Low-cost, Low-Power and Long-range Image Sensor for Visual Surveillance
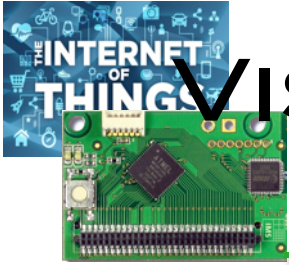
C. Pham
University of Pau, France

SmartObjects'2016
New-York city, USA,
October 3rd, 2016

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

VISUAL DATA FOR SITUATION-AWARENESS
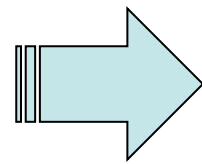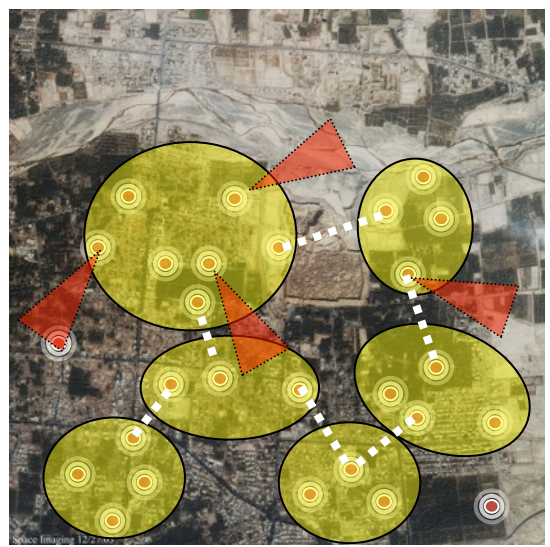
Wireless Sensor Networks

COVERAGE
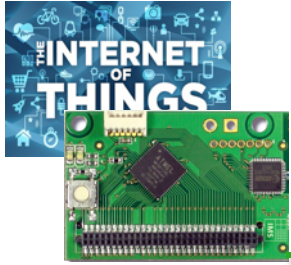**COVER-SET SELECTION**

Multihop routing
& IEEE 802.15.4

Image sensors

Activity-scheduling

MAC layer for low latency
How to synchronize on multi-hop scenario

COLLECT VISUAL DATA FOR SITUATION AWARENESS, SAFETY/RESCUE OPERATIONS

IoT FOR DEVELOPING COUNTRIES

www.waziup.eu

5 EU partners

7 African partners

Irrigation & Agriculture

Livestock farming

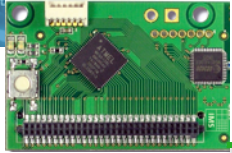Fish farming & aquaculture

Storage & logistic

Health

Water quality

Rural Sensing: more pragmatic?

Moisture/ Temperature of storage areas

10-15kms

Pay subscription
Limitation of coverage
High energy consumption

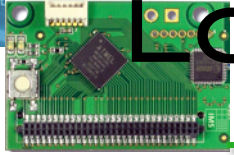| Technology	2G	3G	LAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m
Tx current consumption	200-500mA	500-1000mA	100-300mA
Standby current	2.3mA	3.5mA	NC
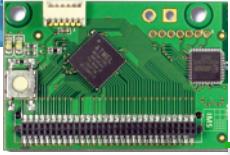
LOW-POWER AND LONG-RANGE?
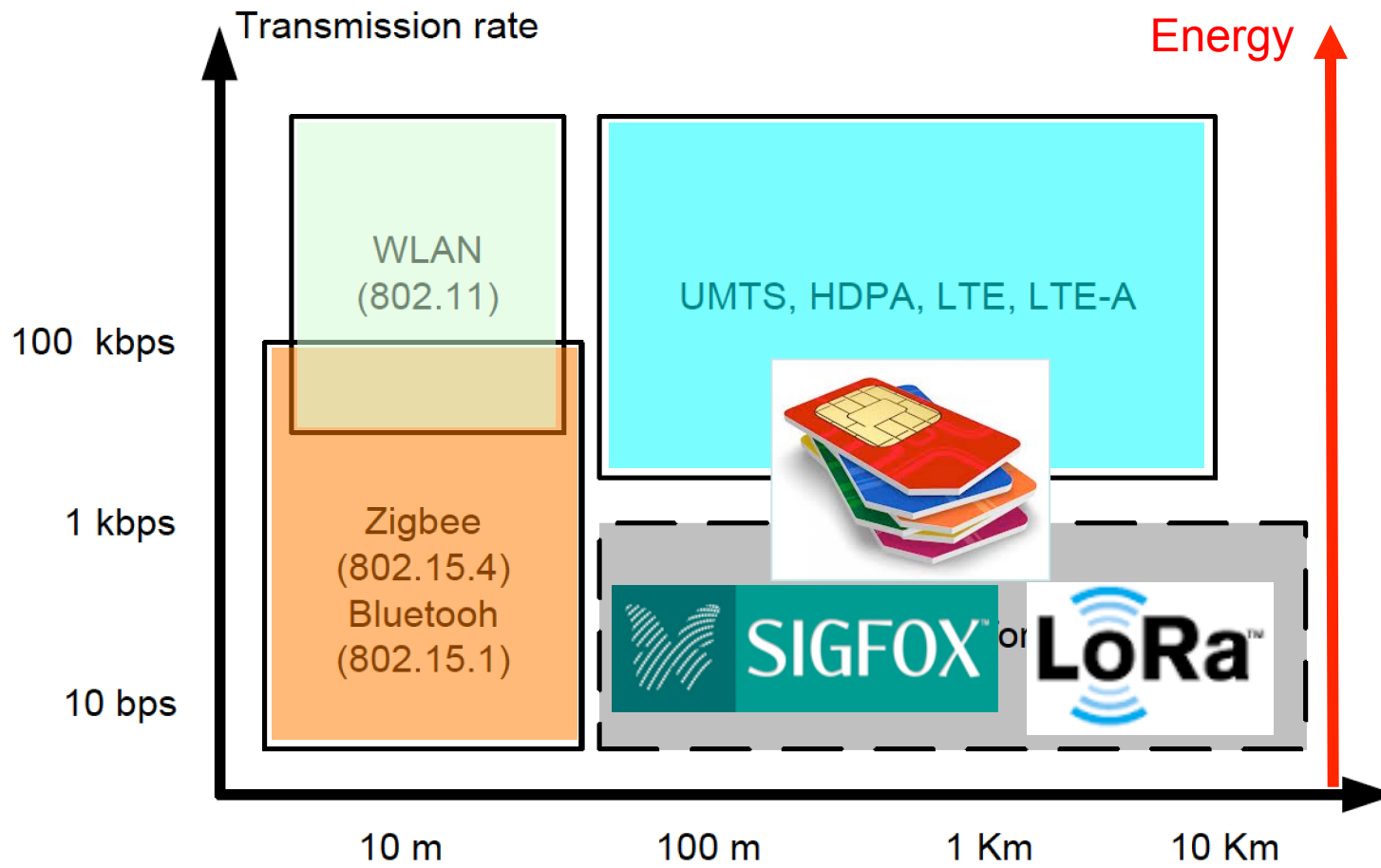
Enhanced from M. Dohler "M2M in SmartCities"

LOW POWER WAN (LPWAN) ?

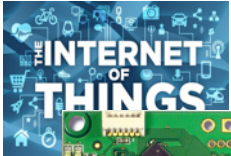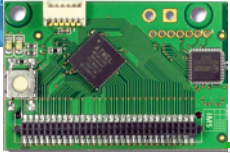| Technology	2G	3G	LAN	ZigBee	Lo Power WAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m	O: 90m I: 30m	Same as 2G/3G
Tx current consumption	200-500mA	500-1000mA	100-300mA	18mA	18mA
Standby current	2.3mA	3.5mA	NC	0.003mA	0.001mA
Energy harvesting (solar, other)	No	No	No	Possible	Possible
Battery 2000mAh (LR6 battery)	4-8 hours(com) 36 days(idle)	2-4 hours(com) X hours(idle)	50 hours(com) X hours(idle)	60hours (com)	120 hours(com) 10 year(idle)
Module Revenue Annually	12 $	20 $	4 $	$3	3 $

Autonomy GSM with 2000mAh -

Autonomy LP WAN with 2000mAh -

Example for energy meter

1 year   5 years   10 years

6

LPWAN ARCHITECTURE

10-15kms in LOS, in 1-hop

End Nodes

- pet tracking
- smoke alarm
- water meter
- trash container
- vending machine
- gas monitoring

Concentrator /Gateway

3G/ Ethernet Backhaul
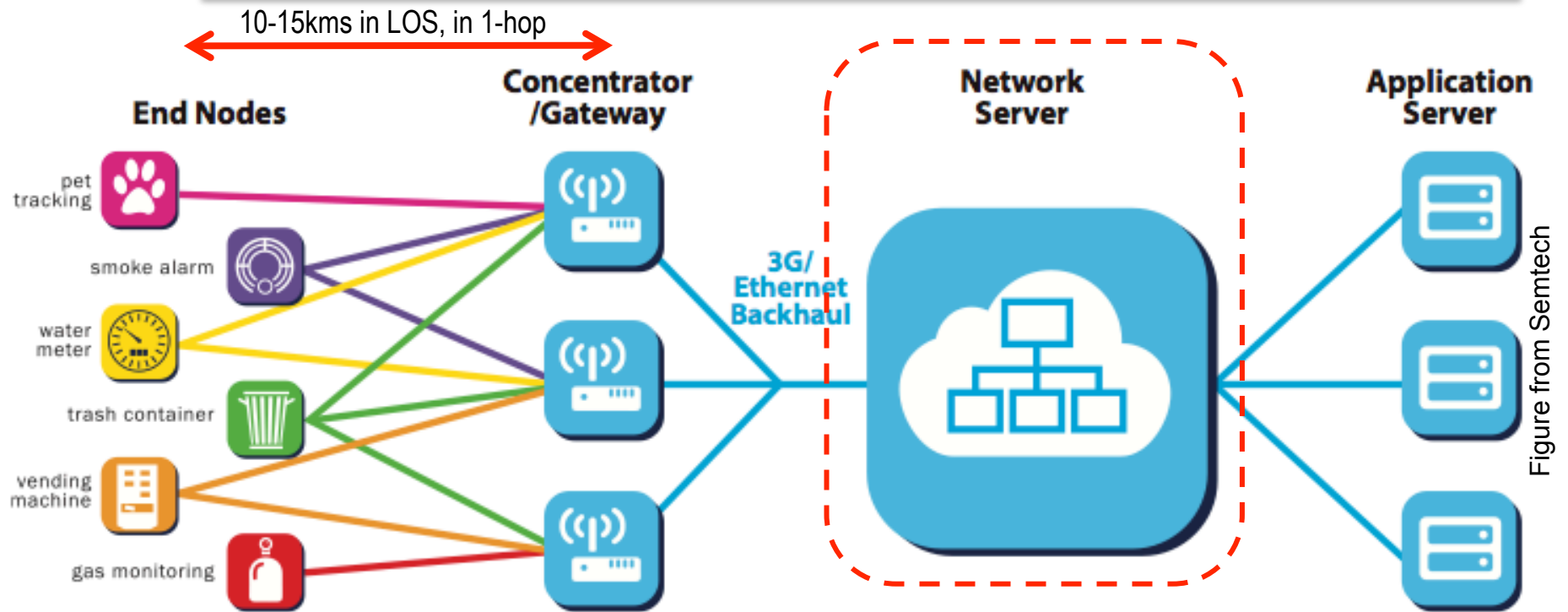
Network Server
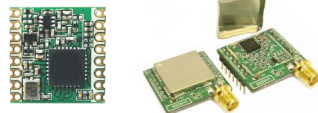
Application Server
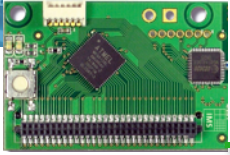
Figure from Semtech

LoRa™

No subscription
Deploy own network
Low energy consumption

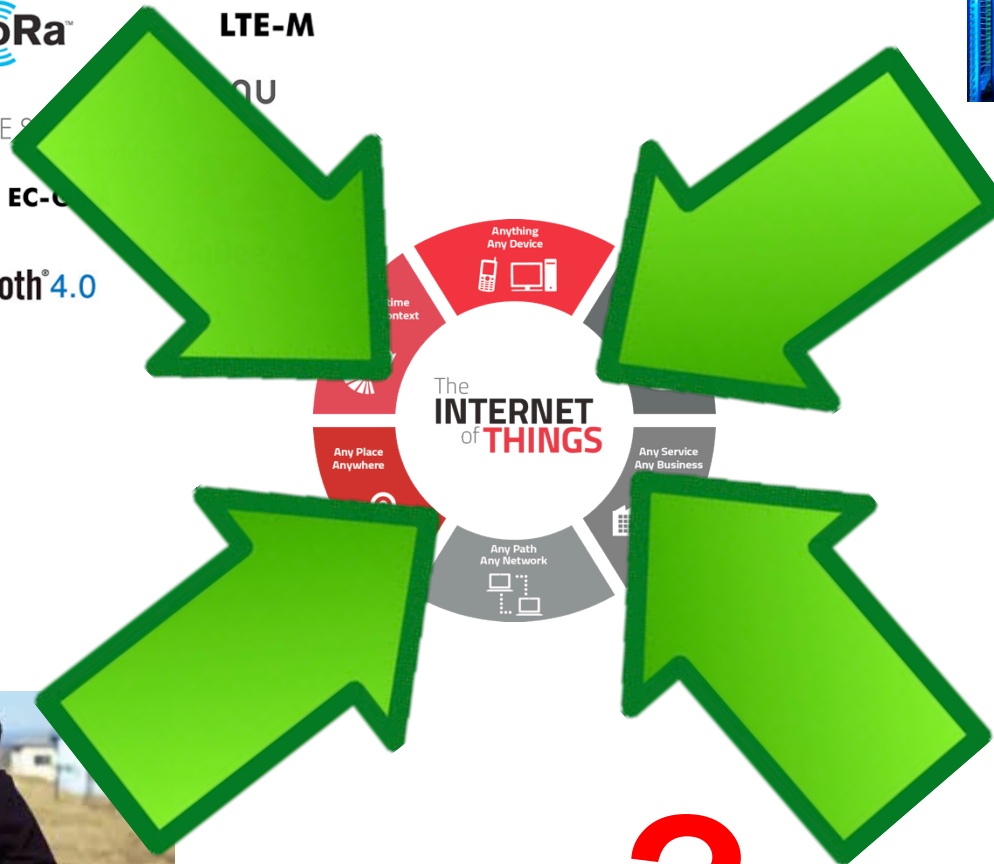Add LoRa radio module to your preferred dev platform

Install a LoRa gateway and start collecting data

7

IoT becomes reality!
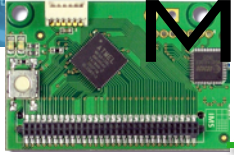
Motivations & objectives

❑ **Simplicity: no specialized hardware**
- ❑ Image encoding with the host µC (no additional nor dedicated µC)
- ❑ Off-the-shelf components
- ❑ Quick appropriation (hardware and software) and high availability
- ❑ Maximum flexibility and simplicity in programming and design
- ❑ "out-of-the-box" deployment (no multi-hop)

❑ **… but still efficient**
- ❑ Fast encoding
- ❑ Packet loss-tolerant bit stream
- ❑ Low-power to run on battery for months

9

The DIY ecosystem

❑ Many powerfull microcontroller boards available
❑ Do-It-Yourself approach with off-the-shelves
  components provides high flexibility/sustainability

Arduino Pro Mini
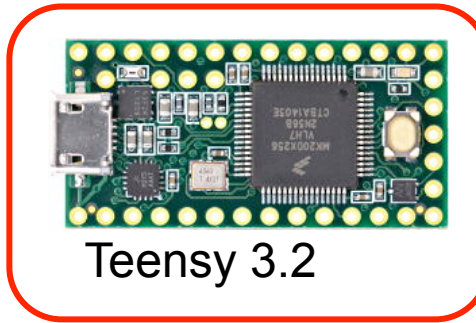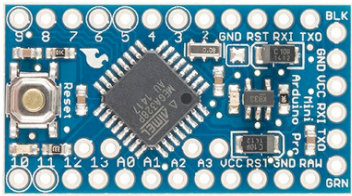
Teensy 3.2

LinkIt Smart 7688 Duo
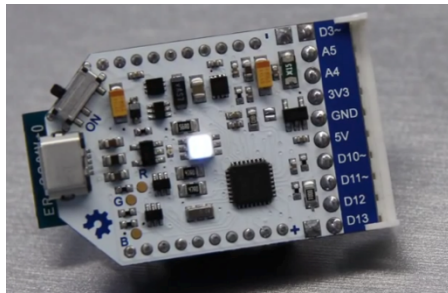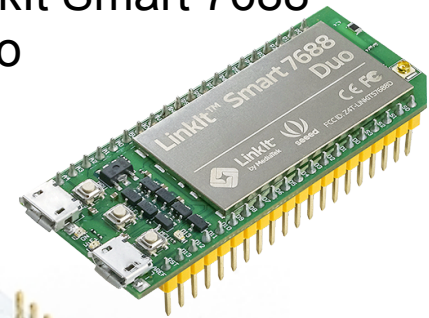
Theairboard on kickstarter
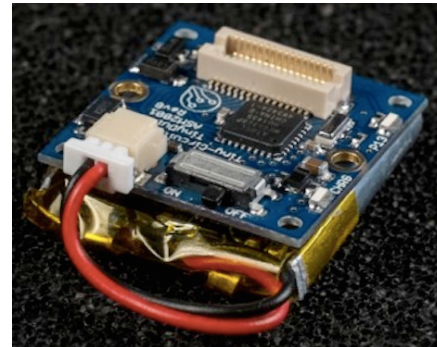
Tinyduino

STM32 Nucleo-32

10
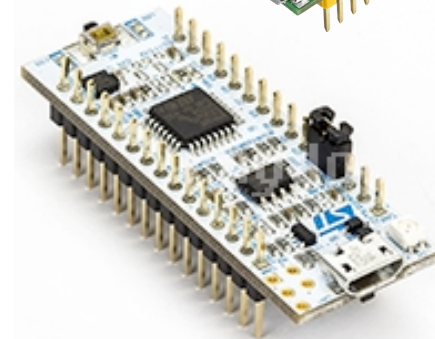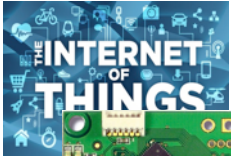
Teensy + uCamII
128x128 8bpp raw images

$15

LoRa™

$35

ucamII

Pin 1

CS

Pin 1

DURACELL PLUS
DURACELL PLUS
DURACELL PLUS
DURACELL PLUS

SCK   3.3v

TX

RX

MOSI   MISO   CS

uart3

MK20DX256
VLH7
2N36B
CTAW1347N

$20

SCK

3.3v   GND   RAW

+
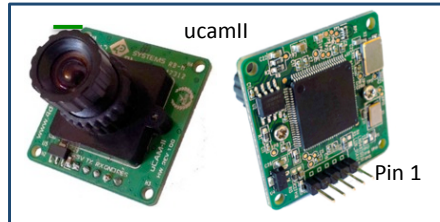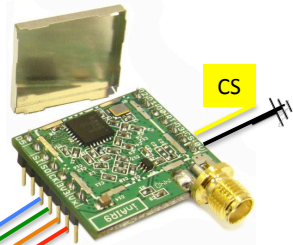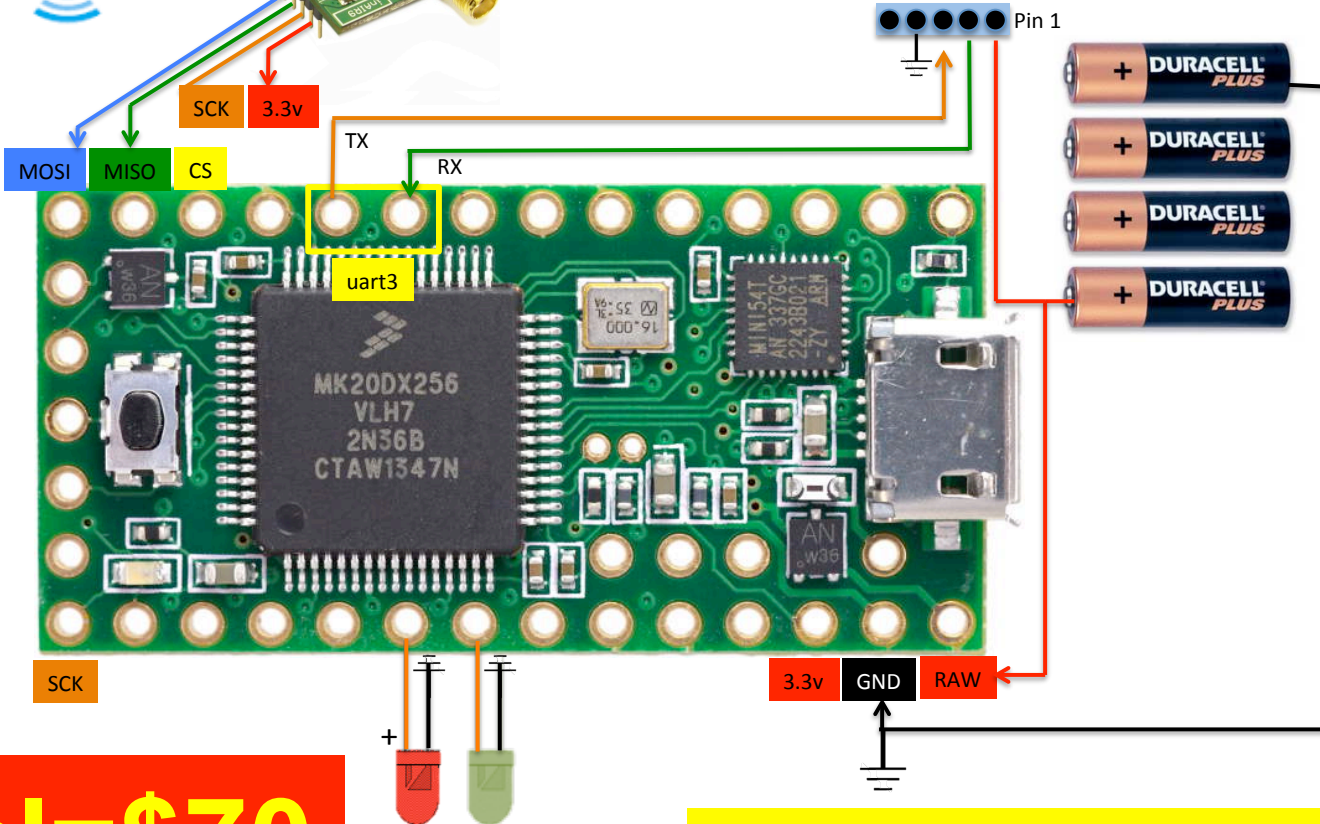
Total=$70

Teensy32, MK20DX256 Cortex-M4
at nominal 72MHz, 64KB SRAM

11

56° lens   76° lens   116° lens

Cam 2

Cam 3   Cam 1
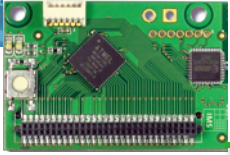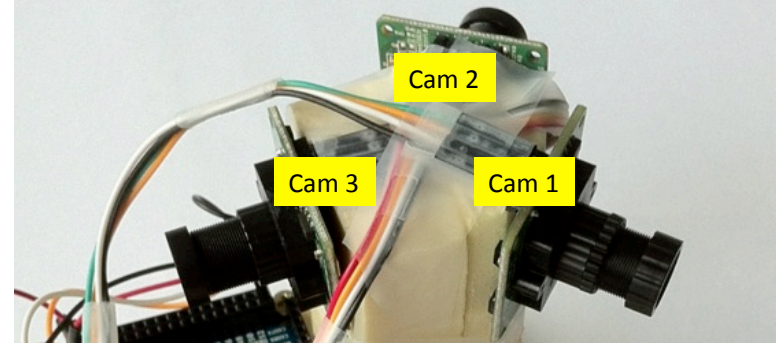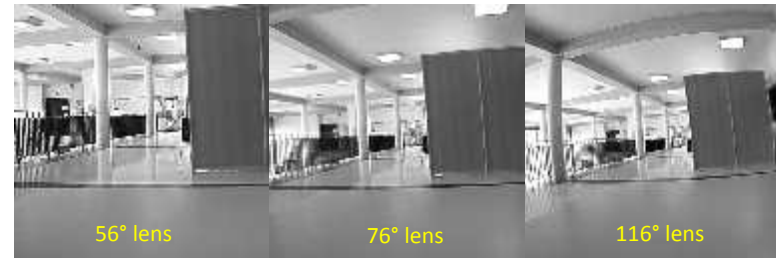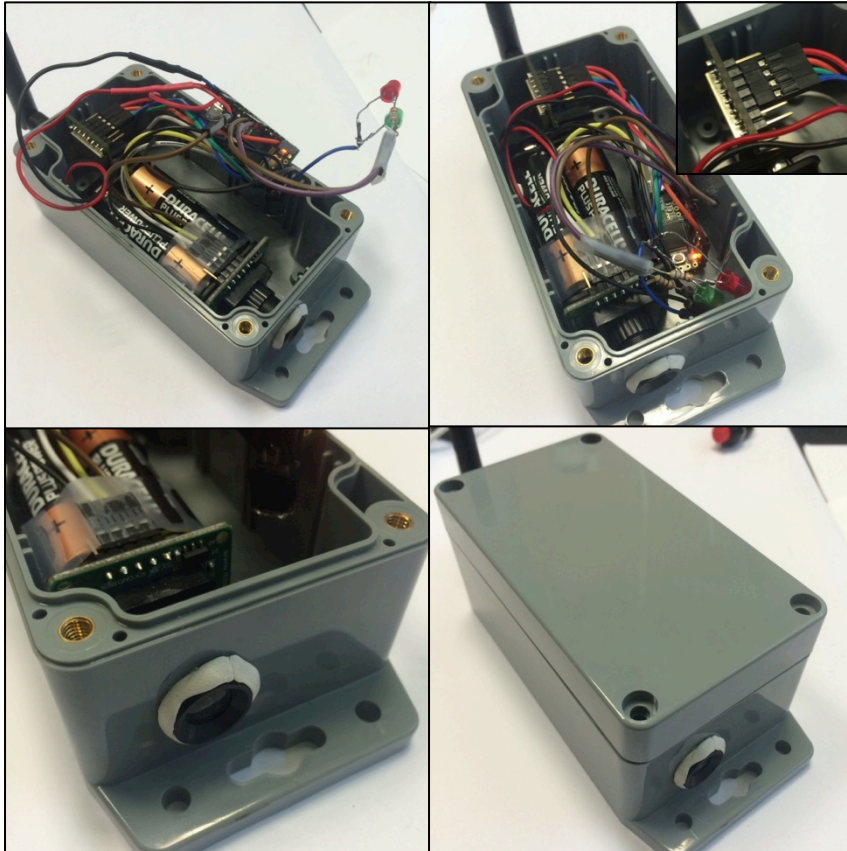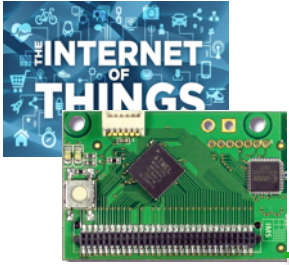
Image encoding

ADJUSTABLE IMAGE QUALITY FACTOR Q

Scientific cooperation with V. Lecuire from CRAN laboratory for the optimized image encoding algorithm

raw 16384b

Q=100; 9768b (1.67)
PSNR=51.344

Q=90; 5125b (3.2)
PSNR=29.414

Q=80; 3729b (4.4)
PSNR=28.866

Q=70; 2957b (5.5)
PSNR=28.477

Q=60; 2552b (6.4)
PSNR=28.024

Q=50; 2265b (7.2)
PSNR=27.912

Q=40; 2024b (8.1)
PSNR=27.423

Q=30; 1735b (9.5)
PSNR=26.933

Q=20; 1366b (12)
PSNR=26.038

Q=10; 911b (18)
PSNR=25.283

Q=5; 576b (28.44)
PSNR=23.507

13
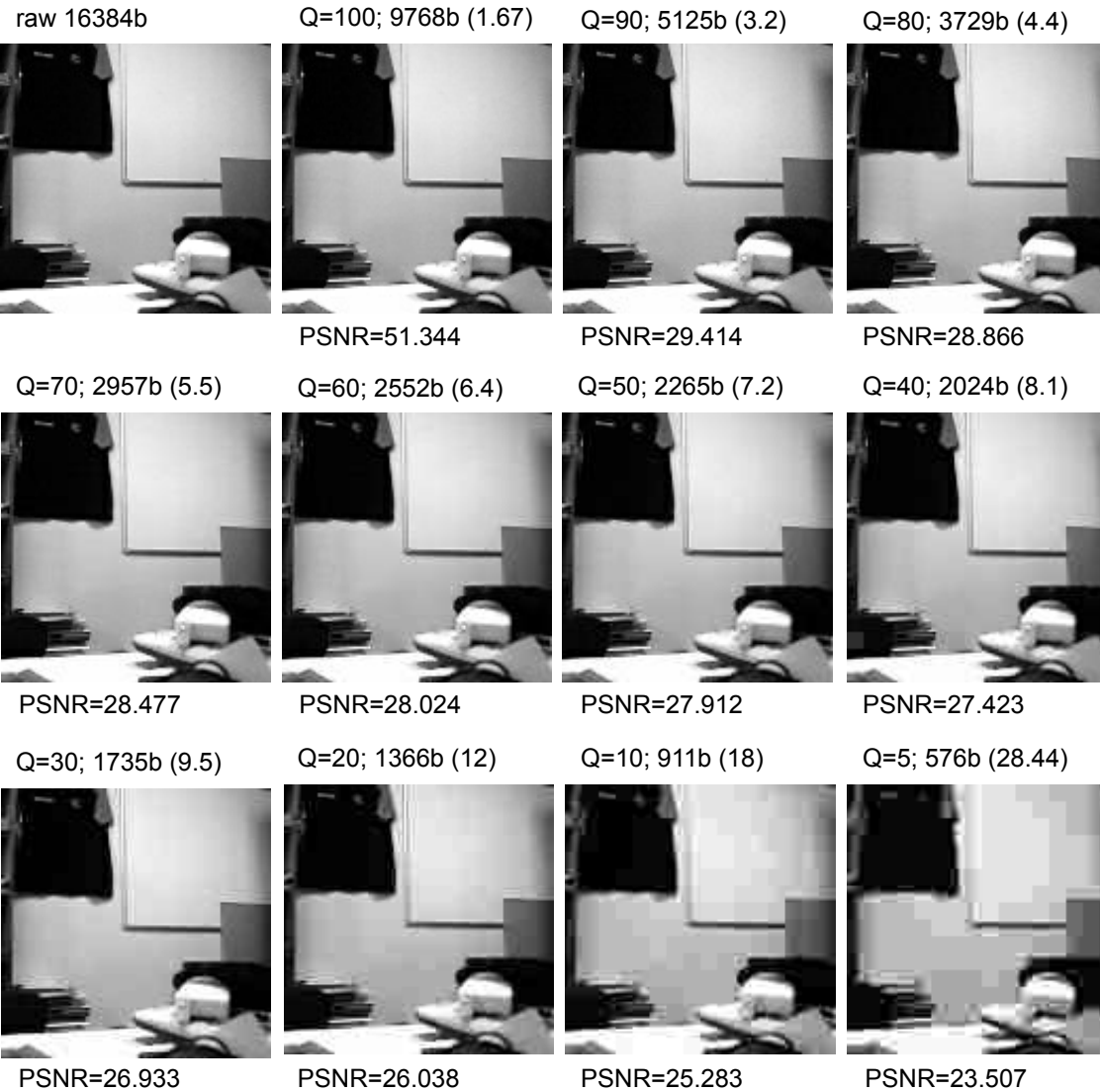
PACKET LOSS-TOLERANT BIT STREAM, ANY RECEPTION ORDER

10-15kms in LOS, in 1-hop

Q=50; 10% pkt losses   Q=50; 20% pkt losses   Q=50; 30% pkt losses

Q=50; 40% pkt losses   Q=50; 50% pkt losses   Q=50; 60% pkt losses

14
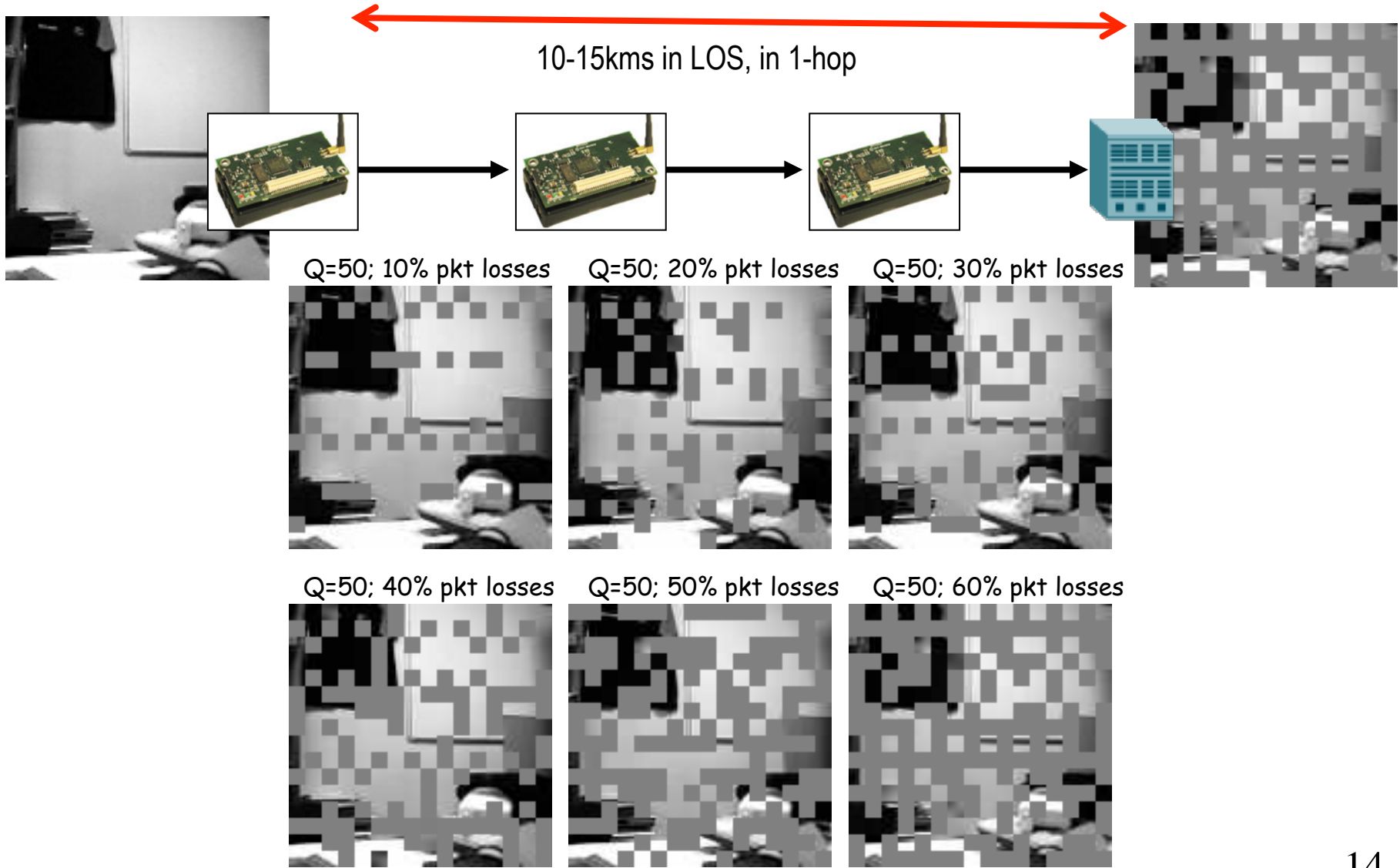
LOW-COST GATEWAY

Moisture/ Temperature of storage areas

10-15kms
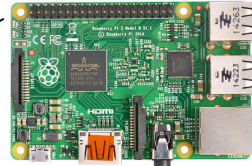
We can use all model of Raspberry. The most important usefull feature is the Ethernet interface for easy Internet connection. Then WiFi and Bluetooth can be added with USB dongles. RPI3 provides built-in Ethernet, WiFi and Bluetooth!

Less than 50€

Out-of-the-box !
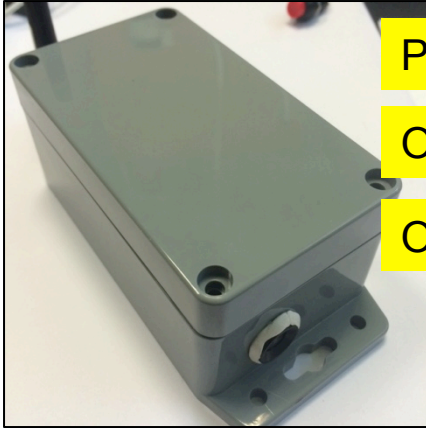
Periodic

On-demand

On event

Single camera
addr is 0x0001

3 cameras
addr is 0x0002
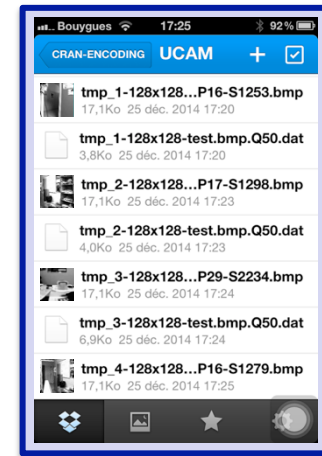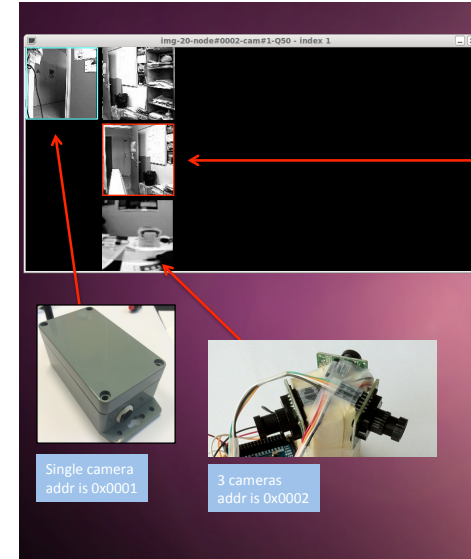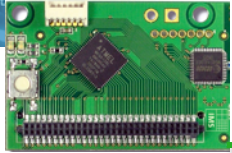
Versatile gateway

Can push raw data on clouds

Can locally decode & push image on clouds

Can locally decode & store

Kept as simple as possible

high-level lang. e.g. python

Most of user or application specific logics is done here! We provide some basic features, up to you to enhance them

radio bridge program

`stdout`

`stdin`

post processing

`stdout`

mongoDB

mongoDB

PHP

jQuery

Wi Fi
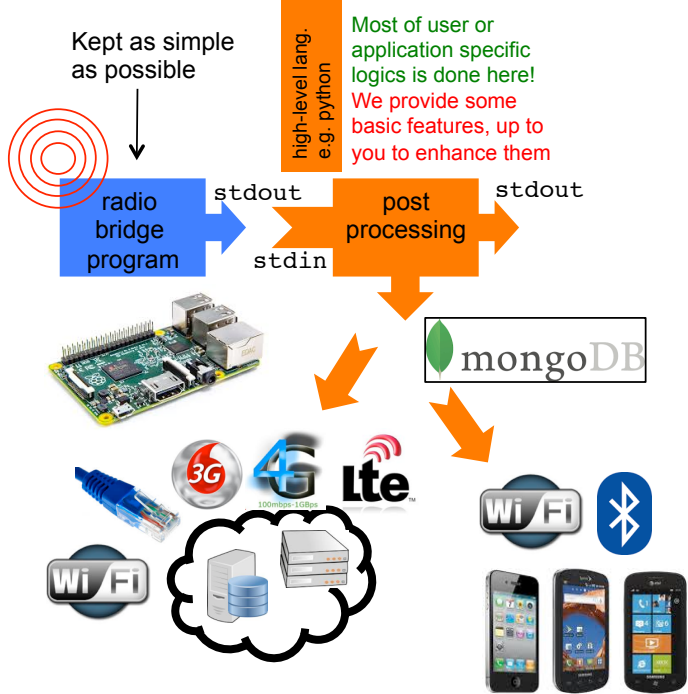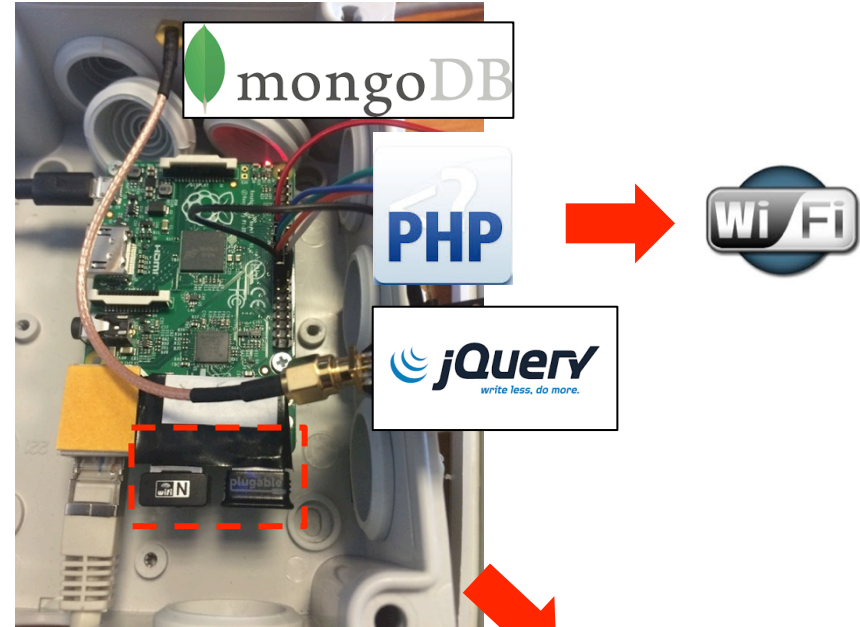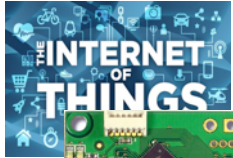
Image encoding performances

Quality Factor Q	96MHz		72MHz		48MHz		24MHz		MSS=240	
									N	S
	encode	packetiza	encode	packetiza	encode	packetiza	encode	packetization time	number of packets	size in bytes (compression ratio)
100								813	47	9982 (1.64)
90								322	23	5090 (3.21)
80								218	16	3595 (4.55)
70	raw 16384b		Q=20; 1366b(12) 6 pkts		Q=10; 911b(18) 4 pkts			178	13	2842 (5.76)
60								162	11	2461 (6.65)
50								150	10	2129 (7.69)
40								139	9	1898 (8.63)
30	224	33	260	44	345	64	637	127	7	1608 (10.19)
20	223	31	260	39	345	58	636	115	6	1279 (12.81)
10	223	26	260	31	345	50	636	99	4	824 (19.88)
5	223	23	259	31	344	45	635	89	3	503 (32.57)

❑ Capturing an image and encoding it roughly take 2.3s
- ❑ Time to sync & config ucam is about 400ms
- ❑ Time to read raw image data from ucam is 1512ms
- ❑ Time for encoding and packetization is about 300ms

19

Teensy 3.2
sync cam, config cam,
read, encode, packetization

Global sync, config, read, encode
consumption is about 1.254 J
about 2.3s

251.42 mJ/s

Led 500ms

Sync cam 127.31 mJ

Led 200ms

Config cam 127.31 mJ

Led 100ms

871.03 mJ

Led 100ms

128.46 mJ

Encode

Led 100ms

Baseline
consumption

E

Read data

Baseline
consumption
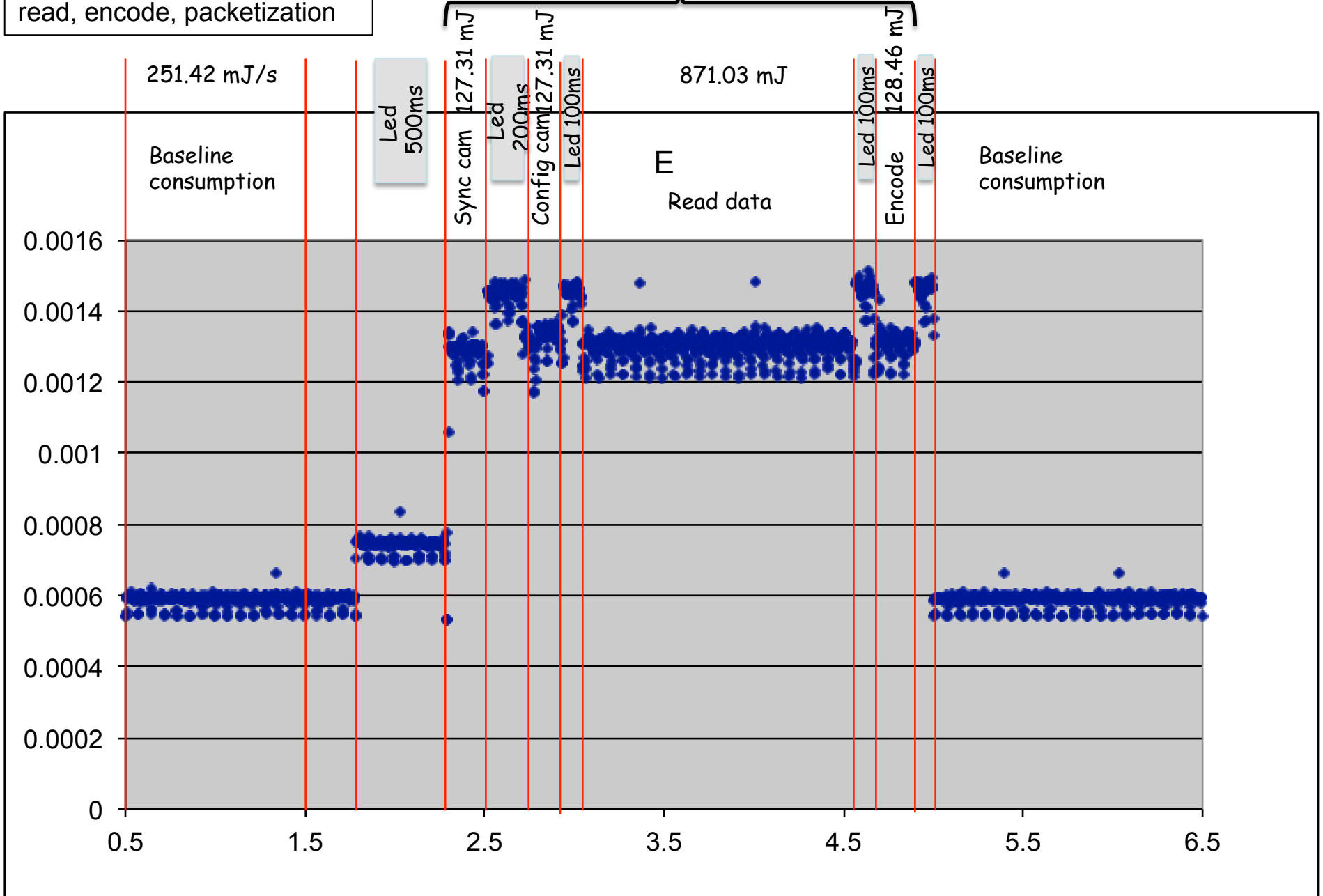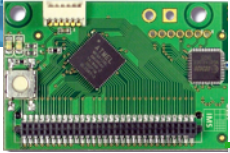
Power consumption

	baseline (mJ/s)	baseline, hibernate (mJ/s)	read (mJ)	encode (mJ)	Read+encode (mJ)
96MHz	251.42	0.834	871.03	128.46	999.49
72MHz	219.54	0.834	834.97	143.58	978.55
48MHz	211.19	0.834	813.30	185.58	998.88
24MHz	160.95	0.834	719.09	302.48	1021.57

❑ Using the nominal 72MHz mode minimizes consumption

❑ Hibernate mode when idle consumes about 167uA

❑ When transmitting the board consumes about 68mA

❑ Assuming
  ❑ 1 image/hour (2s)
  ❑ Image encoding with Q=10 (300ms)
  ❑ Transmission of 4 packets (8s)

❑ Then can run for 268 days on 4 AA batteries

21

Unlicensed 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

- ❏ Time-on-Air (ToA) is the constraint

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
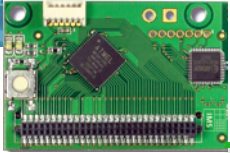
Time-on-Air of Image transmissions

| 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

Q=10; 911b(18)
4 pkts
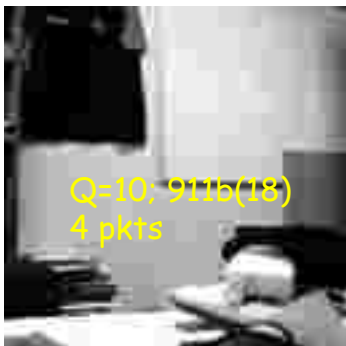
Image encoded at low quality: 16384b down to 911b (ratio 18).

Will generate 4 pkts using 250 max payload

4*9.15= 36.6s

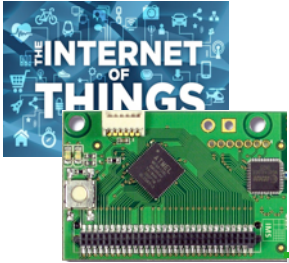**4*1.96 = 7.84s**

23
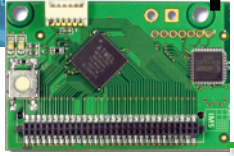
THINGS WE ARE DOING FOR RESEARCH

❑ To leverage the « single » connection gateway approach

   ❑ Smarter radio channel access mechanism

❑ To handle larger amount of data (image)

   ❑ Quality of Service mechanism

   ❑ Activity sharing mechanism

❑ The ad-hoc LoRa framework can be used to set-up your own LoRa test-bed for implementing advanced mechanisms

24

TEST ADVANCED CHANNEL ACCESS

❑ Implement & test channel access methods

    ❑ SIFS=xCAD; DIFS=3SIFS; set x with /@CADONx#

    ❑ Use background traffic generator devices

    ❑ /@T2000# or /@TR5000#
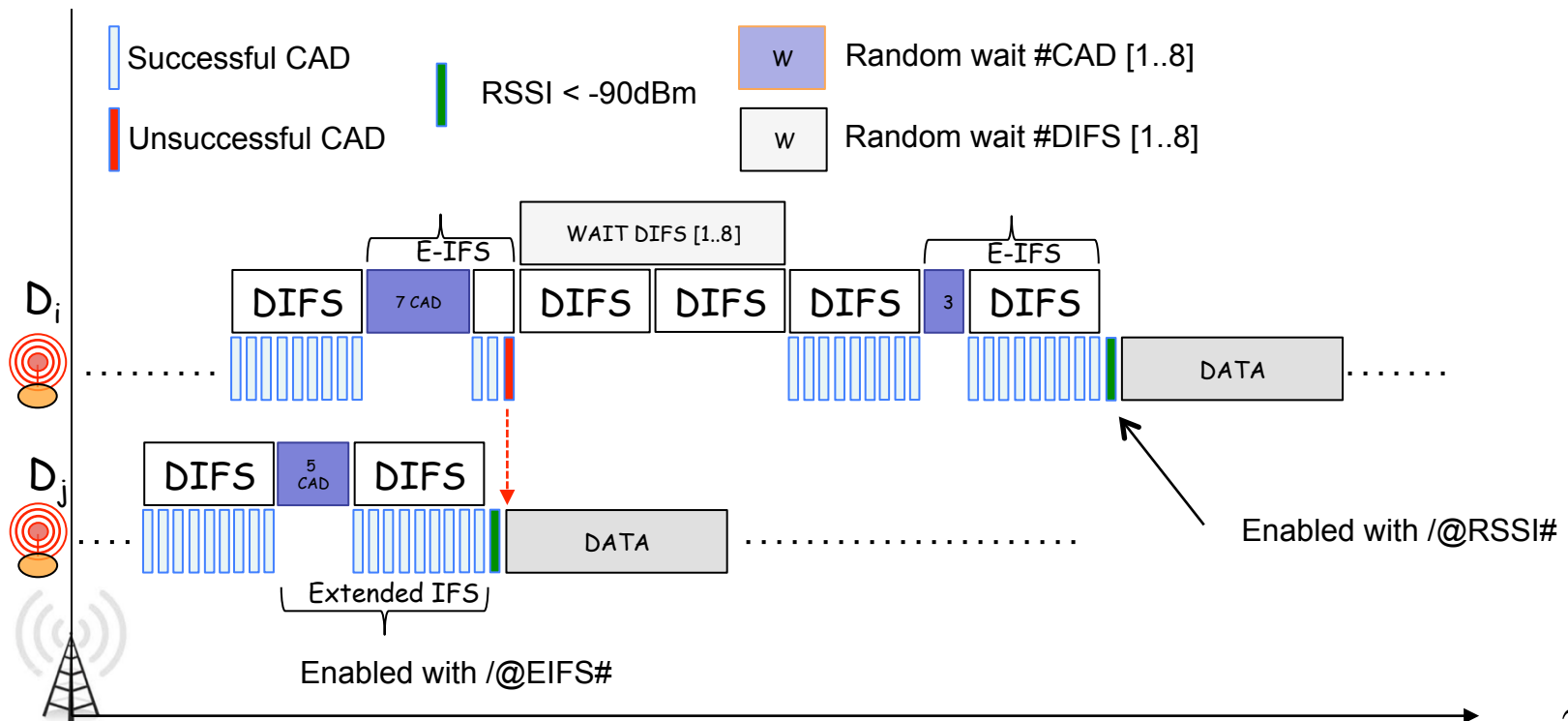
Long-range Activity Sharing (LAS)

$$G_{AT} = \sum_{i=1}^{n} l^i_{RAT0}$$

n=10

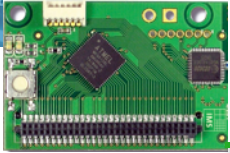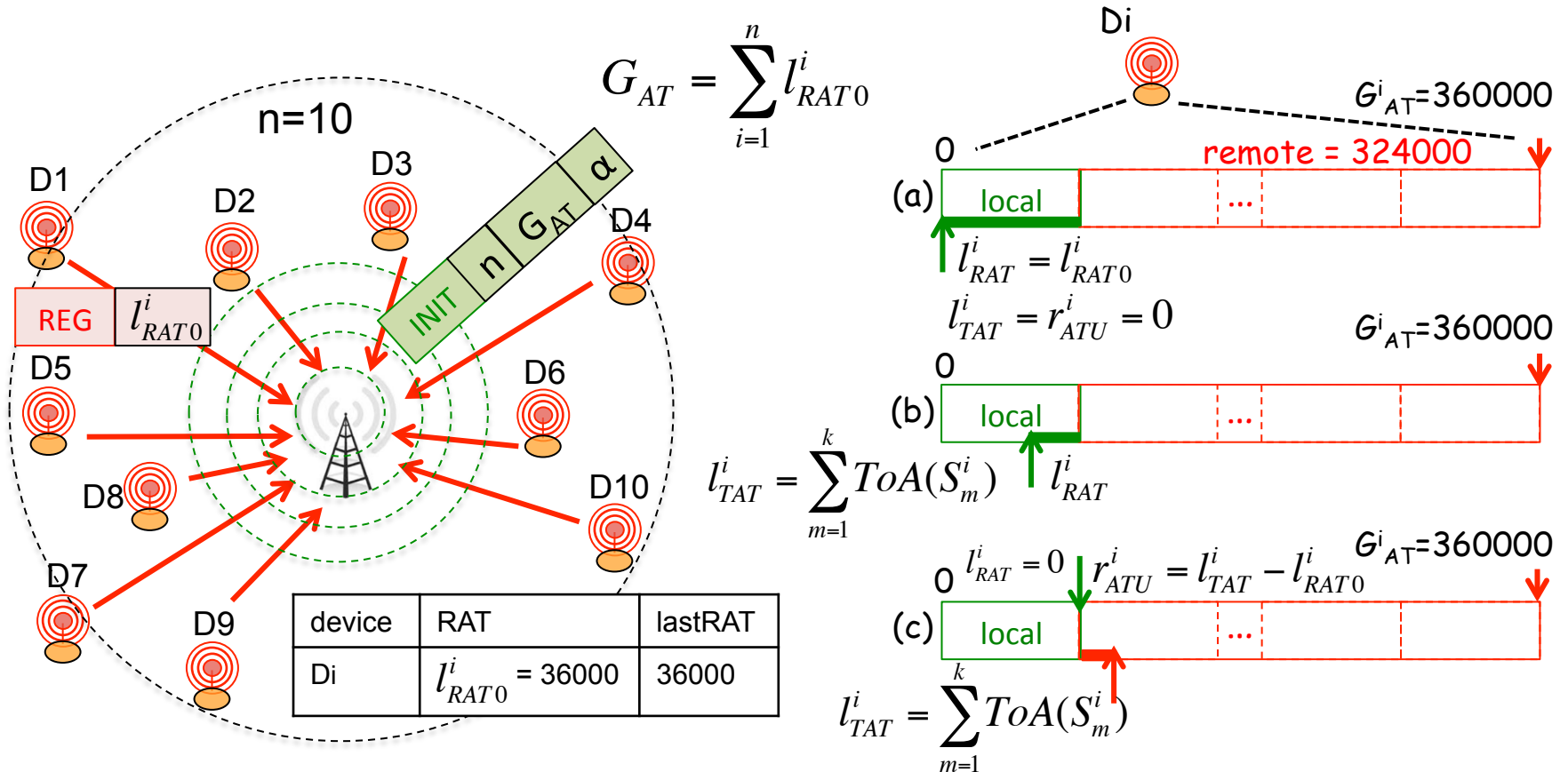D1 D2 D3 D4 D5 D6 D7 D8 D9 D10

REG l^i_{RAT0}

INIT | n | G_{AT} | α

device	RAT	lastRAT
Di	l^i_{RAT0} = 36000	36000

$$l^i_{TAT} = \sum_{m=1}^{k} ToA(S^i_m)$$ l^i_{RAT}

$$l^i_{TAT} = \sum_{m=1}^{k} ToA(S^i_m)$$

Di

G^i_{AT}=360000

remote = 324000

(a) local ...

$l^i_{RAT} = l^i_{RAT0}$

$l^i_{TAT} = r^i_{ATU} = 0$

G^i_{AT}=360000

(b) local ...
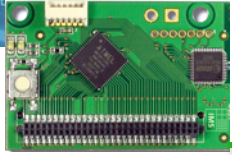
$l^i_{RAT} = 0$ | $r^i_{ATU} = l^i_{TAT} - l^i_{RAT0}$ | G^i_{AT}=360000

(c) local ...

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

26

Conclusions

- ❑ Low-cost, long-range image sensor with efficient packet loss-tolerant encoding
- ❑ Low-power: about 115mA when capturing and encoding (2s)
- ❑ Runs out-of-the box for periodic image or surveillance tasks based on image change detection
- ❑ A complete image cycle is about 10s
- ❑ DIY with off-the-shelves components for maximum product availability and technology appropriation/customization

Thanks.
Let's keep in touch

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