

# DEPLOYING A POOL OF LONG-RANGE WIRELESS IMAGE SENSOR WITH SHARED ACTIVITY TIME

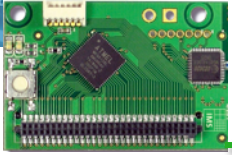
C. PHAM (UNIV. PAU, FRANCE)

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ABOU DHABI, UAE  
OCTOBER 21TH, 2015

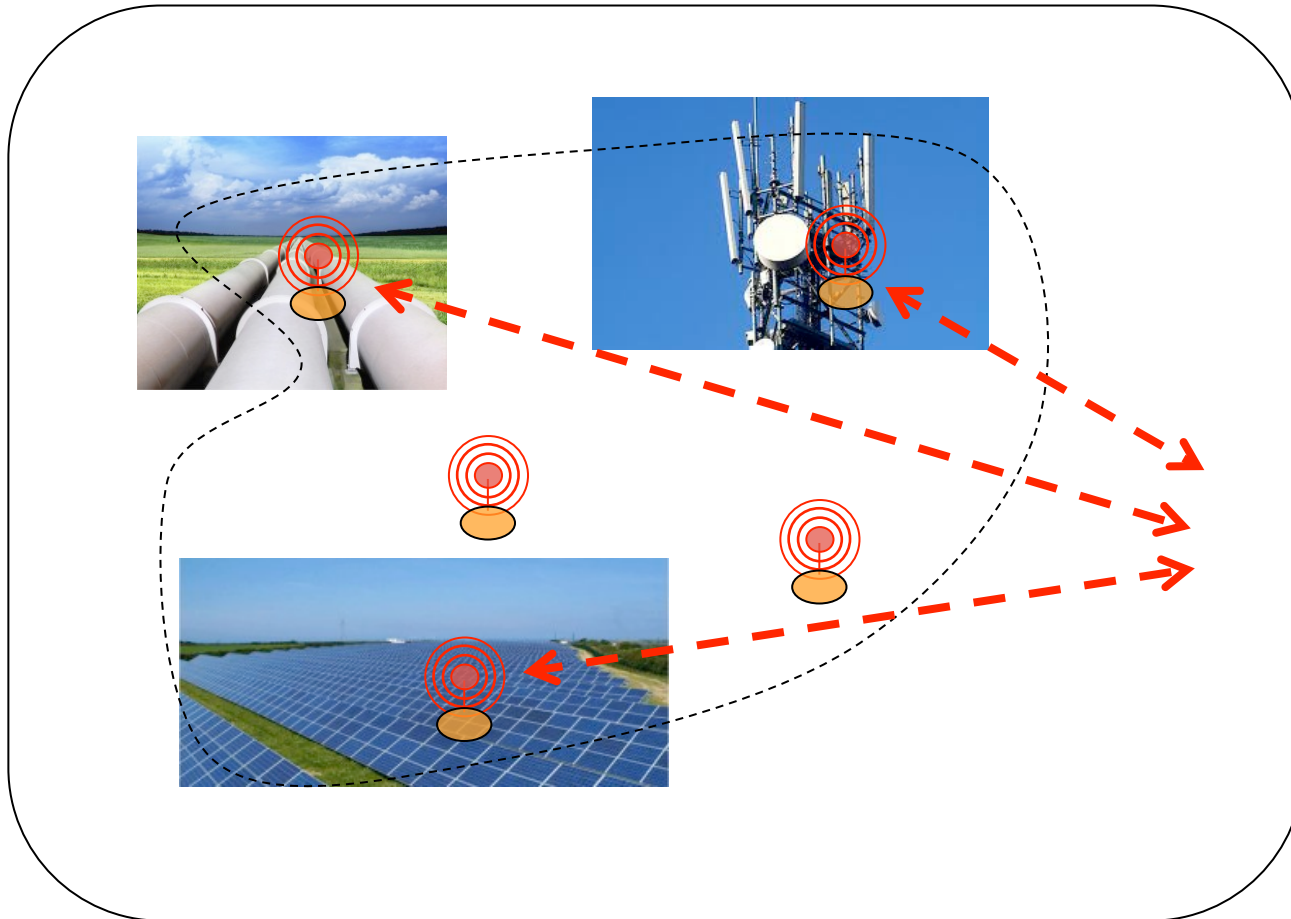


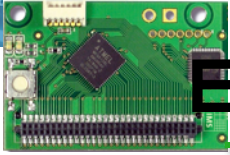
PROF. CONGDUC PHAM  
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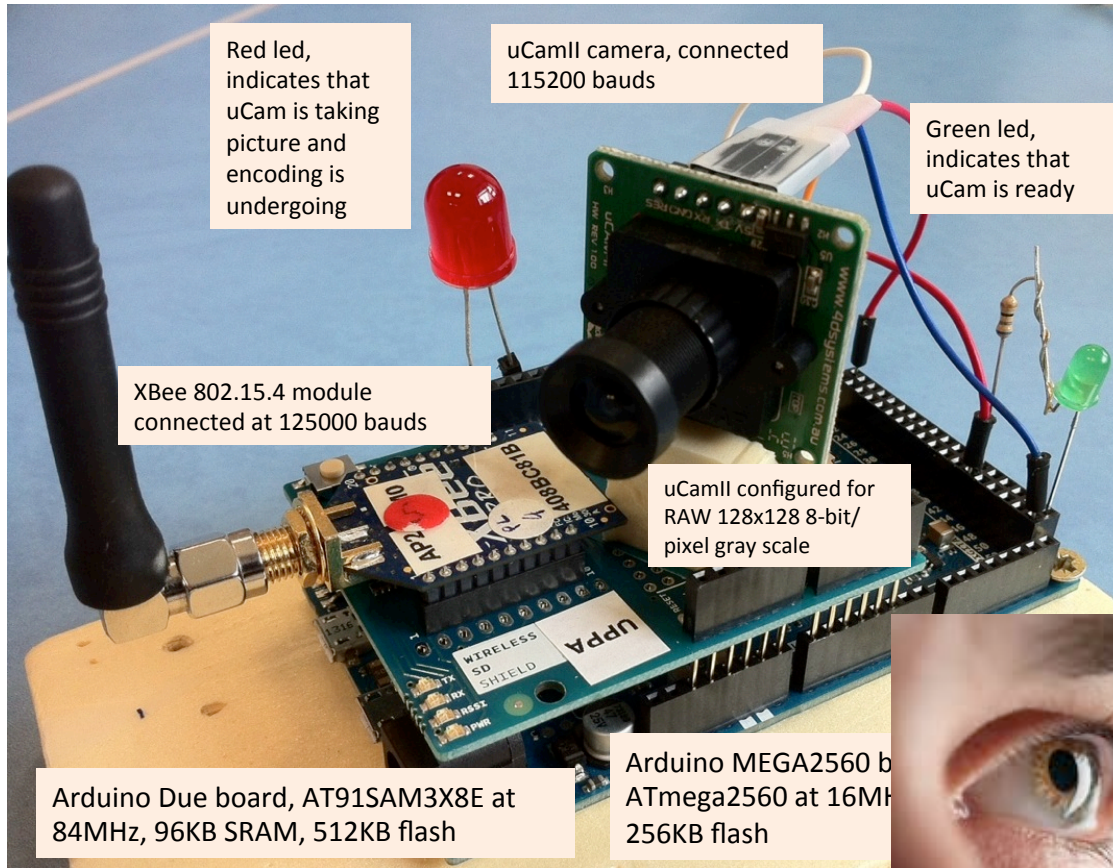


# SENSORS/IOT FOR SURVEILLANCE





# IMAGE SENSORS FOR ENHANCED SURVEILLANCE



Red led, indicates that uCam is taking picture and encoding is undergoing

uCamII camera, connected 115200 bauds

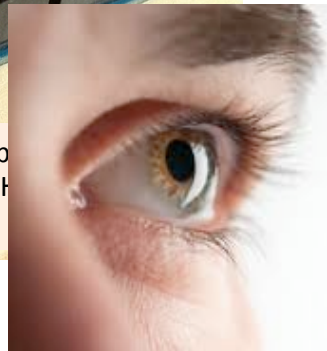
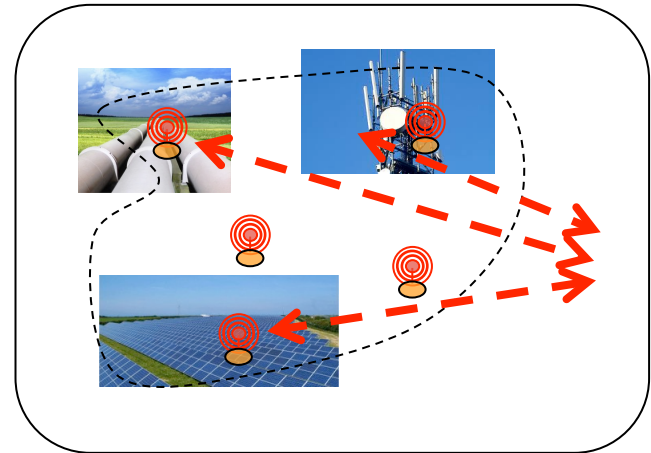
Green led, indicates that uCam is ready

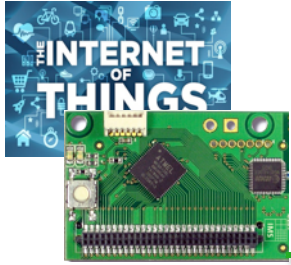
XBee 802.15.4 module connected at 125000 bauds

uCamII configured for RAW 128x128 8-bit/ pixel gray scale

Arduino Due board, AT91SAM3X8E at 84MHz, 96KB SRAM, 512KB flash

Arduino MEGA2560 b ATmega2560 at 16MHz, 256KB flash





# CONNECTIVITY IS A CHALLENGE

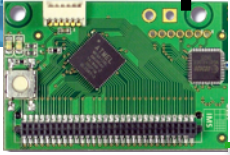
## Internet of Objects 80% of volume



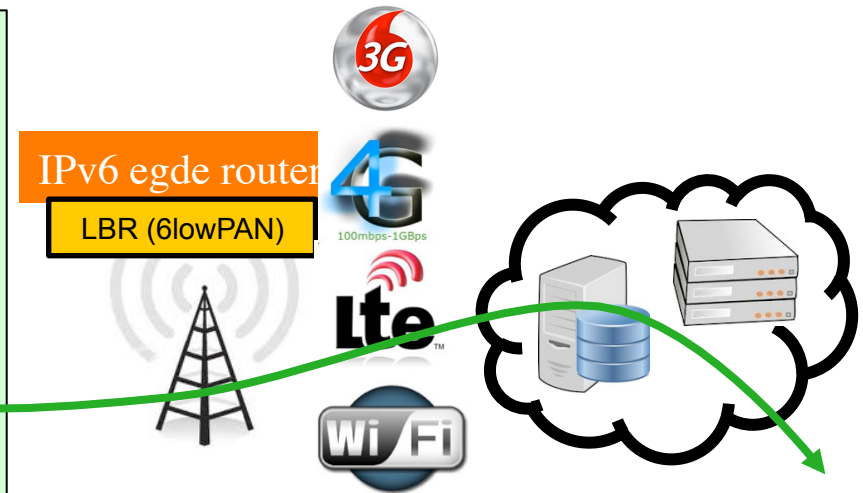
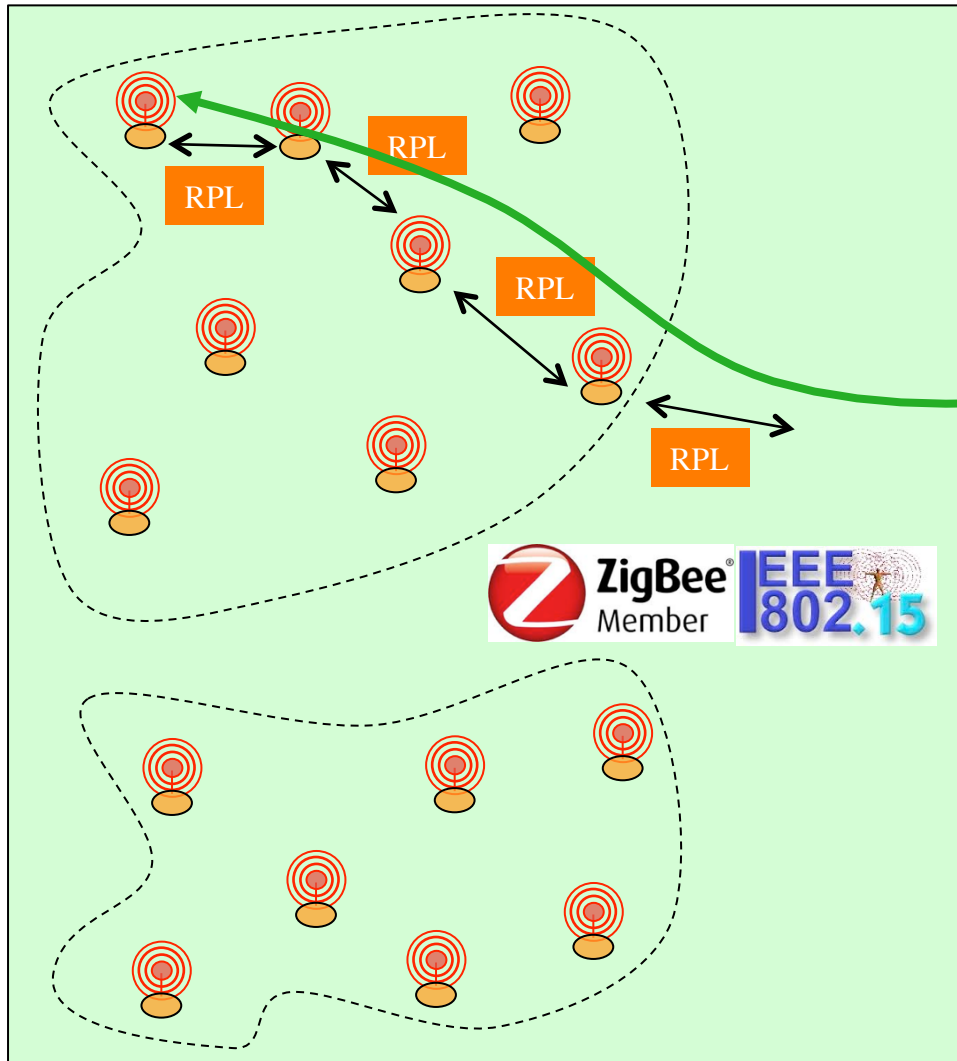
## Requirements:

- How to connect Low Cost Assets or having no Energy source, non rechargeable?
- Low Cost communication
- Low Cost Infrastructure
- Low Power Technology
- Robust Communication
- Allowing Mobility
- Scalability

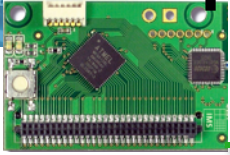




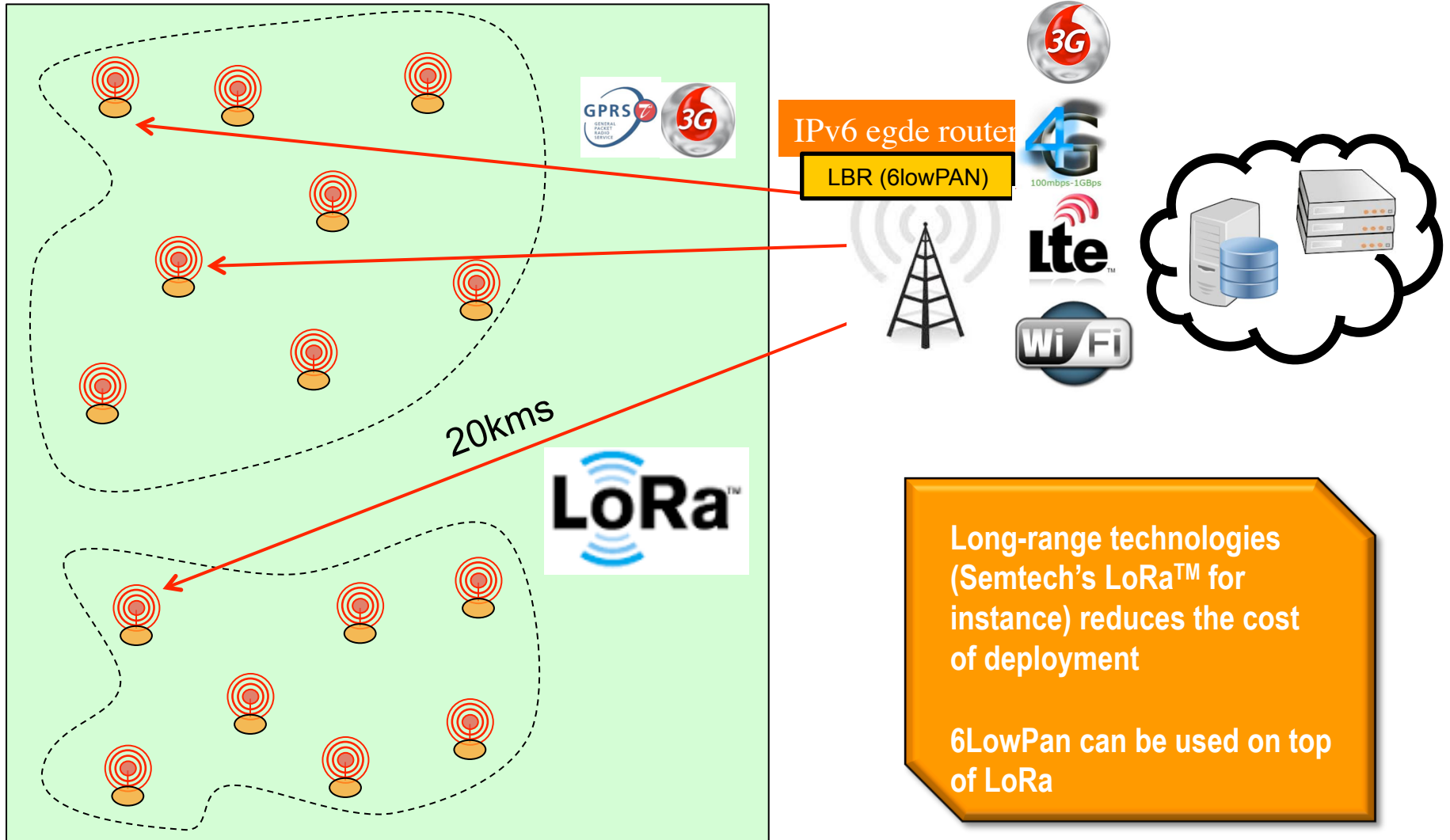
# TRADITIONAL MULTI-HOP TO SINK

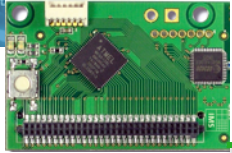


**TOO COMPLEX AND TOO COSTLY TO DEPLOY AND MAINTAIN INTERMEDIATE NODES!**

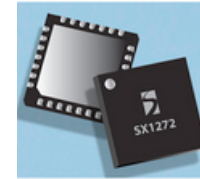


# 1-HOP TO SINK WITH LONG-RANGE TECHNOLOGY





# SEMTECH'S LORA TECHNOLOGY



## Parameters

- Bandwidth: 125kHz, 250kHz, 500kHz
- Coding rate: 4/5, 4/6, 4/7, 4/8
- Spreading factor: 6 to 12

**dBm** – power referred to 1 mW,

$$P_{dBm} = 10 \log(P/1mW)$$

Sensitivity: lowest input power with acceptable link quality, typically 1% PER

| Spreading Factor (RegModemConfig2) | Spreading Factor (Chips / symbol) | LoRa Demodulator SNR |
|------------------------------------|-----------------------------------|----------------------|
| 6                                  | 64                                | -5 dB                |
| 7                                  | 128                               | -7.5 dB              |
| 8                                  | 256                               | -10 dB               |
| 9                                  | 512                               | -12.5 dB             |
| 10                                 | 1024                              | -15 dB               |
| 11                                 | 2048                              | -17.5 dB             |
| 12                                 | 4096                              | -20 dB               |

| Bandwidth (kHz) | Spreading Factor | Nominal Rb (bps) | Sensitivity (dBm) |
|-----------------|------------------|------------------|-------------------|
| 125             | 6                | 9380             | -122              |
| 125             | 12               | 293              | -137              |
| 250             | 6                | 18750            | -119              |
| 250             | 12               | 586              | -134              |
| 500             | 6                | 3750             | -116              |
| 500             | 12               | 1172             | -131              |

### Rule of thumb

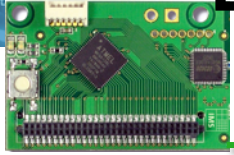
6dB increase = twice the range in LOS

12dB needed for urban areas

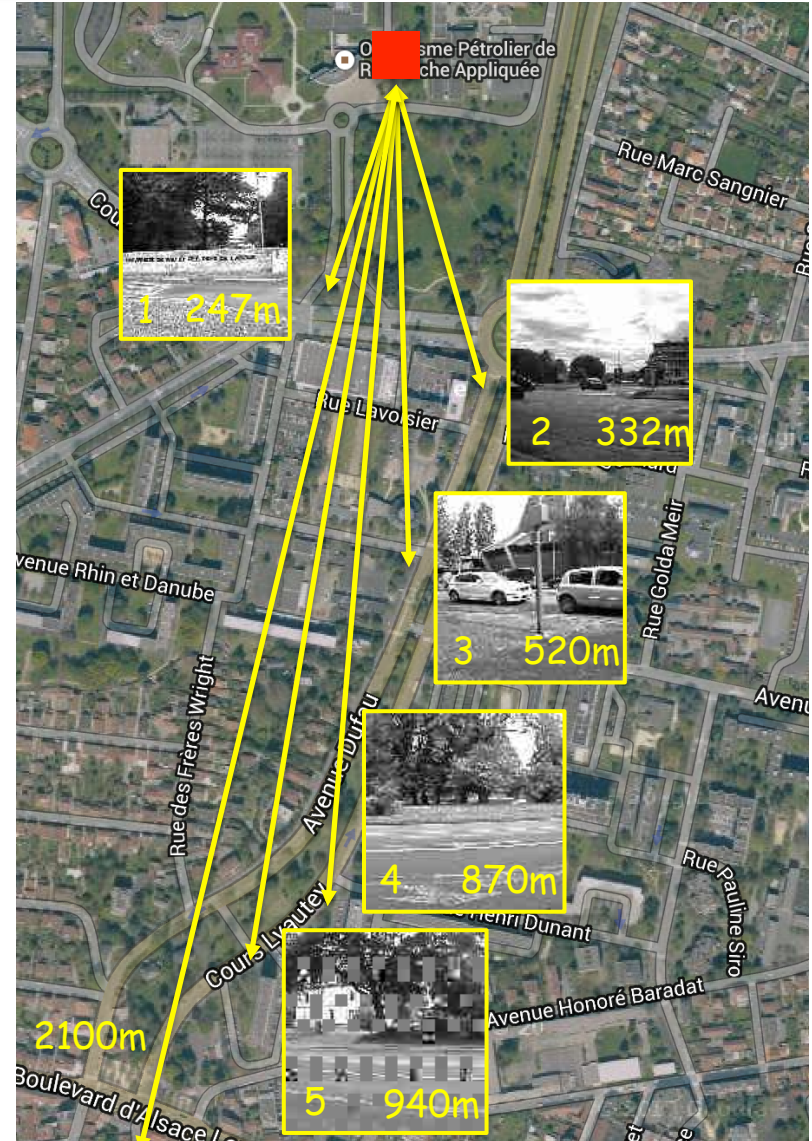
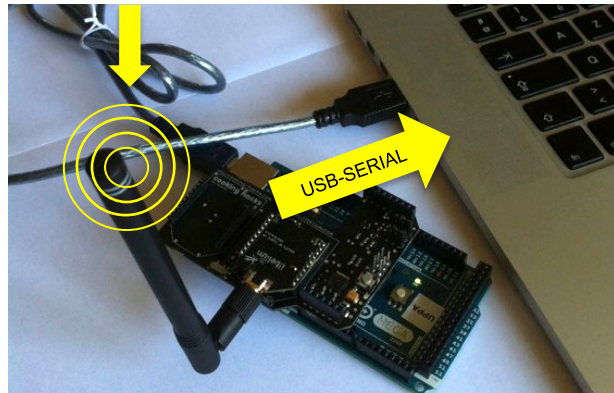
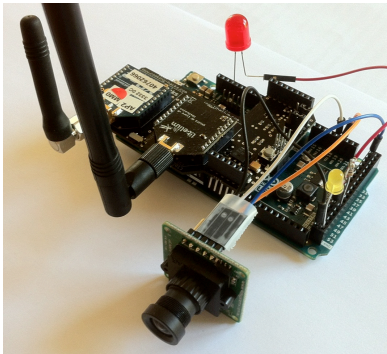
| Bandwidth (kHz) | Spreading Factor | Coding rate | Nominal Rb (bps) | Sensitivity (dBm) |
|-----------------|------------------|-------------|------------------|-------------------|
| 125             | 12               | 4/5         | 293              | -136              |
| 250             | 12               | 4/5         | 586              | -133              |
| 500             | 12               | 4/5         | 1172             | -130              |

Tables from Semtech

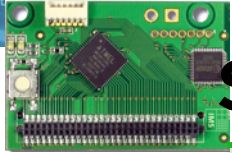




# LONG-RANGE VERSION OF OUR IMAGE SENSOR







# UNLICENSE SUB-GHZ SPECTRUM CONSTRAINTS

- ❑ It is shared medium so long-range transmission in dense environments can create lots of interference!
- ❑ Activity time is constrained from 0.1% to 1% duty-cycle depending on frequency: **3.6s to 36s/hour**

| Band      | Edge Frequencies |            | Field / Power      | Spectrum Access | Band Width |
|-----------|------------------|------------|--------------------|-----------------|------------|
|           | Fc-              | Fc+        |                    |                 |            |
| g(Note 7) | 865 MHz          | 868 MHz    | +6.2 dBm / 100 kHz | 1 % or LBT AFA  | 3 MHz      |
| g(Note 7) | 865 MHz          | 870 MHz    | -0.8 dBm / 100 kHz | 0.1% or LBT AFA | 5 MHz      |
| g1        | 868 MHz          | 868.6      | 14 dBm             | 1 % or LBT AFA  | 600 kHz    |
| g2        | 868.7 MHz        | 869.2 MHz  | 14 dBm             | 0.1% or LBT AFA | 500 kHz    |
| g3        | 869.4 MHz        | 869.65 MHz | 27 dBm             | 10 % or LBT AFA | 250 kHz    |
| g4        | 869.7 MHz        | 870 MHz    | 7 dBm              | No requirement  | 300 kHz    |
| g4        | 869.7 MHz        | 870 MHz    | 14 dBm             | 1 % or LBT AFA  | 300 kHz    |



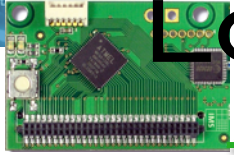
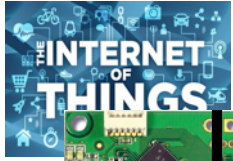
# TIME ON AIR OF LORA TRANSMISSIONS

**With 1% radio activity time...**

|           |     |     |    | time on air in second for payload size of |          |           |           |           |           |
|-----------|-----|-----|----|-------------------------------------------|----------|-----------|-----------|-----------|-----------|
| LoRa mode | BW  | CR  | SF | 5 bytes                                   | 55 bytes | 105 bytes | 155 Bytes | 205 Bytes | 255 Bytes |
| 1         | 125 | 4/5 | 12 | 0.95846                                   | 2.59686  | 4.23526   | 5.87366   | 7.51206   | 9.15046   |
| 2         | 250 | 4/5 | 12 | 0.47923                                   | 1.21651  | 1.87187   | 2.52723   | 3.26451   | 3.91987   |
| 3         | 125 | 4/5 | 10 | 0.28058                                   | 0.69018  | 1.09978   | 1.50938   | 1.91898   | 2.32858   |
| 4         | 500 | 4/5 | 12 | 0.23962                                   | 0.60826  | 0.93594   | 1.26362   | 1.63226   | 1.95994   |
| 5         | 250 | 4/5 | 10 | 0.14029                                   | 0.34509  | 0.54989   | 0.75469   | 0.95949   | 1.16429   |
| 6         | 500 | 4/5 | 11 | 0.11981                                   | 0.30413  | 0.50893   | 0.69325   | 0.87757   | 1.06189   |
| 7         | 250 | 4/5 | 9  | 0.07014                                   | 0.18278  | 0.29542   | 0.40806   | 0.5207    | 0.63334   |
| 8         | 500 | 4/5 | 9  | 0.03507                                   | 0.09139  | 0.14771   | 0.20403   | 0.26035   | 0.31667   |
| 9         | 500 | 4/5 | 8  | 0.01754                                   | 0.05082  | 0.08154   | 0.11482   | 0.14554   | 0.17882   |
| 10        | 500 | 4/5 | 7  | 0.00877                                   | 0.02797  | 0.04589   | 0.06381   | 0.08301   | 0.10093   |

↑ Range  
↓ Throughput

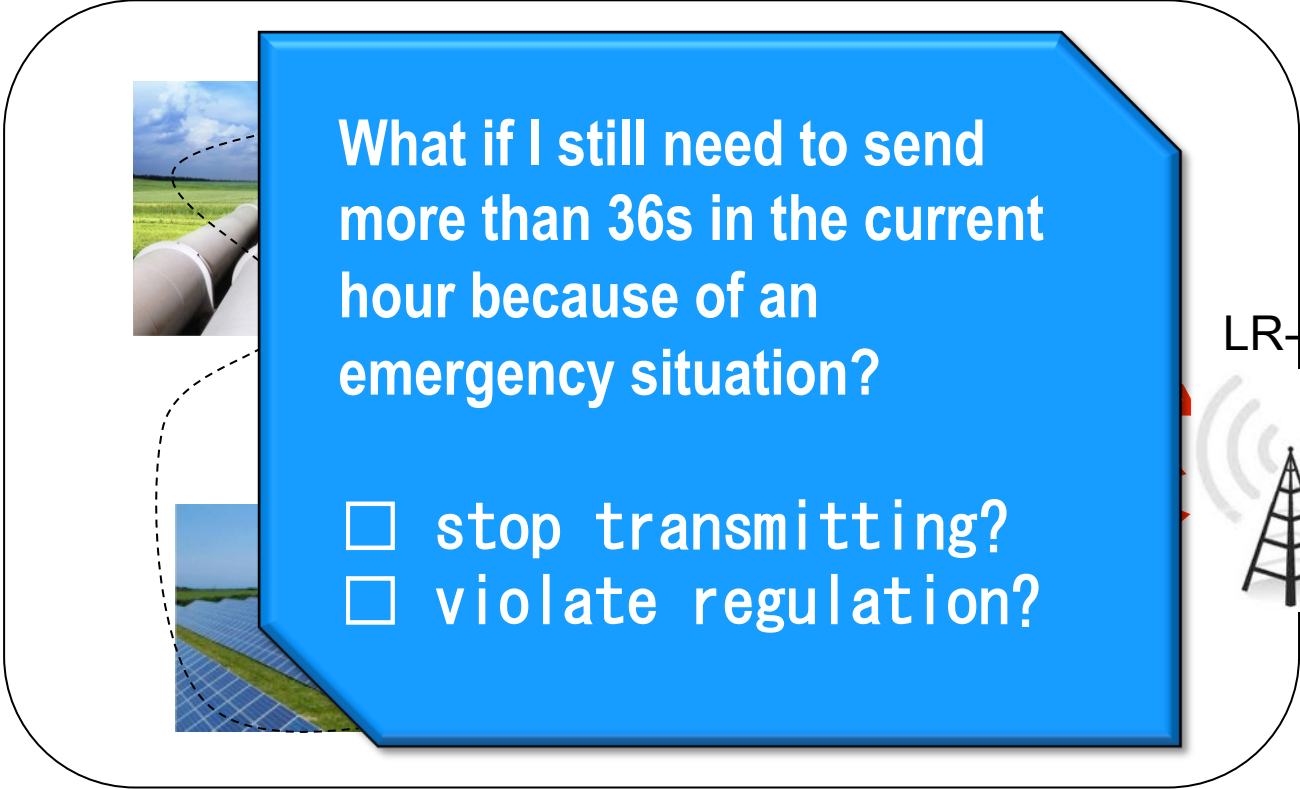
**...can send 13 50-byte msg/h or 59 50-byte msg/h**



# LORA DEVICES & GATEWAYS

Regulations stipulate that **radio activity duty-cycle should be enforced at devices** and that end-users should not be able to modify it « easily ».

LoRaWAN specification from LoRa Alliance is a first attempt to standardize LoRa networks but **no issues on quality of service**.

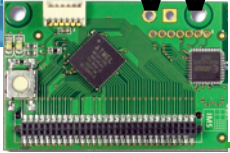


What if I still need to send more than 36s in the current hour because of an emergency situation?

- stop transmitting?
- violate regulation?

LR-BS





# WHAT IF I WANT TO TRANSMIT IMAGES?

| LoRa mode | BW  | CR  | SF | time on air in second for payload size of |          |           |           |           |           |
|-----------|-----|-----|----|-------------------------------------------|----------|-----------|-----------|-----------|-----------|
|           |     |     |    | 5 bytes                                   | 55 bytes | 105 bytes | 155 Bytes | 205 Bytes | 255 Bytes |
| 1         | 125 | 4/5 | 12 | 0.95846                                   | 2.59686  | 4.23526   | 5.87366   | 7.51206   | 9.15046   |
| 2         | 250 | 4/5 | 12 | 0.47923                                   | 1.21651  | 1.87187   | 2.52723   | 3.26451   | 3.91987   |
| 3         | 125 | 4/5 | 10 | 0.28058                                   | 0.69018  | 1.09978   | 1.50938   | 1.91898   | 2.32858   |
| 4         | 500 | 4/5 | 12 | 0.23962                                   | 0.60826  | 0.93594   | 1.26362   | 1.63226   | 1.95994   |
| 5         | 250 | 4/5 | 10 | 0.14029                                   | 0.34509  | 0.54989   | 0.75469   | 0.95949   | 1.16429   |
| 6         | 500 | 4/5 | 11 | 0.11981                                   | 0.30413  | 0.50893   | 0.69325   | 0.87757   | 1.06189   |
| 7         | 250 | 4/5 | 9  | 0.07014                                   | 0.18278  | 0.29542   | 0.40806   | 0.5207    | 0.63334   |
| 8         | 500 | 4/5 | 9  | 0.03507                                   | 0.09139  | 0.14771   | 0.20403   | 0.26035   | 0.31667   |
| 9         | 500 | 4/5 | 8  | 0.01754                                   | 0.05082  | 0.08154   | 0.11482   | 0.14554   | 0.17882   |
| 10        | 500 | 4/5 | 7  | 0.00877                                   | 0.02797  | 0.04589   | 0.06381   | 0.08301   | 0.10093   |



Optimized image encoding at medium quality: 16384b down to 1366b (ratio 12).

Will generate 7 pkts using 250 max payload



$$7 * 9.15 = 64.05s$$

$$7 * 1.96 = 13.72s$$





# DEPLOYING YOUR LORA NETWORK

OPERATOR-BASED  
APPROACH (BY  
SUBSCRIPTION)



Whatever the deployment approach, the gateway knows how many devices are deployed by a given organization

Our proposition is to view all device' activity time in a global manner, with the gateway taking care of radio time usage consistency

PRIVATELY-BASED  
APPROACH



Multitech Conduit

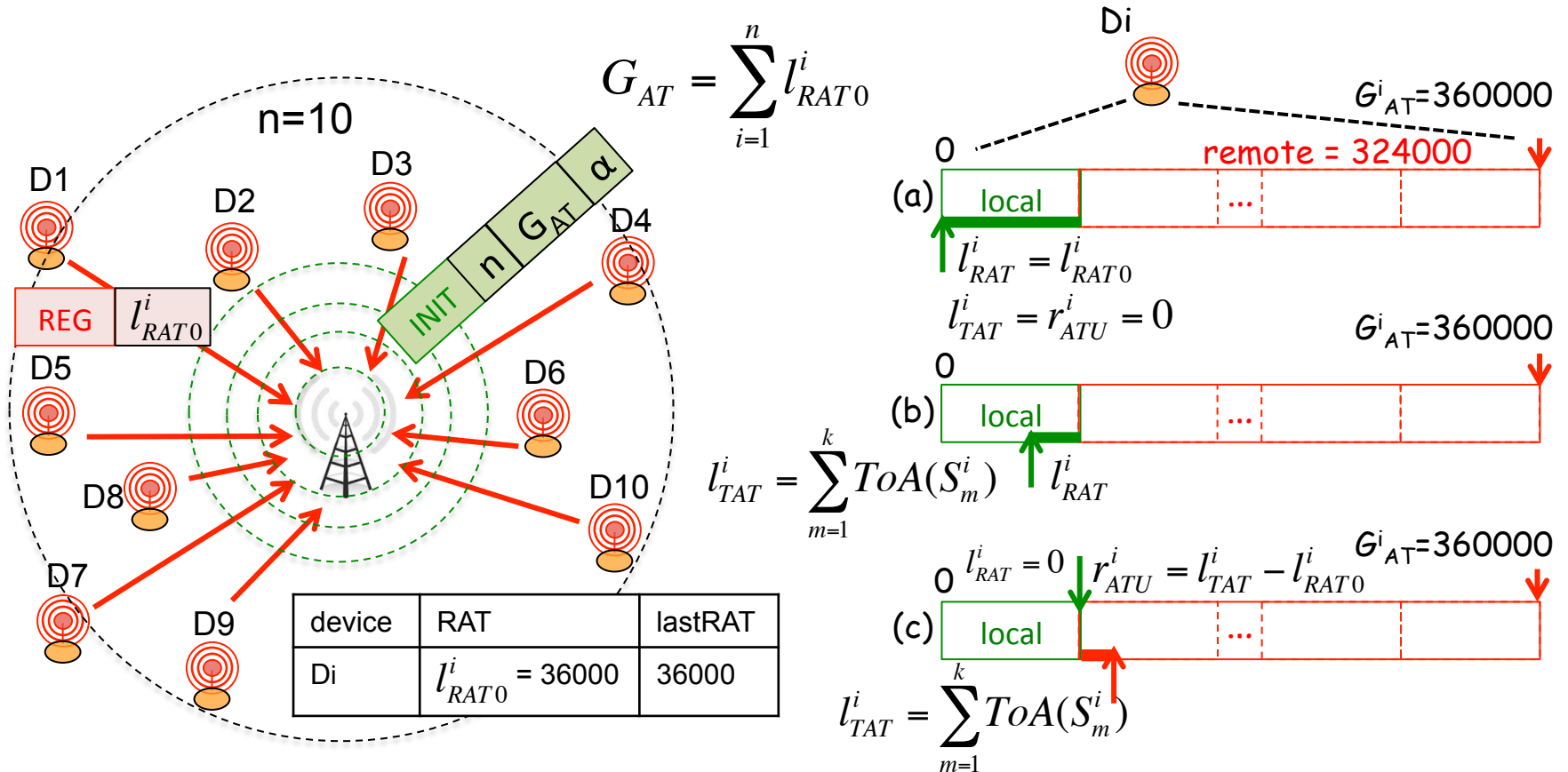


Kerlink IoT Station

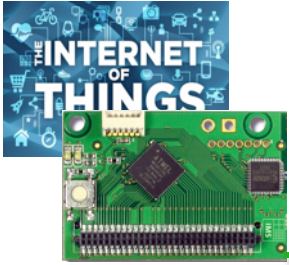
AND MUCH MORE...



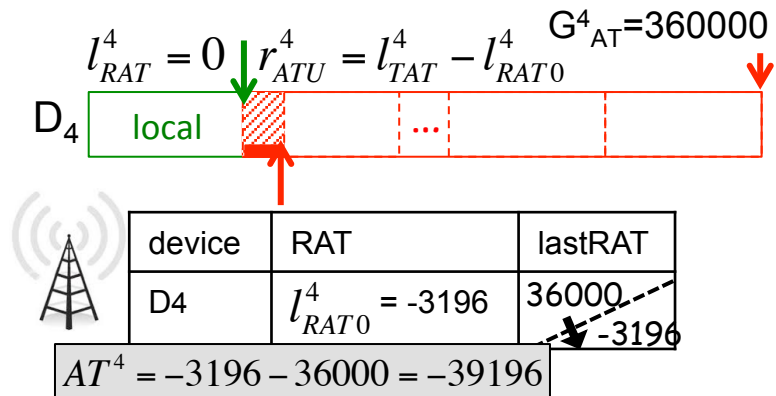
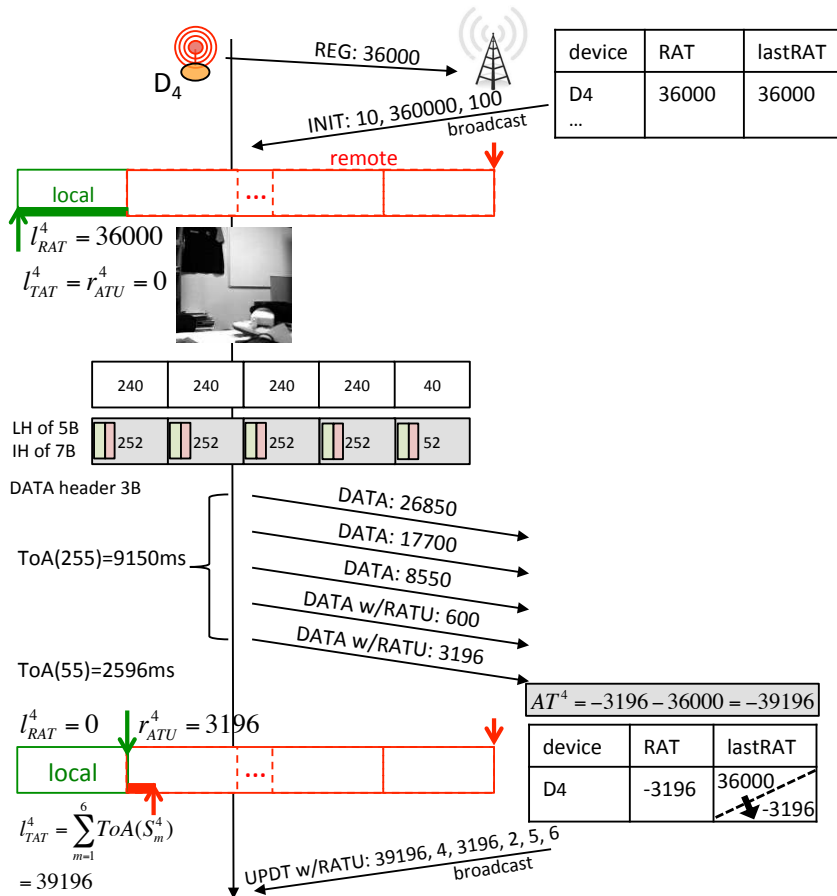
# LONG-RANGE ACTIVITY SHARING (LAS)



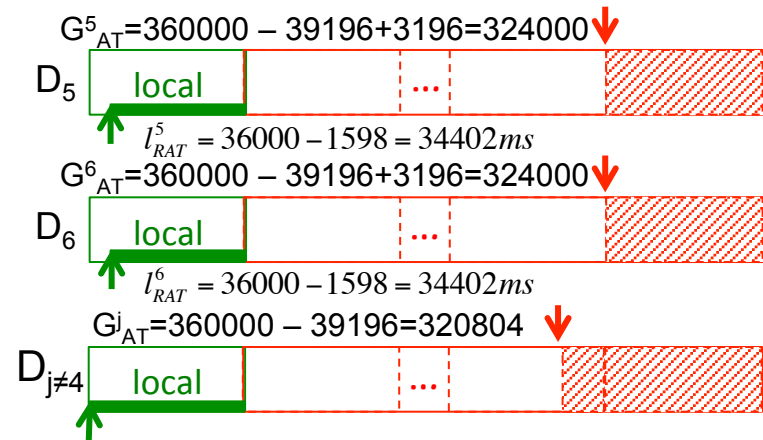
A device can transmit more if needed, provided that other devices will decrease their radio activity time accordingly.

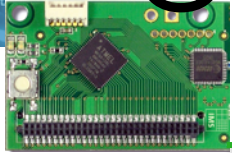


# DISTRIBUTING REMOTE ACTIVITY TIME USAGE



| UPDT w/RATU | 39196 | 4 | $n_d=2$ | 3196 | 5 | 6 |
|-------------|-------|---|---------|------|---|---|
|-------------|-------|---|---------|------|---|---|



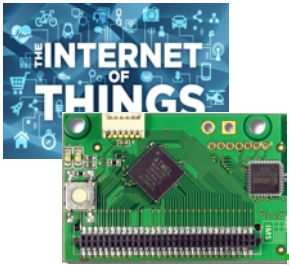


# OTHER ISSUES TO TAKE INTO ACCOUNT

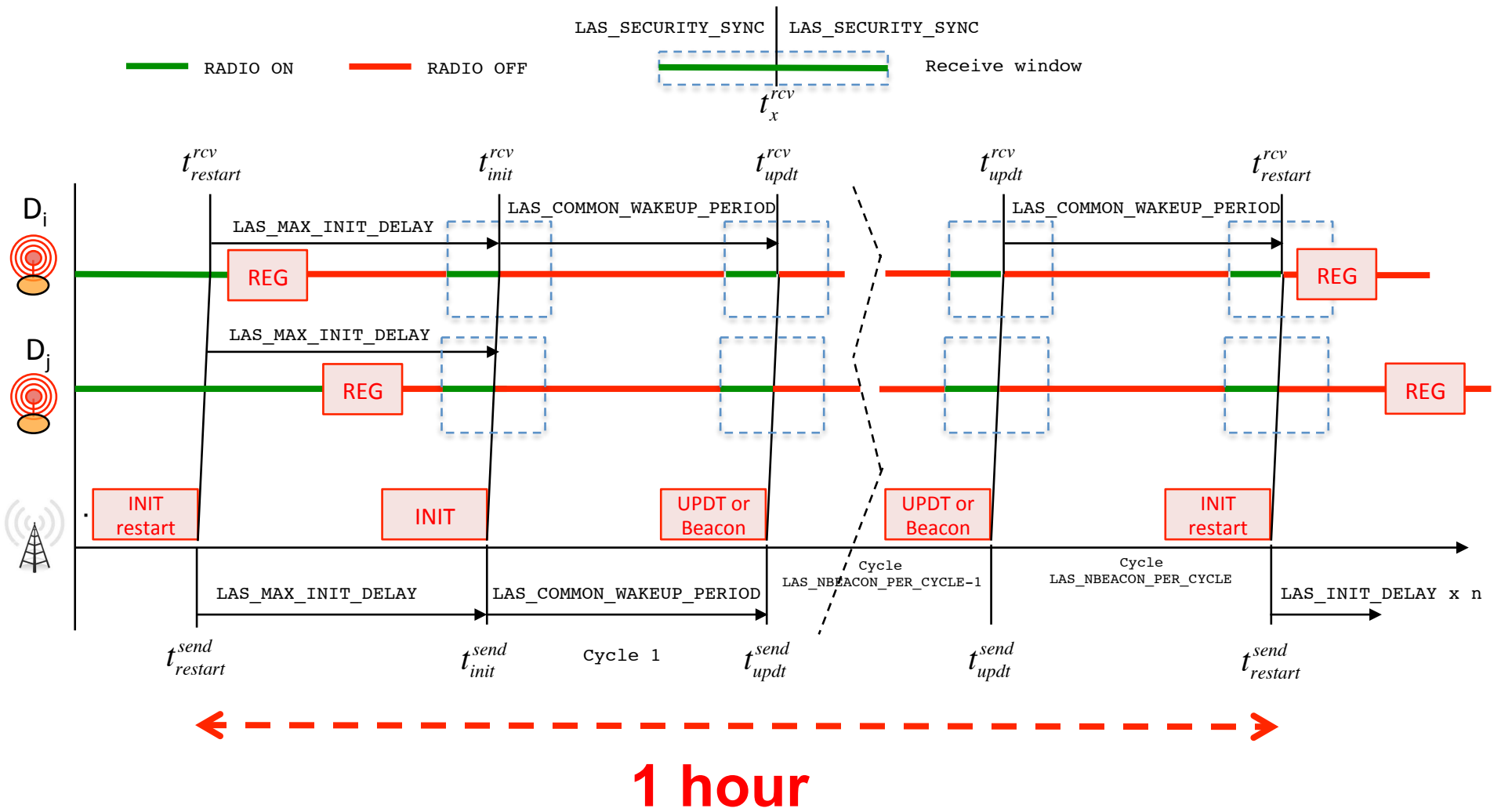
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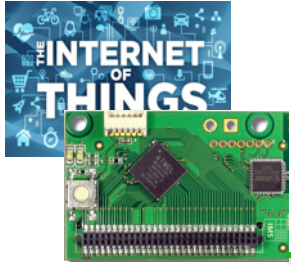
- ❑ Minimise the number of UPDT messages sent by the gateway because the gateway's radio time is also limited
  - ❑ UPDT can have cumulative behavior if no remote activity time has been used
- ❑ Support sleep periods of end-devices
  - ❑ The network is synchronized for control messages (REG, INIT, UPDT). UPDT msg that can not use cumulative behavior are queued for transmission at next transmission slot. At rcv, UPDT have to be applied sequentially.
- ❑ Maintain (loose) synchronization
  - ❑ If no UDPT are scheduled, the gateway periodically sends a BEACON. Clock drift is limited to a BEACON period
- ❑ Dynamic insertion of new end-devices
  - ❑ New devices can either stay out of the managed pool (then only 36s of activity time/h is allowed), or join by waiting for the next UPDT/BEACON msg
  - ❑ Every hour, end-devices decide if they want to join the pool or not
- ❑ Give priority to control msg
  - ❑ SIFS/DIFS mechanism are implemented using LoRa Channel Activity Detection
- ❑ Avoid interleaving of several image transmissions
  - ❑ Use DIFS for first image packet, then SIFS
- ❑ Improve LoRa network efficiency
  - ❑ Move from pure ALOHA to CSMA mechanism with CAD+RSSI tests prior to any transmission





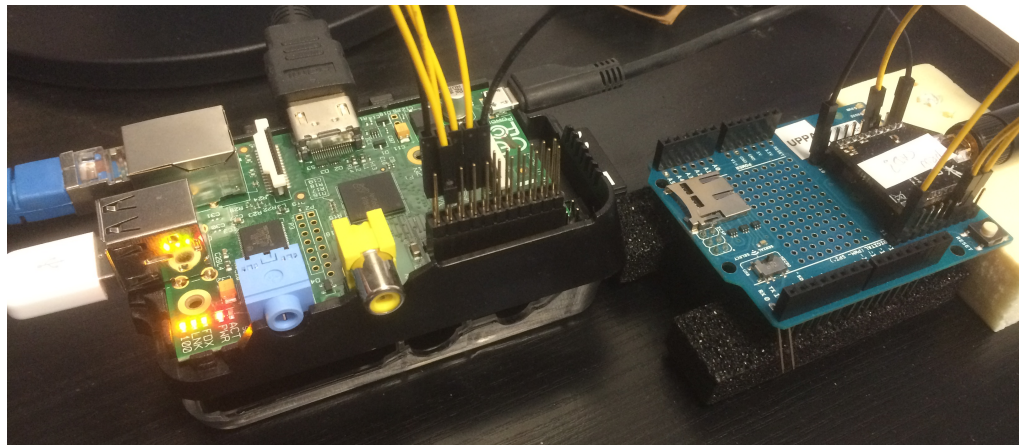
# SUMMARY OF GATEWAY-DEVICE SCHEDULING





# IMPLEMENTATIONS & LIBRARIES

- ❑ Own gateway based either Raspberry PI or Arduino MEGA/Due with gateway LAS services
- ❑ C/C++ Library for end-devices to send data packets under LAS services. Radio duty-cycling and interactions with LAS gateway are performed automatically





# GATEWAY STARTUP



```

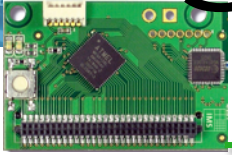
pi@raspberr... x pi@raspberr... x
pi@raspberrypi ~$ sudo ./loRa_gateway | python ./parseLoRaStdin.py
Power ON: state ...
0
LoRa mode: state 0
Channel CH_10_868: state 0
Power M: state 0
Get Preamble Length: state 0
Preamble Length: 8
LoRa addr 1 : state 0
SX1272 configured as LR-BS. Waiting RF input for transparent RF-serial bridge
%LASBase::ON
%LAS::ON
%LASBase::clear dev table
----- Rcv from LoRa. src=10 seq=7 len=10 SNR=7 RSSIpkt=-62
rcv ctrl pkt info: 10,7,10,7,-62

splitted in: [10, 7, 10, 7, -62]
(src=10 seq=7 len=10 SNR=7 RSSI=-62)
%LASBase::rcv LAS message
%LASBase::LAS payload size is 10
%LASBase::DATA msg
%LASBase::process DATA msg from 10
%LASBase::advertised lrat is 33301
%LASBase::dev_table index 0
%LASBase::can find device
hello
  
```

```

Kcv serial: hello
Sending. Length is 5
hello
LASDevice::Payload size is 15
LASDevice::ToA is 322
LASDevice::alpha*gat is 36000
LASDevice::_lrat is 2699
LASDevice::_lrat is 33301
LASDevice::sending w/LP
LAS::CAD duration 138
LAS::CAD OK1
--> waiting for 6 CAD = 96
--> CAD duration 138
LAS::CAD OK2
LAS::check RSSI
--> RSSI -114
LASDevice::LoRa Sent in 541
LASDevice::LoRa Sent w/CAD in 916
Packet sent, state 0
  
```





# SENDING MESSAGE UNDER LAS SERVICES

```
pi@raspberr... x pi@raspberr... x
----- Rcv from LoRa. src=10 seq=8 len=5 SNR=7 RSSIpkt=-55
rcv_ctrl_pkt_info: 10,8,5,7,-55

splitted in: [10, 8, 5, 7, -55]
%LASBase::rcv LAS message
%LASBase::LAS payload size is 5
%LASBase::REG msg
%LASBase::process REG msg from 10
%LASBase::advertised lrat0 is 36000
%LASBase::dev_table index 0
%LASBase::added in dev_table
%LASBase::_n_d is 1

----- Rcv from LoRa. src=10 seq=9 len=10 SNR=9 RSSIpkt=-53
rcv_ctrl_pkt_info: 10,9,10,9,-53

splitted in: [10, 9, 10, 9, -53]
(src=10 seq=9 len=10 SNR=9 RSSI=-53)
%LASBase::rcv LAS message
%LASBase::LAS payload size is 10
%LASBase::DATA msg
%LASBase::process DATA msg from 10
%LASBase::advertised lrat is 32979
%LASBase::dev_table index 0
%LASBase::data length is 10
%LASBase::computes ToA on 15B is 322
%LASBase::mismatched lrat, update
%LASBase::w/LP
%LASBase::send UPDT with 3021,10
%LASBase::Payload size is 11
%LASBase::ToA is 281
%LASBase::toa control disabled
%LAS::CAD duration 66
%LAS::CAD OK1
%LAS::check RSSI
--> RSSI -100
hello
```



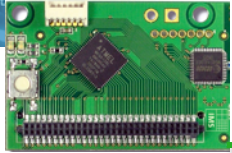
```
Rcv serial: /@REG#
Parsing command
Send LAS REG msg
LASDevice::REG with 36000
LASDevice::Payload size is 10
LASDevice::ToA is 281
LASDevice::disabled
LAS::CAD duration 46
LAS::CAD OK1
LAS::check RSSI
--> RSSI -115
LASDevice::LoRa Sent in 499
LASDevice::LoRa Sent w/CAD in 546
```

```
hello
LASDevice::Payload size is 15
LASDevice::ToA is 322
LASDevice::alpha*gat is 36000
LASDevice::_ltat is 3021
LASDevice::_lrat is 32979
LASDevice::sending w/LP
LAS::CAD duration 138
LAS::CAD OK1
--> waiting for 6 CAD = 96
--> CAD duration 138
LAS::CAD OK2
LAS::check RSSI
--> RSSI -115
LASDevice::LoRa Sent in 541
LASDevice::LoRa Sent w/CAD in 915
Packet sent, state 0
Rcv from LoRa. src=1 seq=0 len=6 SNR=8
^1,0,6,8,-55

LASDevice::rcv LAS message

LASDevice::UPDT msg
LASDevice::process UPDT msg 4426617
LASDevice::AT is 3021
LASDevice::Di is 10
LASDevice::nothing to be done
```





# CONCLUSIONS

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- ❑ Long-range radios appear as a very promising technology to deploy sensors and so-called IoT devices without the complexity and cost of multi-hop networking
- ❑ However, as the radio activity time is limited by regulations, it is difficult to guarantee a level of service of the deployed infrastructure, especially for some data-intensive applications
- ❑ We propose a Long-range Activity Sharing mechanism to manage a pool of deployed devices in a flexible manner
- ❑ Quality of Service can be ensured as devices can transmit critical information when needed