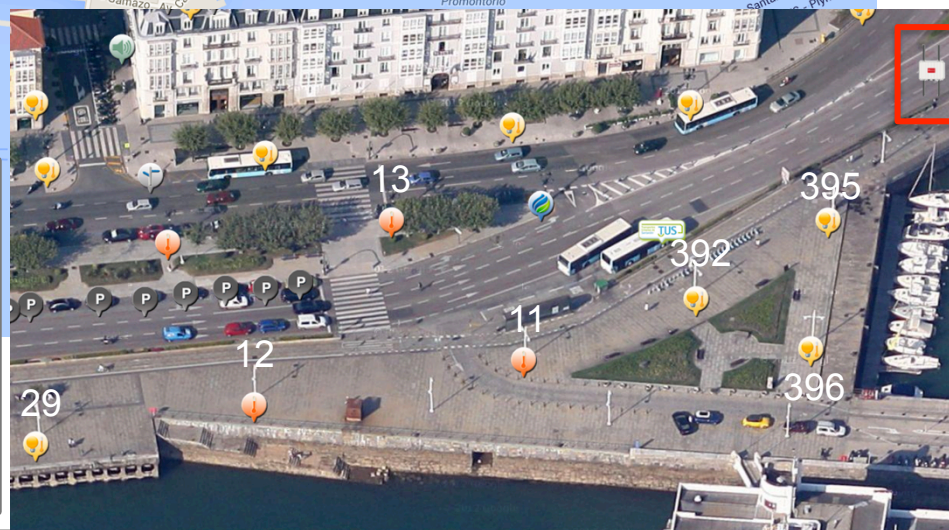
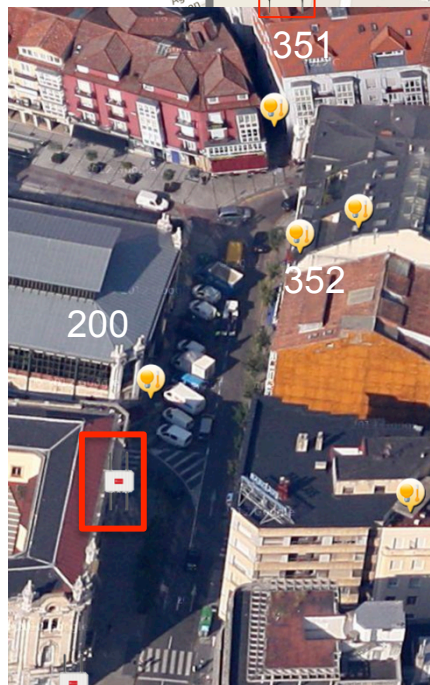
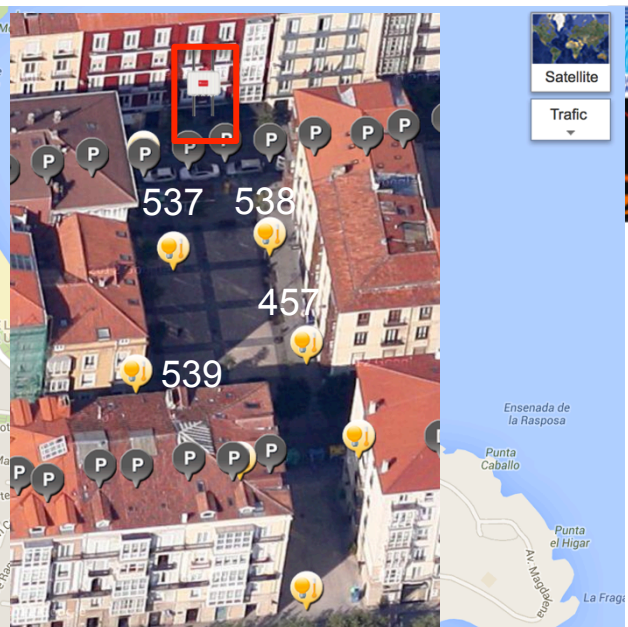
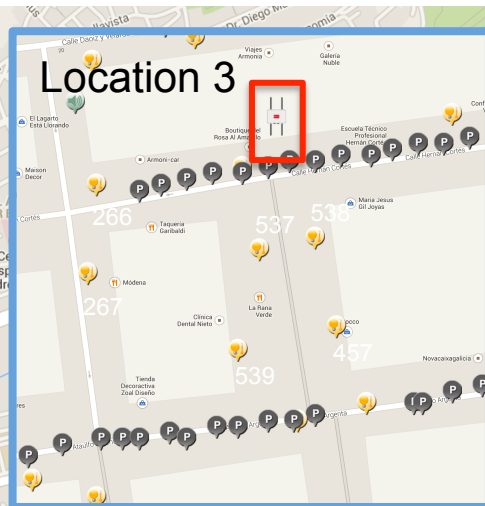
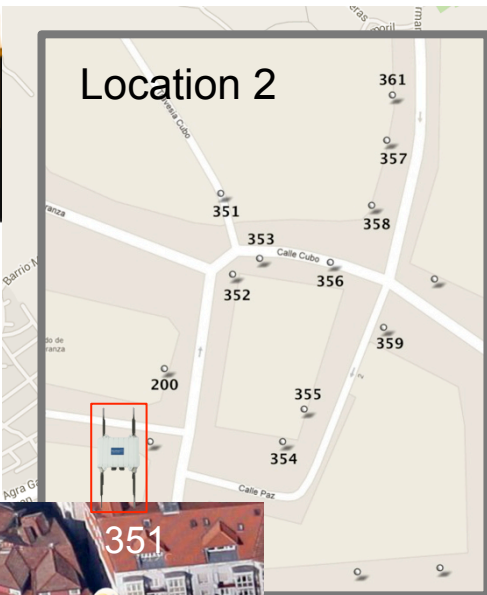
# Benchmarks in Santander

## February, 2014

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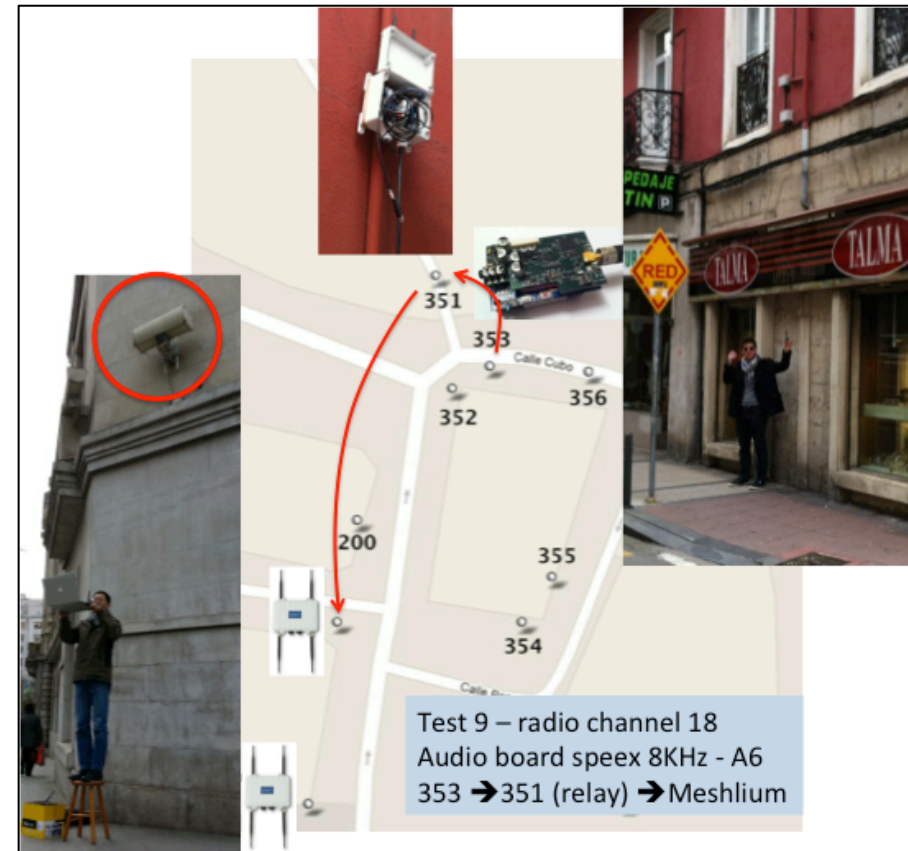
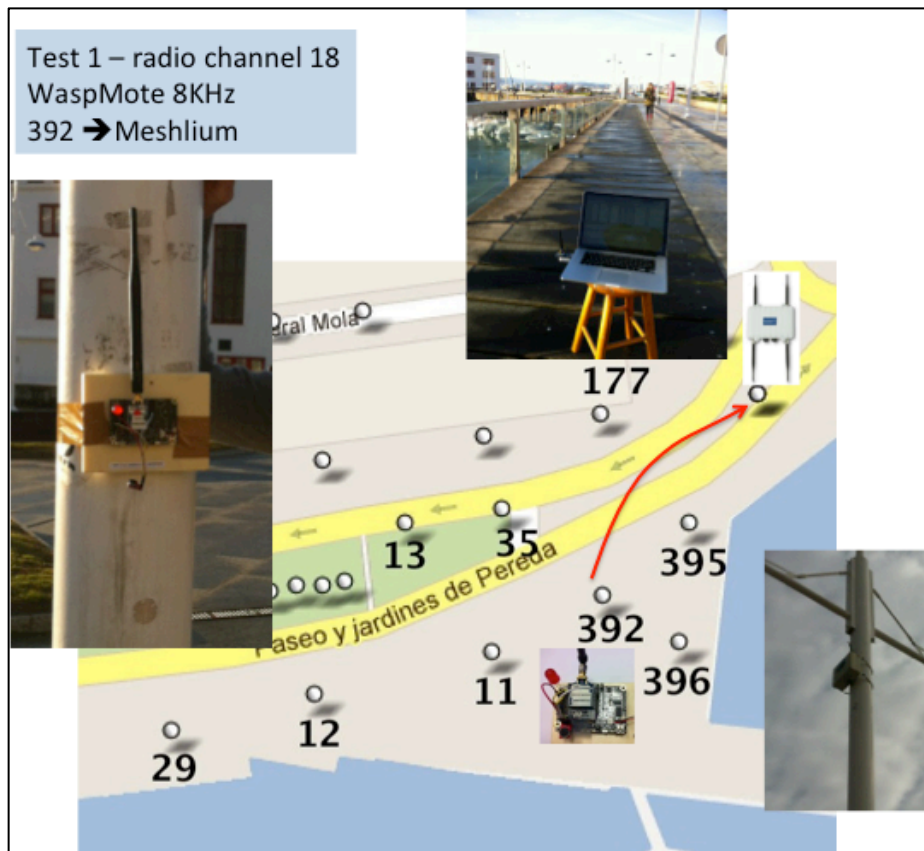


- 11 tests in 3 locations
- 1-hop and 2-hop tests
- Raw audio and compressed audio
- LOS and NLOS transmission
- Open space and dense urban area
- NETWORK indicators and AUDIO indicators

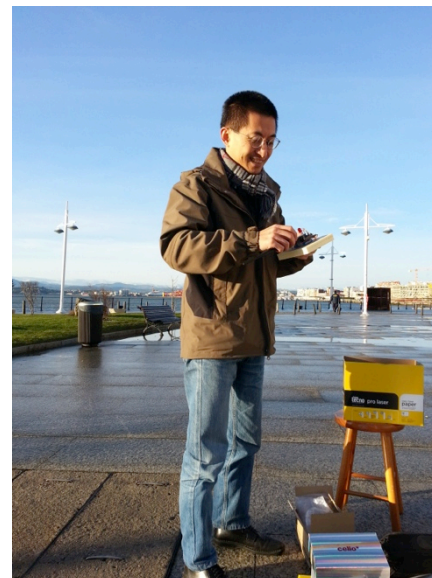




# Some benchmark settings

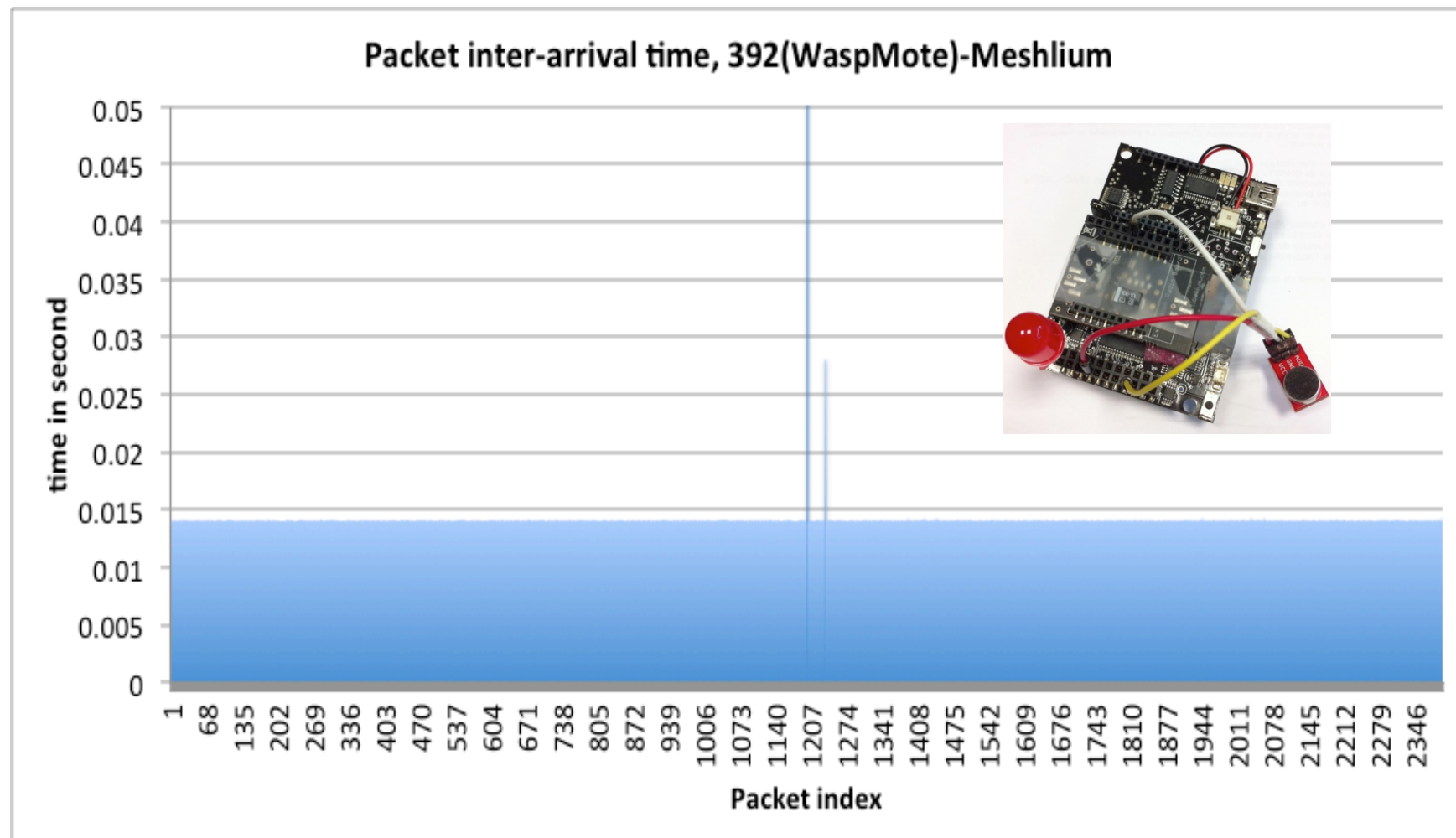


# Benchmark campaign pictures

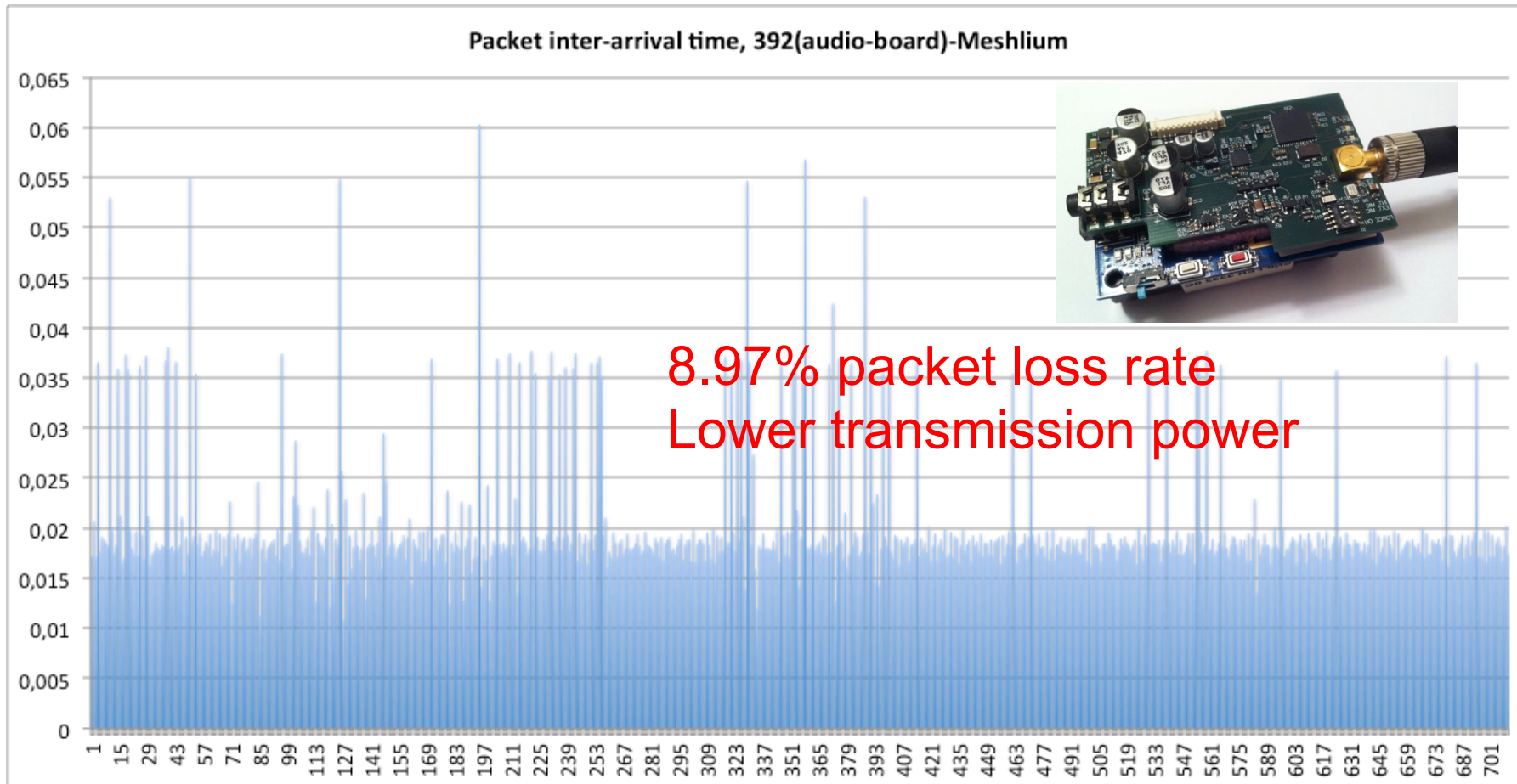




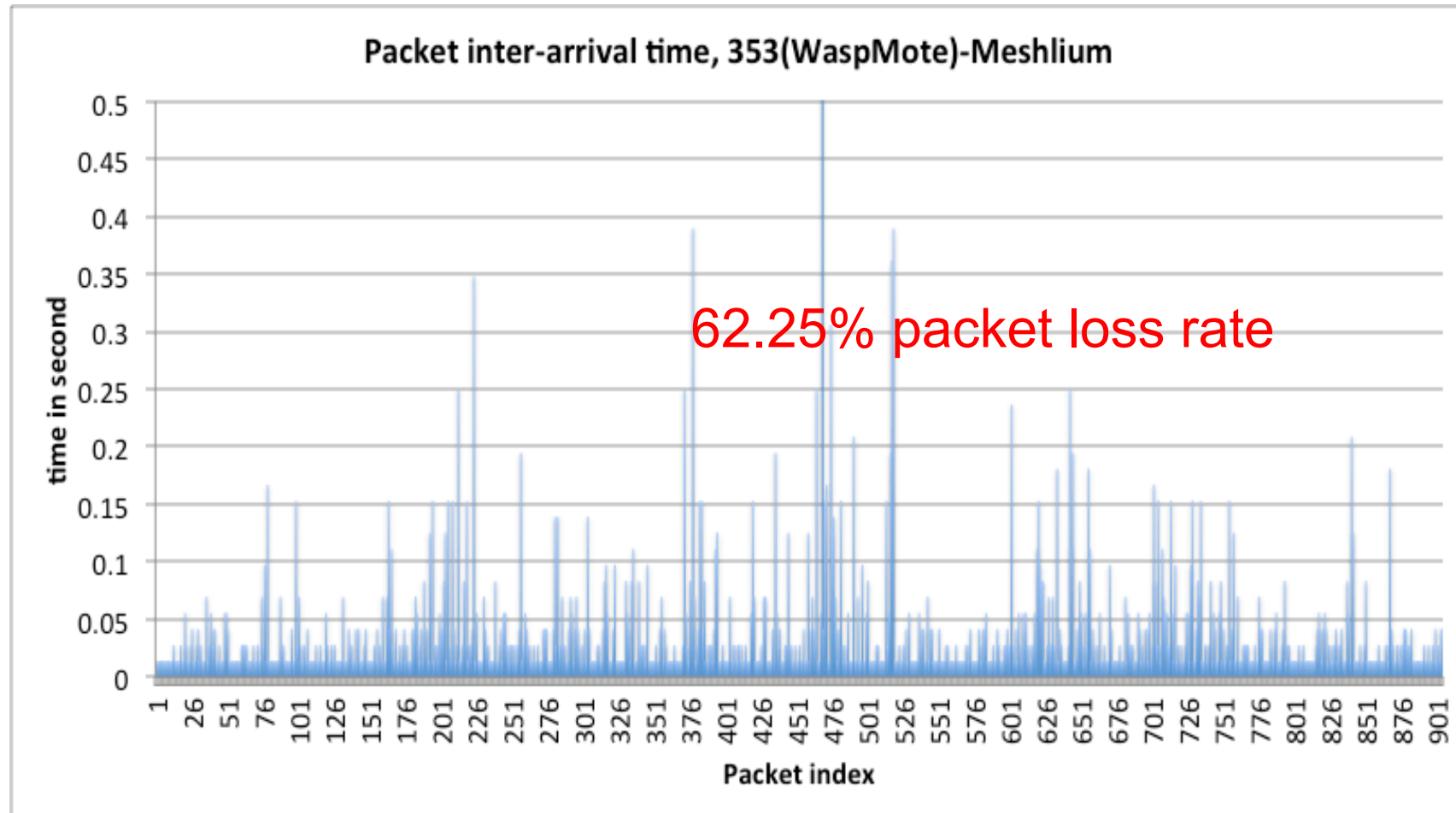
# 1-hop raw audio, LOS



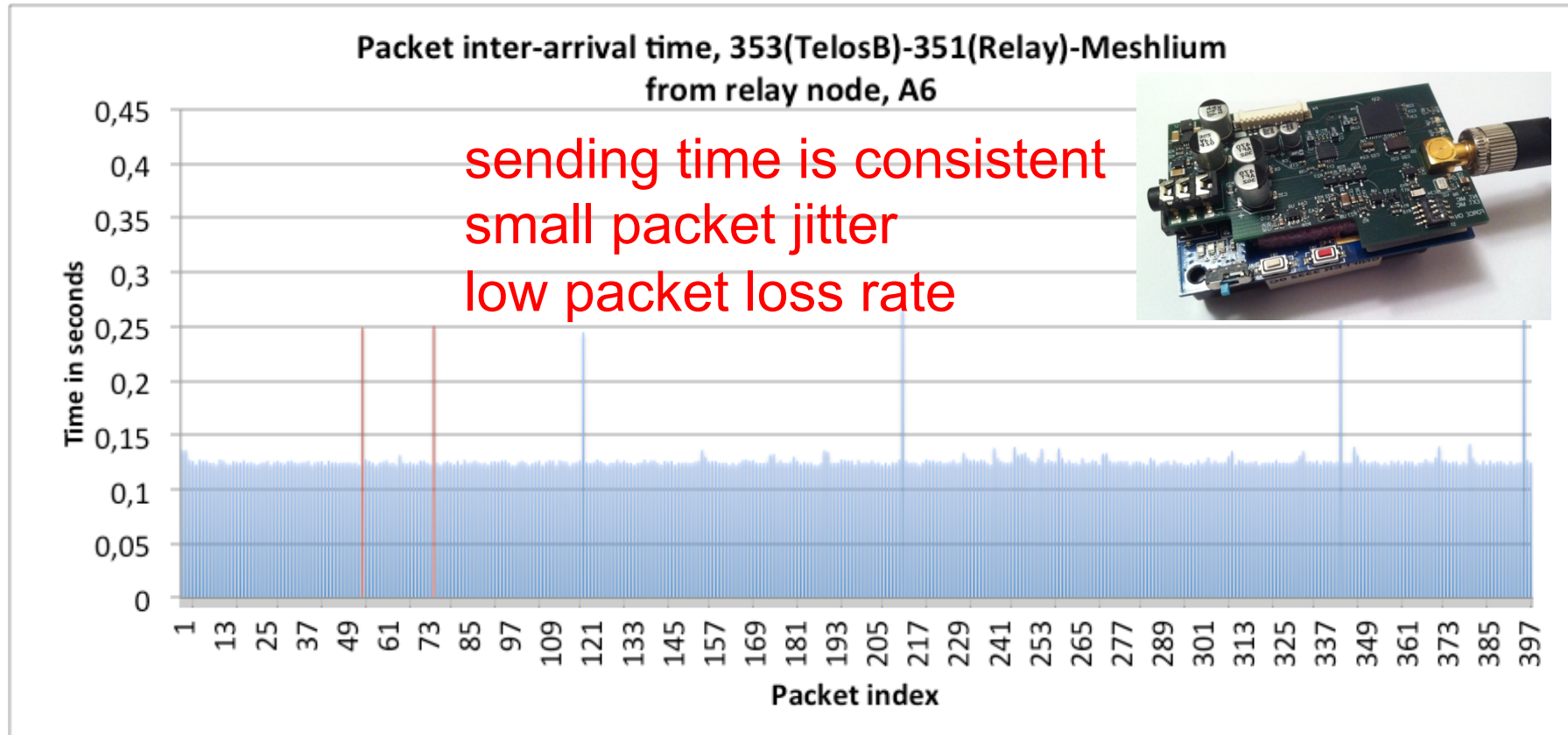
# 1-hop compressed audio, LOS



# 1-hop WaspMote audio, NLOS



# 2-hop compressed audio, NLOS



# Summary for Santander

| Santander, SmartSantander test-bed |                      |                     |               |
|------------------------------------|----------------------|---------------------|---------------|
| test scenario                      | Pkt jitter at source | pkt jitter at relay | pkt loss rate |
| 1-hop LOS open s                   |                      |                     | 0% - 12% (2)  |
| 1-hop LOS urban                    |                      |                     | 35% (2)       |
| 1-hop NLOS urba                    |                      |                     | 60% - 92% (2) |
| 2-hop open space                   |                      |                     | 5% - 23% (3)  |
| 2-hop urban                        |                      |                     | 53% (3)       |

The SmartSantander test-bed in Santander is capable of supporting streamed audio both in open space and urban environment when LOS transmission is possible. In NLOS conditions, care must be taken to choose relay nodes. In all cases, the packet jitter at the source and at the relay nodes is very small.

(1) The packet jitter at the buffer.

(2) The packet loss rate is very high.

(3) At 2-hop or more, using However, the choice of the can still be high and more

(4) The packet relaying capabilities, and relay nodes.

(5) The packet relay jitter is very

a very simple playout

packet loss rate can be

can greatly be improved. In addition, the packet loss rate

According to the maximum losses at intermediate

simple playout buffer.

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# Benchmarks in Geneva

## March, 2014

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- HEPIA building
- 7 tests in 3 locations of HEPIA
- Various in-door conditions, LOS and NLOS transmission
- 1-hop and 2-hop tests
- Raw audio and compressed audio
- NETWORK indicators and AUDIO indicators



*the sounds of smart environments*

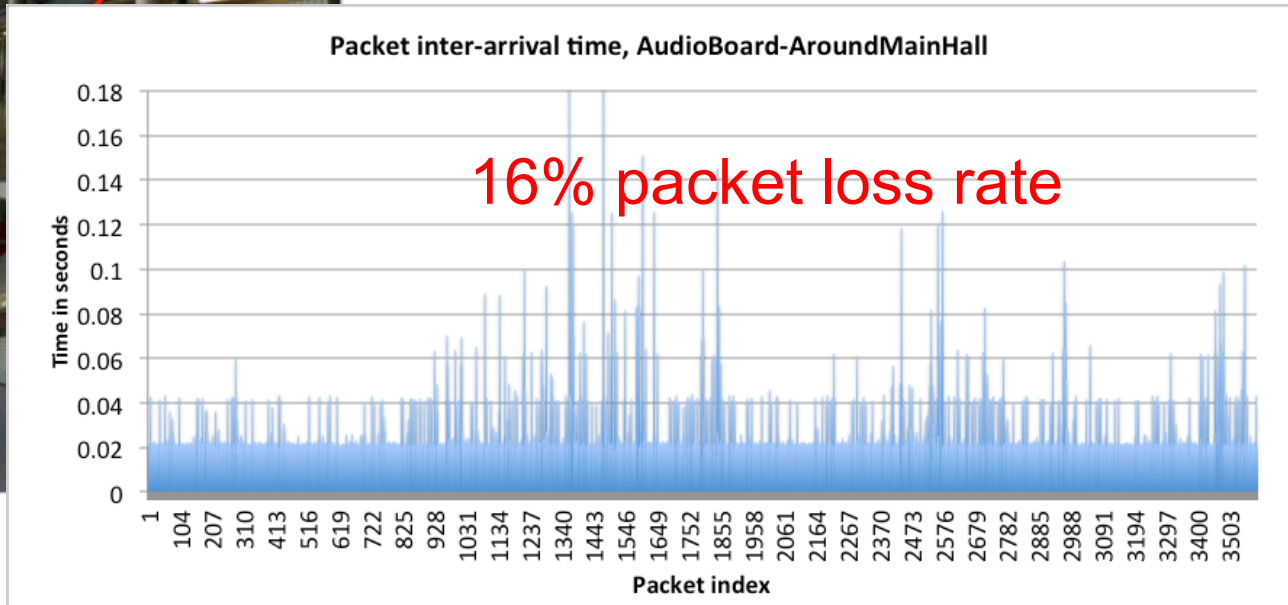
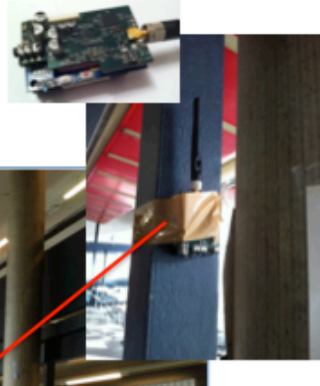


# Benchmark campaign pictures



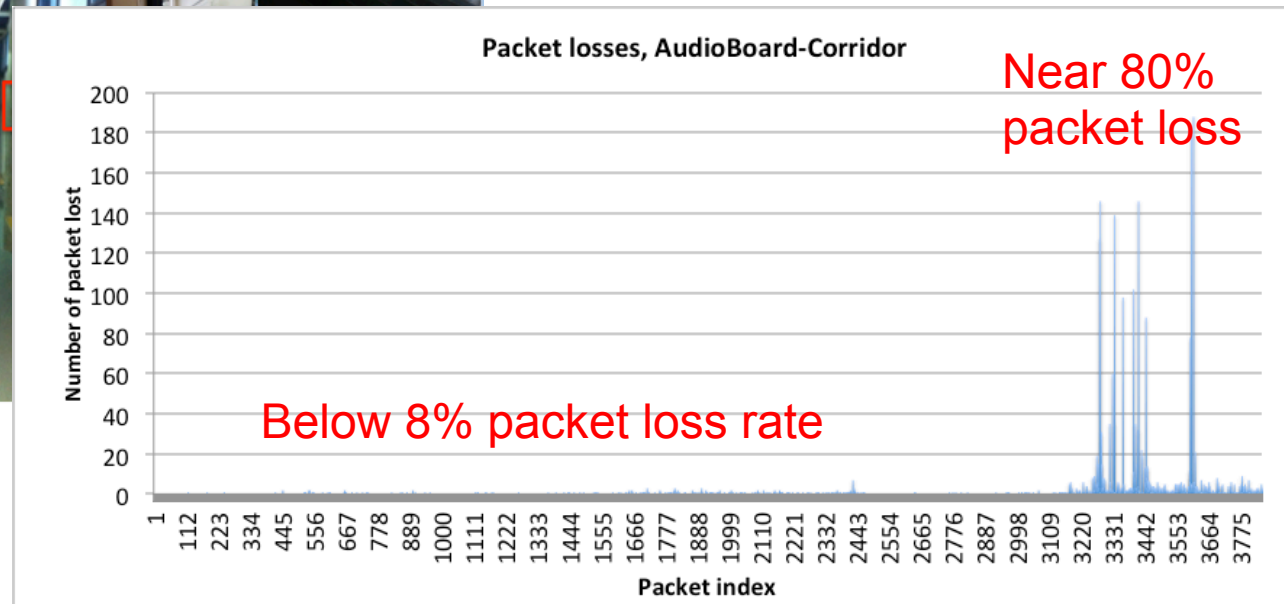
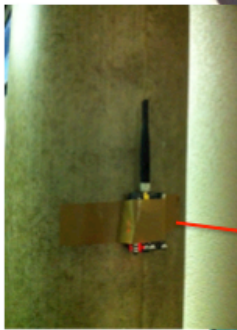
# 1-hop compressed audio

Test 1 – radio channel 12  
Audio board speex 8KHz - A1  
Inside restaurant → around main hall



# 1-hop compressed audio

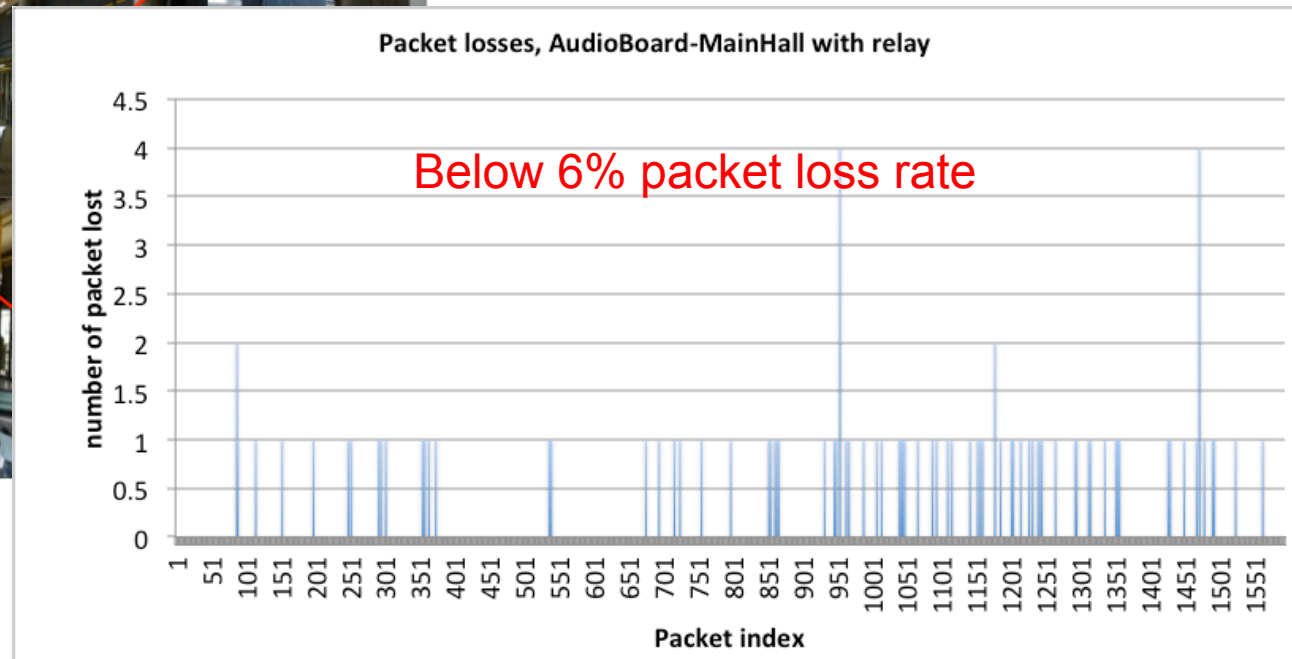
Test 5 – radio channel 12  
Audio board speex 8KHz - A1  
3<sup>rd</sup> → corridor → 2<sup>nd</sup>





# 2-hop compressed audio

Test 2 & 3 – radio channel 12  
Audio board speex 8KHz - A1 & A2  
Inside restaurant → relay → main hall





# Summary for Geneva

| Geneva, HEPIA building |                      |                     |               |
|------------------------|----------------------|---------------------|---------------|
| test scenario          | Pkt jitter at source | pkt jitter at relay | pkt loss rate |
| 1-hop no occlusion     | very small (1)       | NA                  | 0% - 8% (3)   |
| 1-hop occlusion        | very small (1)       | NA                  | 16% - 81% (4) |
| 2-hop                  |                      |                     | 5% - 30% (2)  |

The Geneva's HEPIA test-bed in Santander is capable of supporting streamed audio in LOS transmission. In NLOS conditions, care must be taken to choose relay nodes. In all cases, the packet jitter at the source and at the relay nodes is very small.

(1) The packet jitter at the source is very small and can be easily compensated at the destination with a very simple playout buffer.

(2) At 2-hop or more, using relay nodes can greatly be improved. This is particularly important in NLOS conditions, where the choice of the relay nodes can have a big impact on the reception quality.

(3) In indoor environment, the reception quality is generally better than in open space.

(4) In indoor environment, the reception quality is generally better than in open space.

(5) The packet relaying time is very small. According to the maximum relaying capabilities, an appropriate number of relay nodes can be chosen to compensate the losses at intermediate nodes.

(6) The packet relay jitter is very small and can be easily compensated at the destination with a very simple playout buffer.

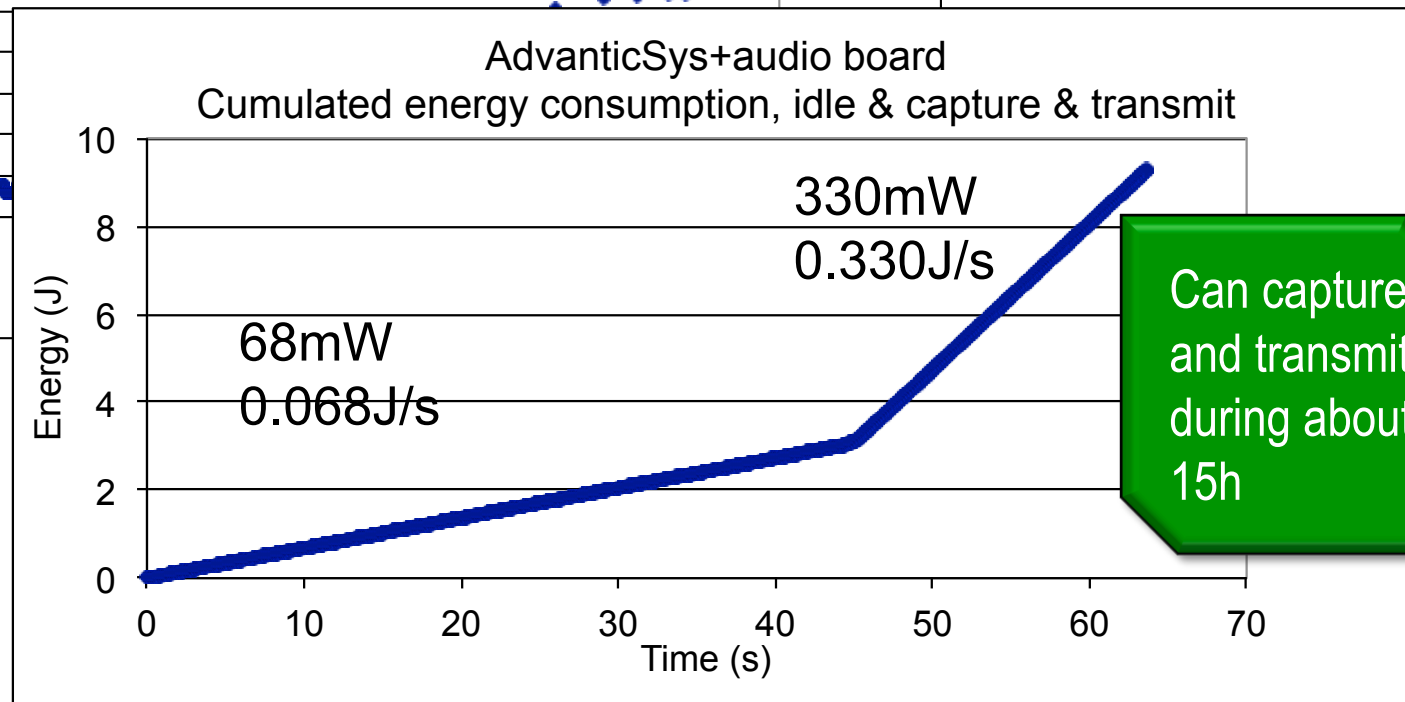
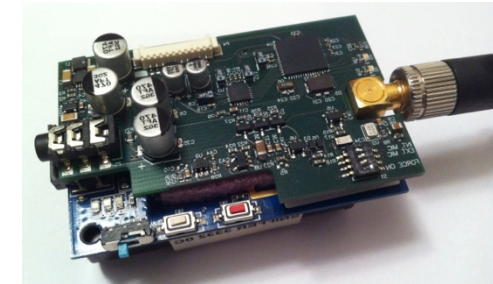
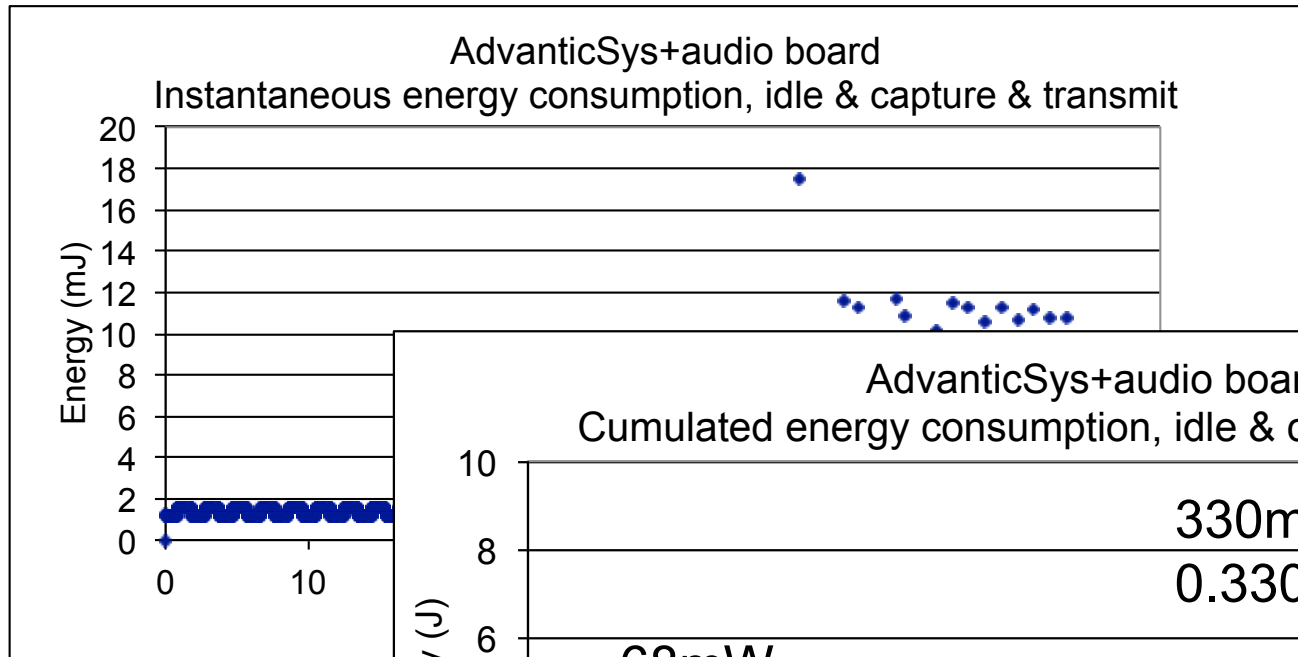
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# Energy consumption measures

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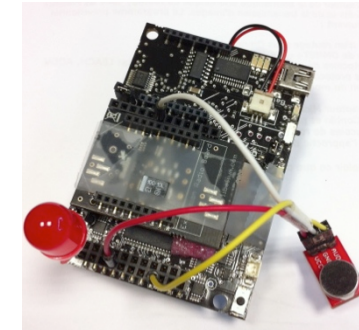
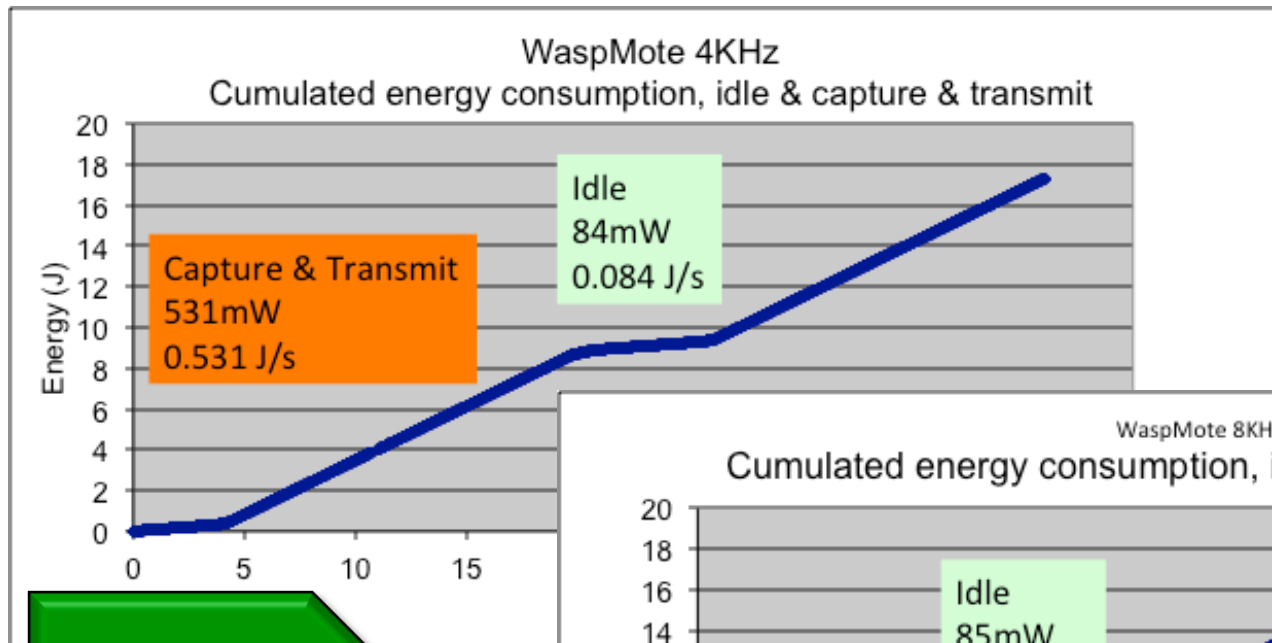


# Audio board energy consumption

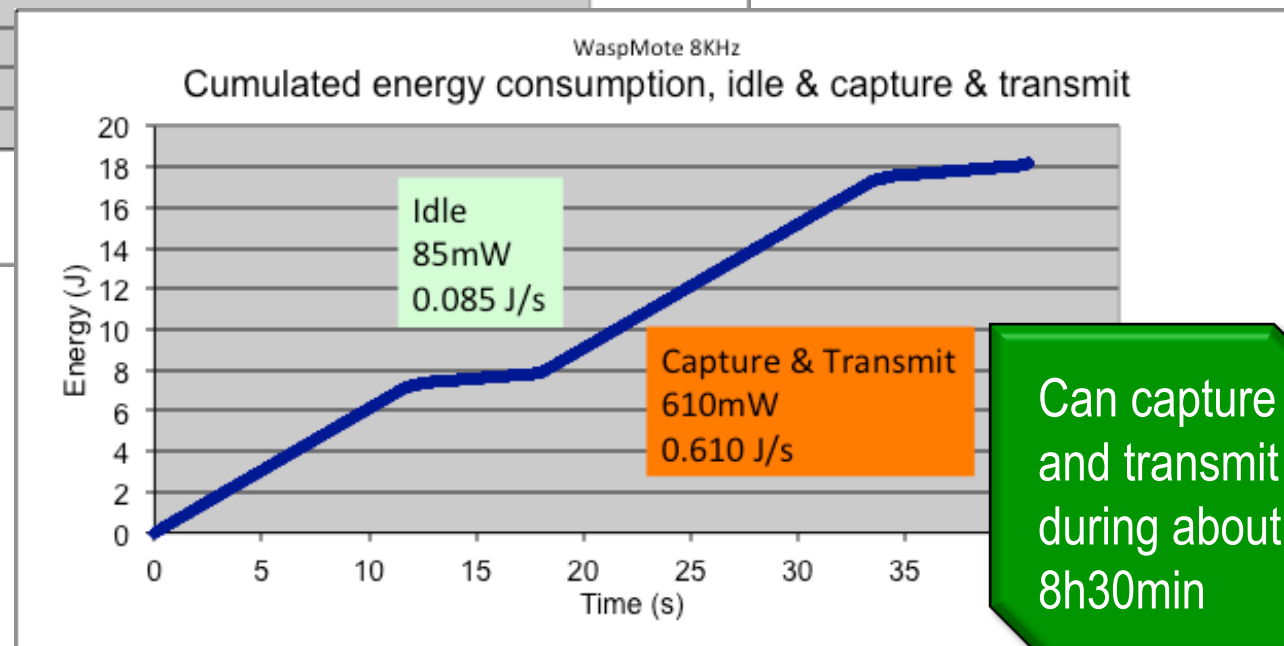


Can capture and transmit during about 15h

# Raw audio energy consumption



Can capture  
and transmit  
during about  
9h47min

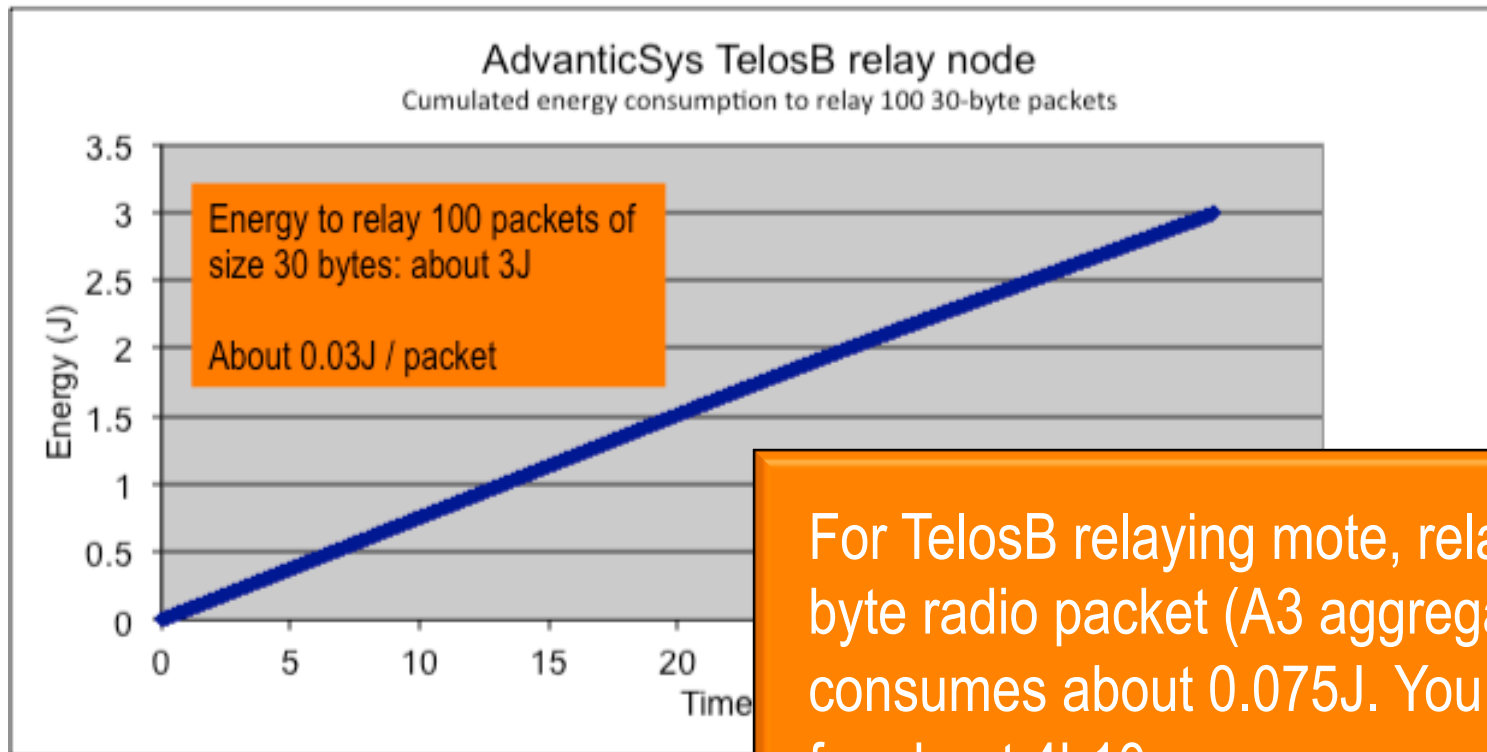


Can capture  
and transmit  
during about  
8h30min

# TelosB relay



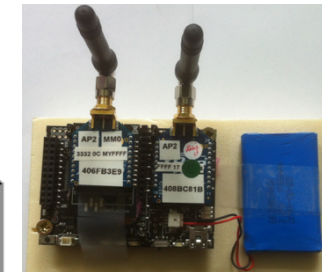
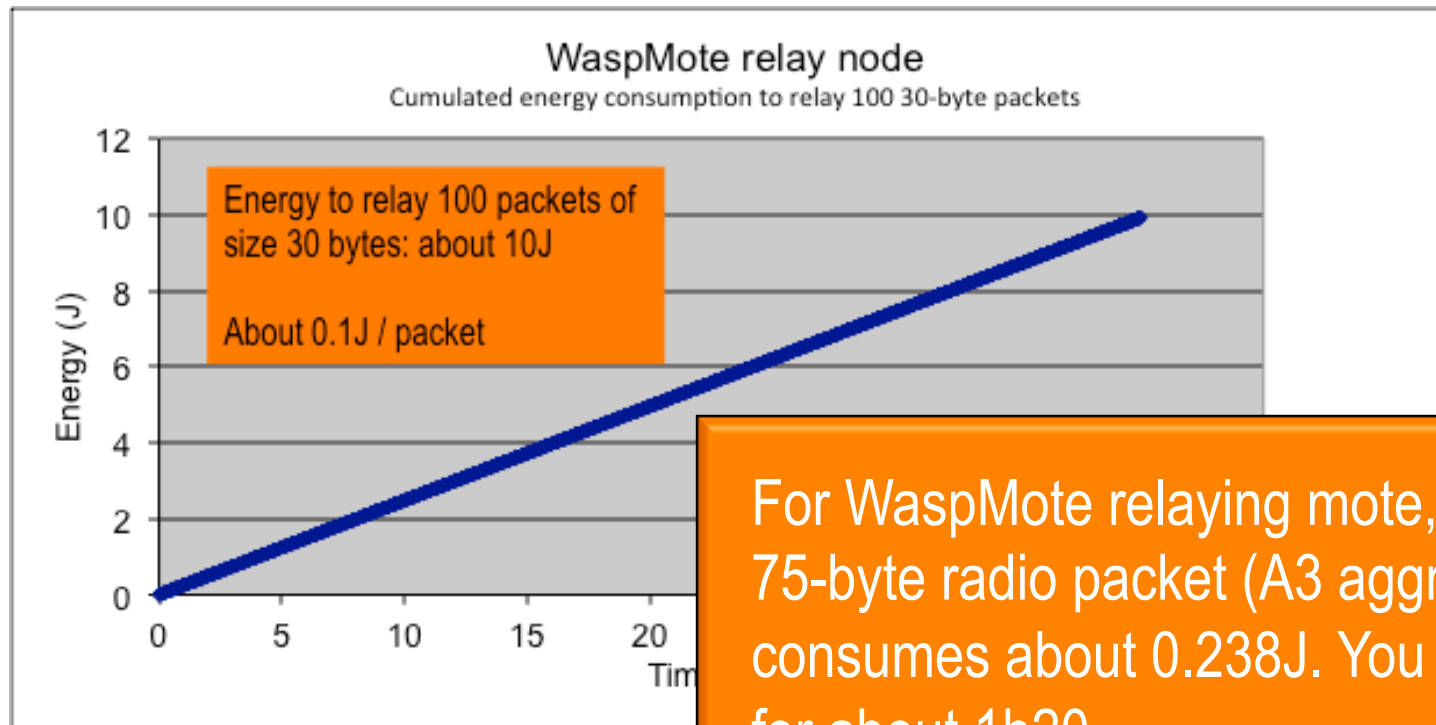
ADVANTICSYS  
TELOSB



For TelosB relaying mote, relaying a 75-byte radio packet (A3 aggregation) consumes about 0.075J. You can relay for about 4h10.



# WaspMote relay



LIBELIUM  
WASPMOTE

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

# Call for benchmark

- We have defined a benchmark procedure and made available promiscuous sniffer tools and Excel templates
- Univ. of Surrey test-bed for packet loss rate
- EGM TST-based mote test-bed for sending and relaying time
- <http://www.ear-it.eu/audio-benchmarking>

# Developed hardware & tools

- Raw audio and compressed audio platforms. Full design of audio board. Control software for audio board
- Traffic generators based on real audio hardware
- Promiscuous packet sniffer control software and link with wireshark
- Radio gateway software to control wireless devices
- Fully controllable relay nodes for multi-hop
- Excel templates and script for benchmark analysis

# Conclusions

- Experimental tests in Santander and Geneva test-bed have validated the benchmark procedure
- We determined value for NETWORK, AUDIO and ENERGY indicators.
- Audio sources have **very small packet jitter** and fully satisfied the constraints of audio transmission
- Relaying time **are consistent with measured values**, again with very small jitter
- According to the maximum relaying capabilities, an **appropriate aggregation level at the source can be used to reduce the packet losses** at intermediate relay nodes
- LOS transmissions show **small packet loss rates** therefore audio quality is high
- NLOS transmissions (oftenly the case in in-door) **is very challenging** and relay nodes have to be carefully chosen



# Conclusions (con't)

- EAR-IT WP1 demonstrated that low-power acoustic IoT nodes can provide complementary acoustic information
- Audio streaming capabilities on limited-resource IoT infrastructures have been demonstrated
- WP1.3 also provided
  - useful & important experimental competencies in IoT network qualification and benchmarking
  - **set of tools for benchmarking other test-beds**



*the sounds of smart environment*



Questions ?