2018 IEEE Middle East & North Africa COMMunications Conference

IEEE MENACOMM 2018

Enabling and deploying long-range IoT image sensors with LoRa technology

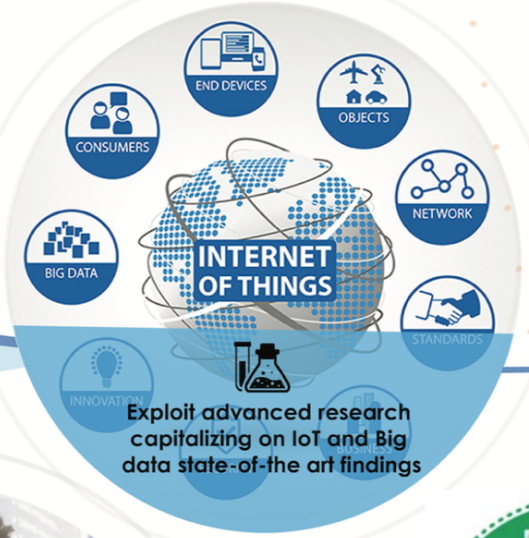
Congduc PHAM, University of Pau, France

April 18-20, 2018

WAZIUP Open IoT and Big data platform for Africans, by Africans

HORIZON 2020

Affordable technologies to empower rural economics



Exploit advanced research capitalizing on IoT and Big data state-of-the art findings

Develop IoT solutions and applications meeting African needs

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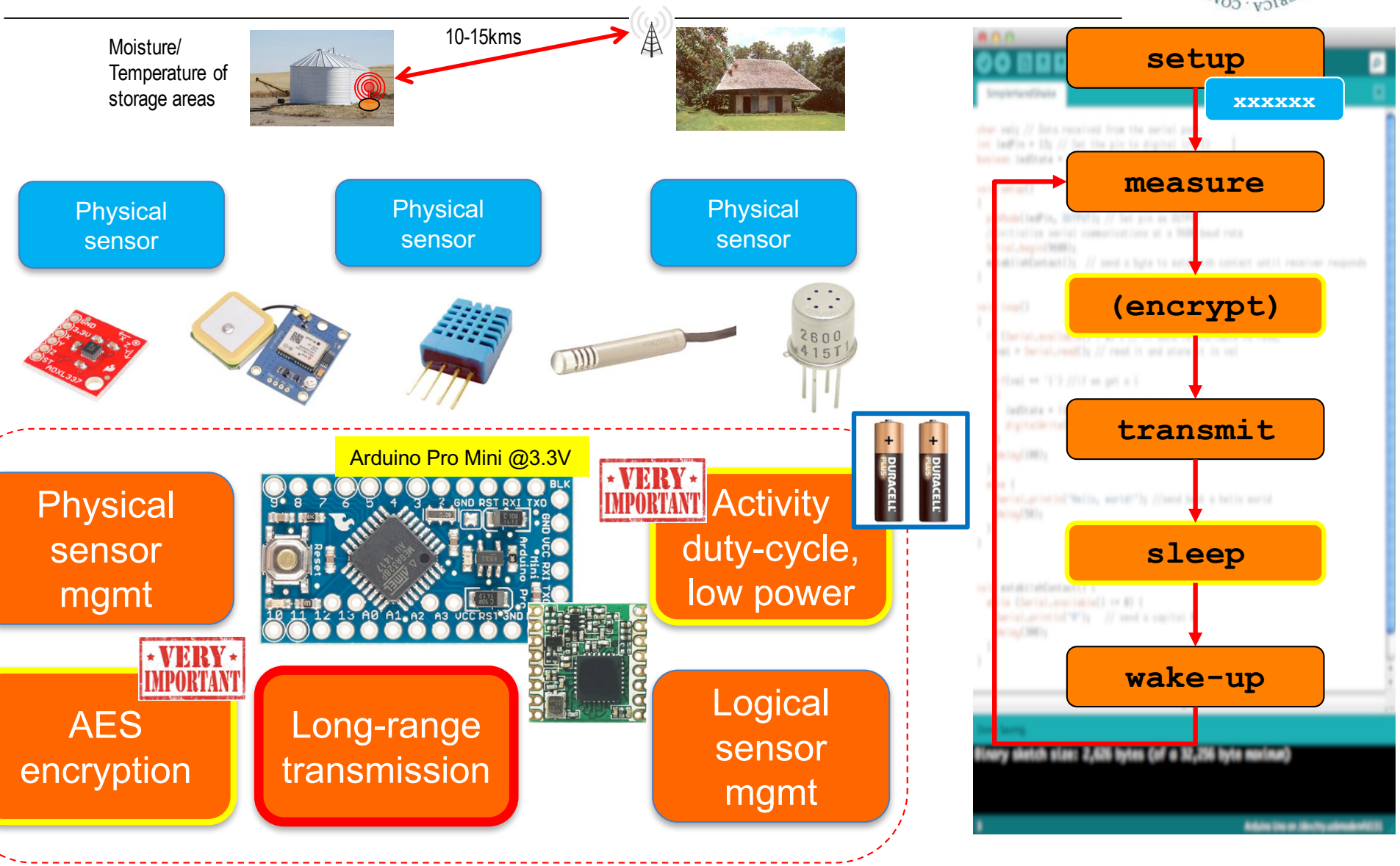
Generic low-cost IoT device



From generic to specific applications

LARGE MESSAGES

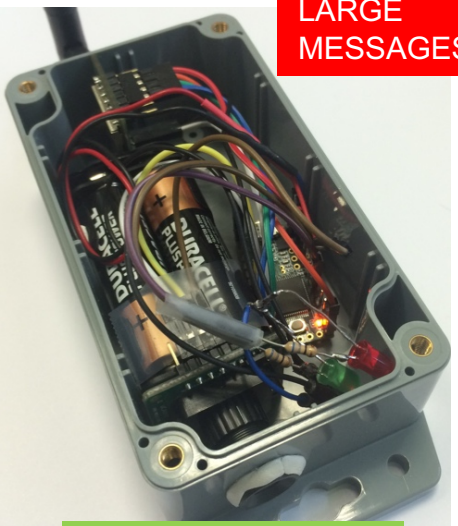
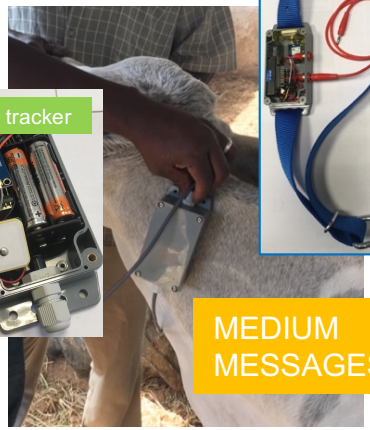
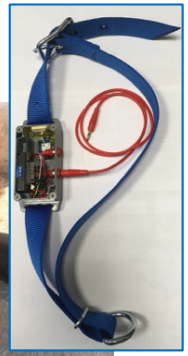


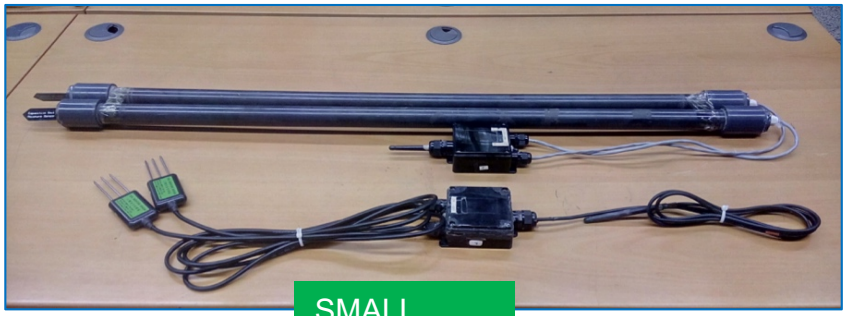
Image sensors



GPS tracker



MEDIUM MESSAGES



SMALL MESSAGES

Soil moisture

Bin presented at Woelab

SMALL MESSAGES

Waste Mngt

MEDIUM MESSAGES

Photo from EGM

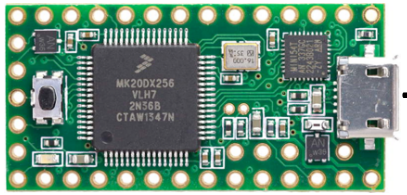
Buoy for water quality

MEDIUM MESSAGES

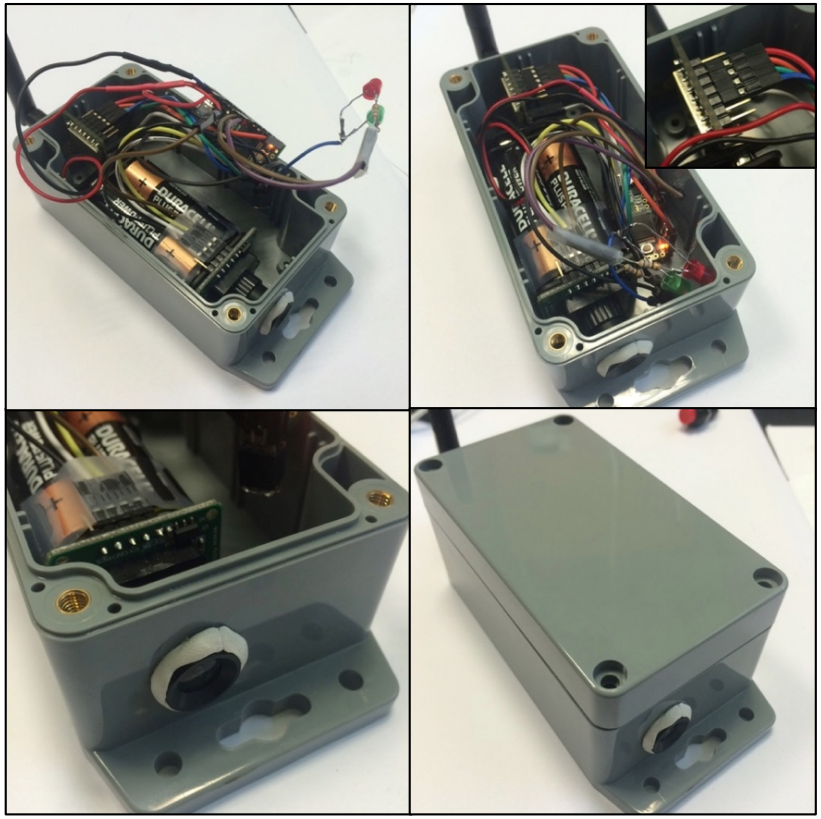
Photo from Unparallel

Weather Station

Image sensor device

➢ Teensy32 

+ uCamII/III 



56° lens

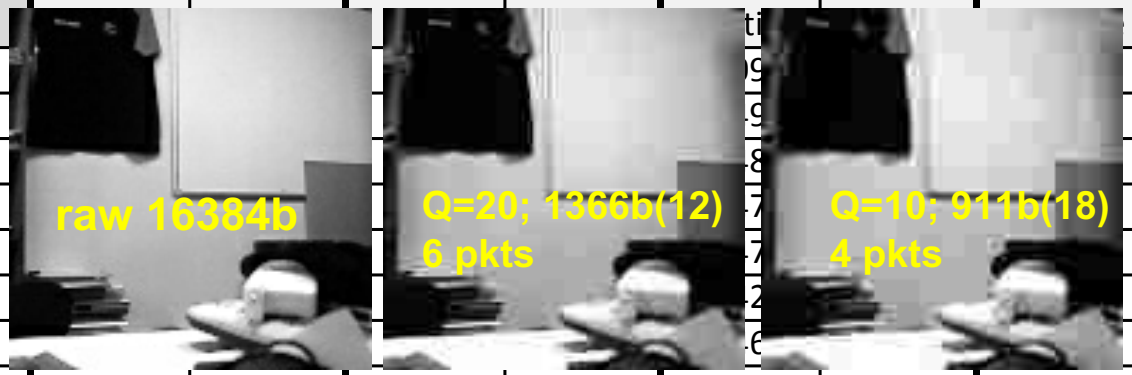
76° lens

116° lens

The uCam is shipped with a 56° angle of view lens but 76° and 116° lenses are also available for various application needs.

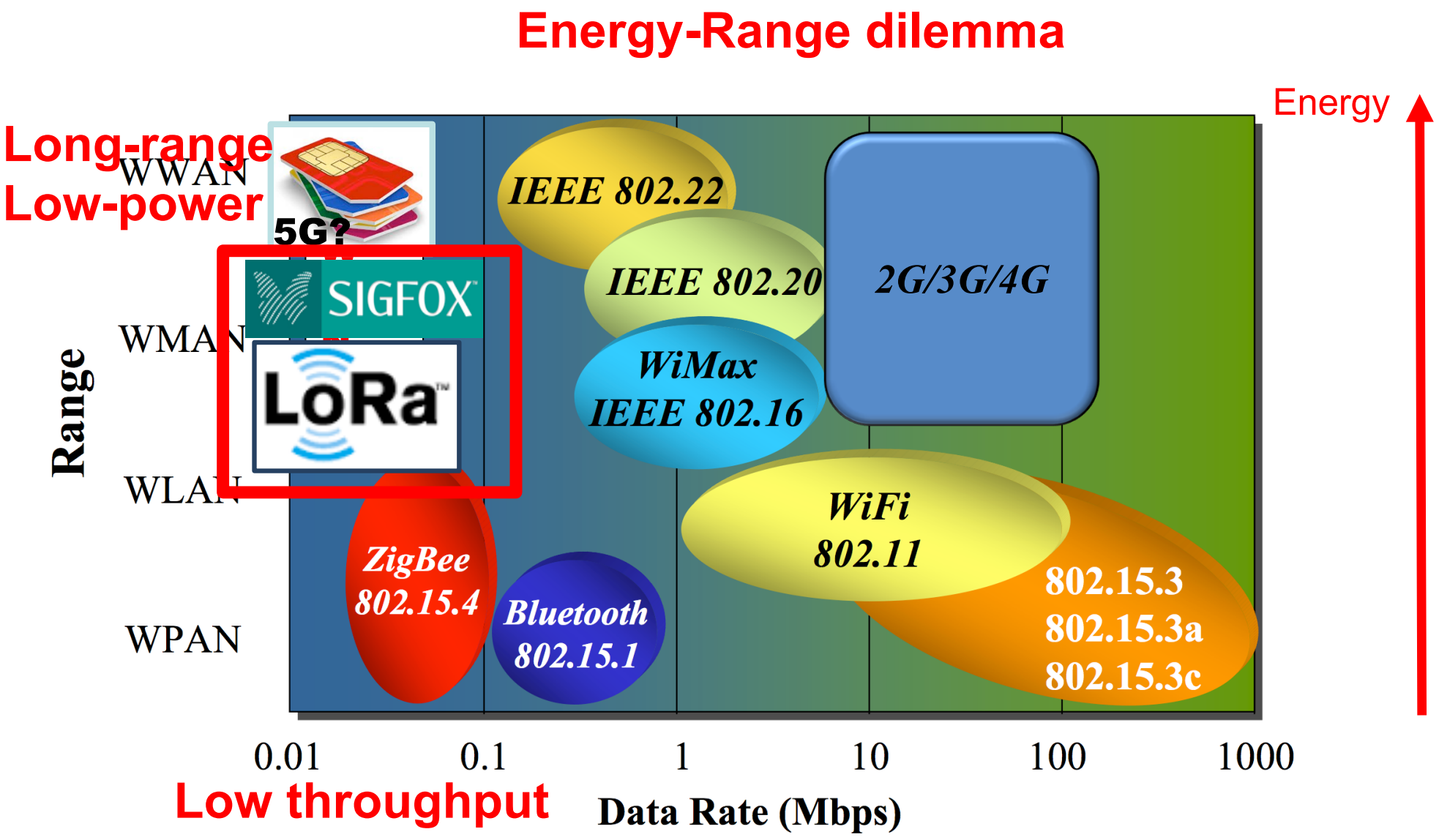
Image encoding performances, Q=10 & 20

	96MHz		72MHz		48MHz		24MHz		MSS=240 N	MSS=240 S
Quality Factor Q	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								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)



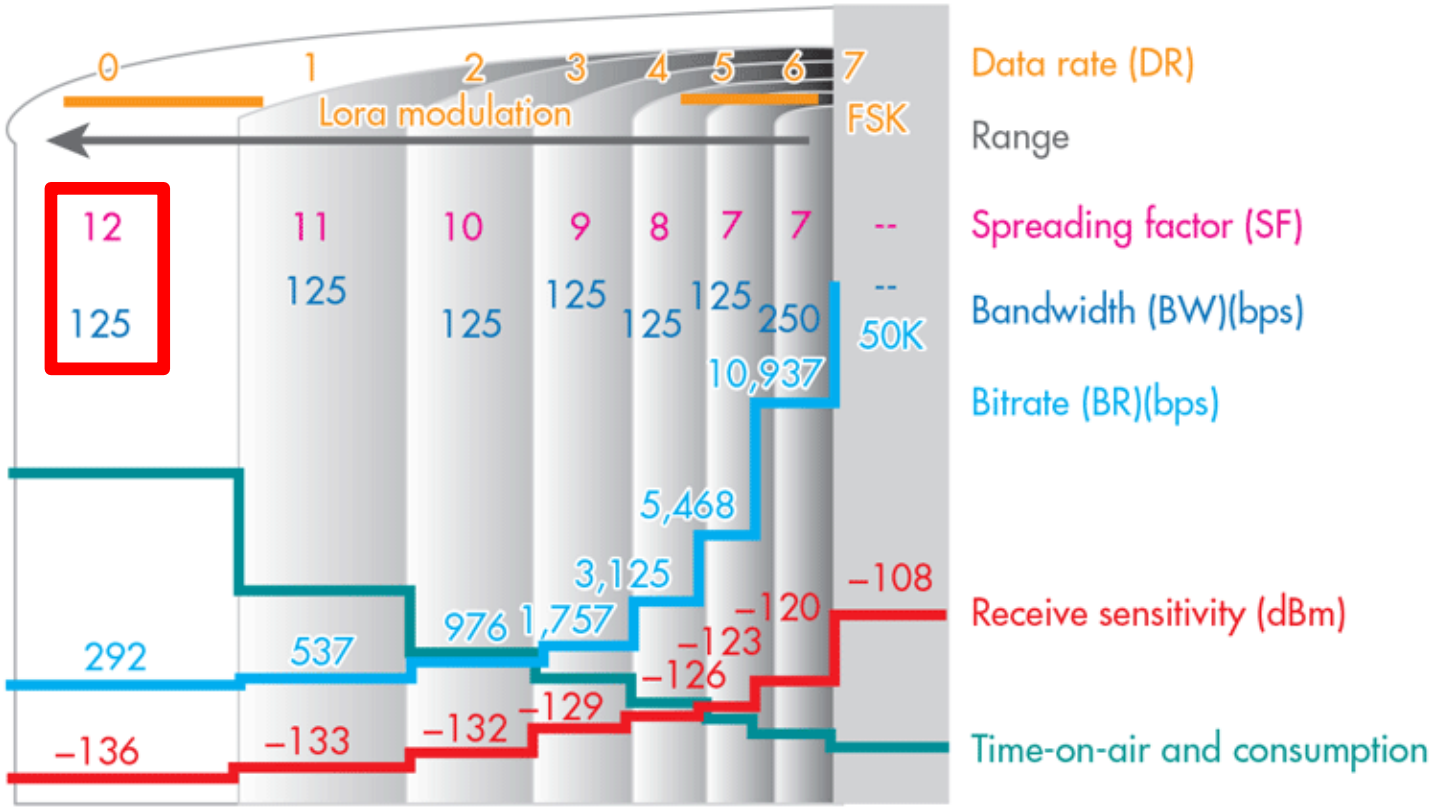
- Capturing an image and encoding it roughly take 2.3s
  - Time to sync & config ucam is about 400ms
  - Time to read raw image data from ucam is 1512ms
  - Time of compare with reference image is neglectible
  - Time for encoding and packetization is about 300ms

Low-power & long-range radio technologies



Main LoRa parameters

- Main parameters
  - Bandwidth: 62.5kHz, 125kHz, 250kHz, 500kHz
  - Spreading factor: 6 to 12

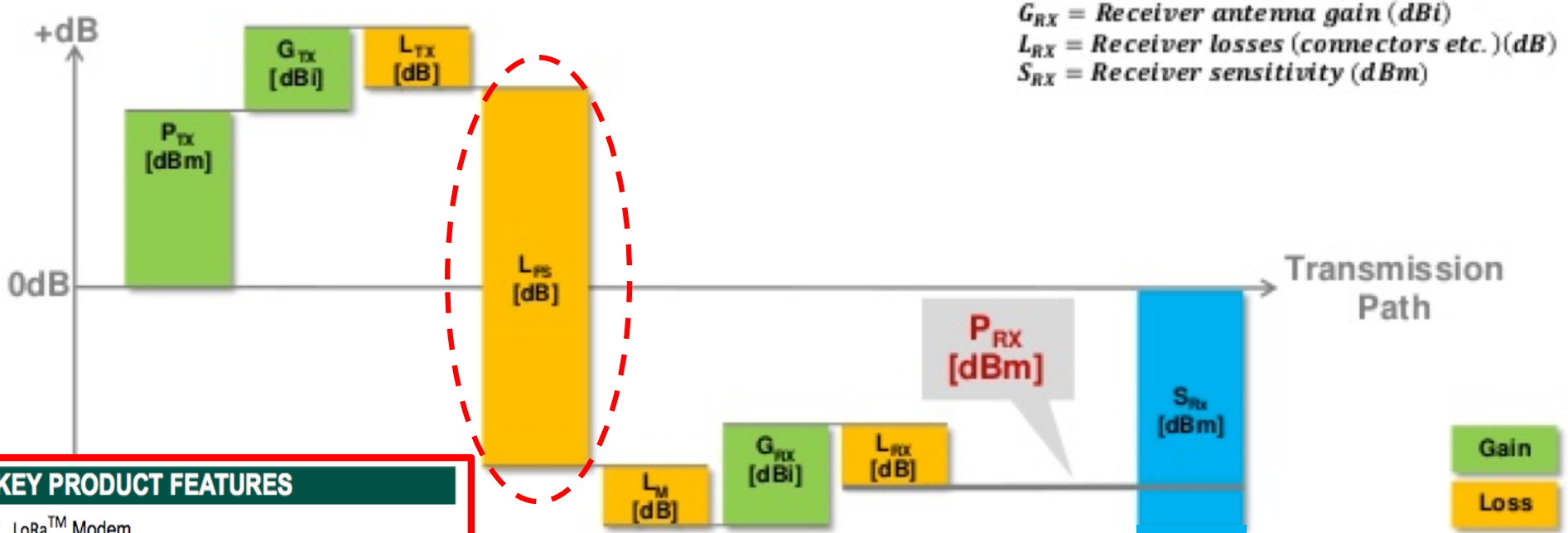


Link budget of LPWAN

$$P_{RX} = P_{TX} + G_{TX} - L_{TX} - L_{FS} - L_M + G_{RX} - L_{RX}$$

From Peter R. Egli, INDIGOO.COM

P_{RX} = Received power (dBm)
P_{TX} = Sender output power (dBm)
G_{TX} = Sender antenna gain (dBi)
L_{TX} = Sender losses (connectors etc.)(dB)
L_{FS} = Free space loss (dB)
L_M = Misc. losses (multipath etc.)(dB)
G_{RX} = Receiver antenna gain (dBi)
L_{RX} = Receiver losses (connectors etc.)(dB)
S_{RX} = Receiver sensitivity (dBm)



KEY PRODUCT FEATURES

- LoRa™ Modem
- 157 dB maximum link budget
- +20 dBm at 100 mW constant RF output vs. V supply
- +14 dBm high efficiency PA
- Programmable bit rate up to 300 kbps
- High sensitivity: down to -137 dBm

The price to pay!

Very low throughput

Transmission time can be several seconds

Range ⟷ Throughput

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	max thr. for 255B in bps
1	125	4/5	12	0.95846	2.59686	4.23526	5.87366	7.51206	9.15046	223
2	250	4/5	12	0.47923	1.21651	1.87187	2.52723	3.26451	3.91987	520
3	125	4/5	10	0.28058	0.69018	1.09978	1.50938	1.91898	2.32858	876
4	500	4/5	12	0.23962	0.60826	0.93594	1.26362	1.63226	1.95994	1041
5	250	4/5	10	0.14029	0.34509	0.54989	0.75469	0.95949	1.16429	1752
6	500	4/5	11	0.11981	0.30413	0.50893	0.69325	0.87757	1.06189	1921
7	250	4/5	9	0.07014	0.18278	0.29542	0.40806	0.5207	0.63334	3221
8	500	4/5	9	0.03507	0.09139	0.14771	0.20403	0.26035	0.31667	6442
9	500	4/5	8	0.01754	0.05082	0.08154	0.11482	0.14554	0.17882	11408
10	500	4/5	7	0.00877	0.02797	0.04589	0.06381	0.08301	0.10093	20212

Issue #1: channel access

- LoRa networks will get densier with a large variety of devices and data traffic profiles

  - Traditional simple sensor ➔small messages
  - Traditional multi-sensor ➔ medium messages
  - Innovative image sensors ➔ large messages ➔ Time on Air can be of several seconds!

			time on air in second for payload size of						
LoRa mode	BW (kHz)	SF	5 bytes	55 bytes	105 bytes	155 Bytes	205 Bytes	255 Bytes	max thoughput in bps
1	125	12	0.9585	2.5969	4.2353	5.8737	7.5121	9.1505	223
2	250	12	0.4792	1.2165	1.8719	2.5272	3.2645	3.9199	520
3	125	10	0.2806	0.6902	1.0998	1.5094	1.919	2.3286	876
4	500	12	0.2396	0.6083	0.9359	1.2636	1.6323	1.9599	1041
5	250	10	0.1403	0.3451	0.5499	0.7547	0.9595	1.1643	1752
6	500	11	0.1198	0.3041	0.5089	0.6932	0.8776	1.0619	1921
7	250	9	0.0701	0.1828	0.2954	0.4081	0.5207	0.6333	3221
8	500	9	0.0351	0.0914	0.1477	0.204	0.2604	0.3167	6442
9	500	8	0.0175	0.0508	0.0815	0.1148	0.1455	0.1788	11408
10	500	7	0.0088	0.028	0.0459	0.0638	0.083	0.1009	20212

- Objectives are to reduce packet collisions, thus reducing delivery latency, and reduce power consumption due to unsuccessfull transmissions
- Current raw LoRa networks are mainly pure ALOHA systems
- Some LoRaWAN implementations proposes simple Listen-Before-Talk mechanism

Issue #2: Unlicensed sub-GHz spectrum constraints

- It is shared medium so long-range transmission in dense environments can create lots of interference!
- In Europe, 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

What if I want to transmit images?

				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

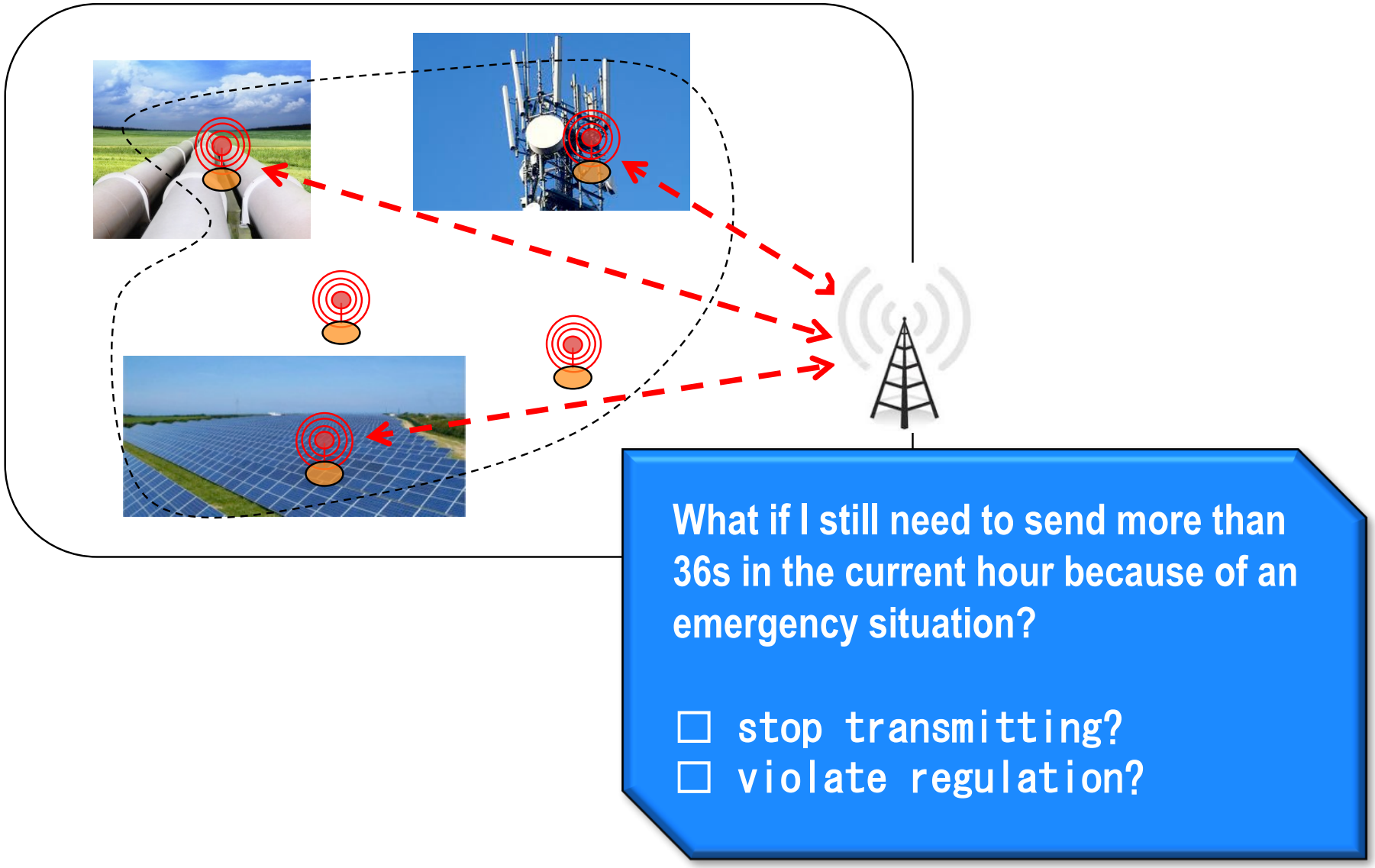
Optimized image encoding at medium quality: 16384B down to 824B (ratio >19).

Will generate 4 pkts using 250 max payload

3*9.15+3.41= 30.86s

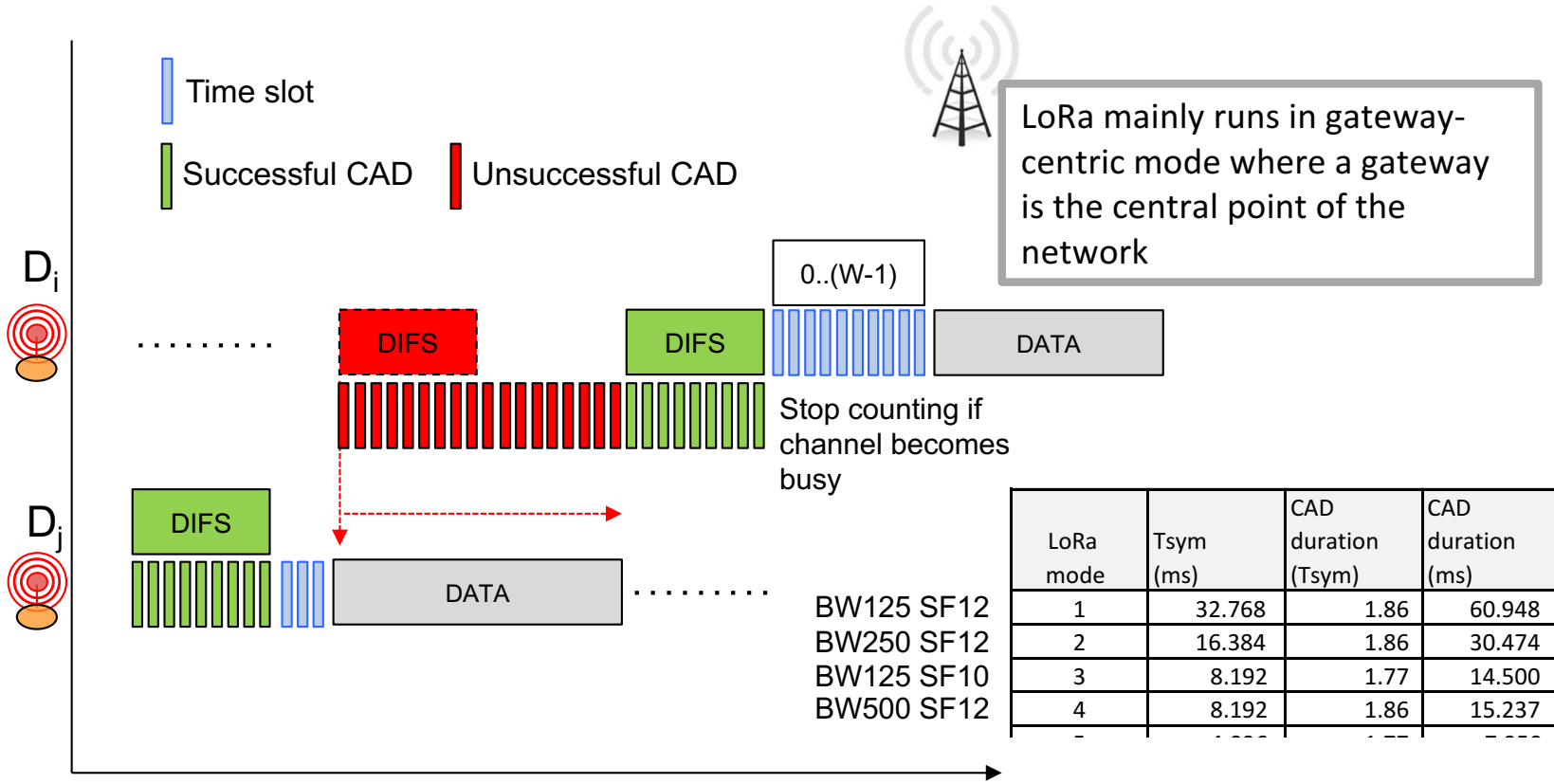
3*1.96+0.77 = 6.65s

Critical surveillance applications



LoRa CSMA derived from 802.11

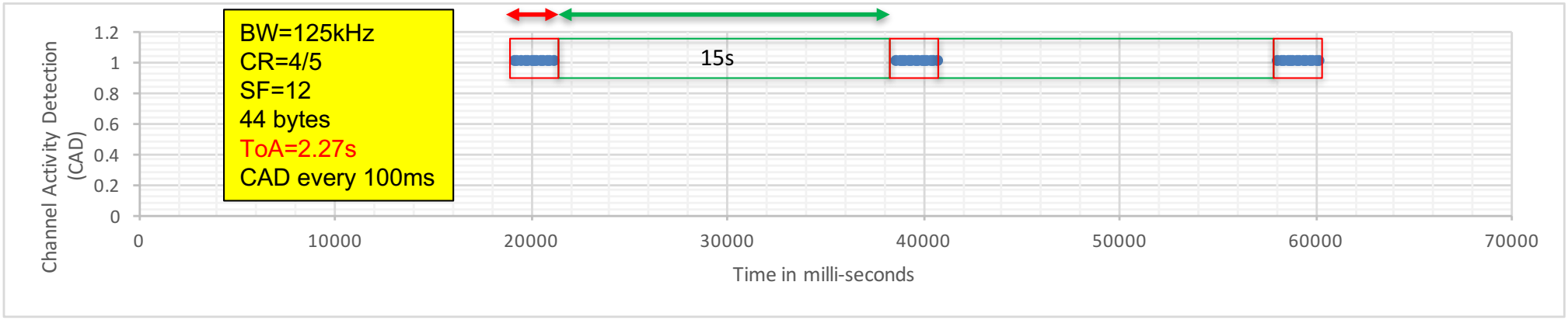
- CAD duration is between $1.75T_{sym}$ and $2.25T_{sym}$
- T_{sym} depends on bandwidth & spreading factor
- SIFS & DIFS are mapped to a number of CAD

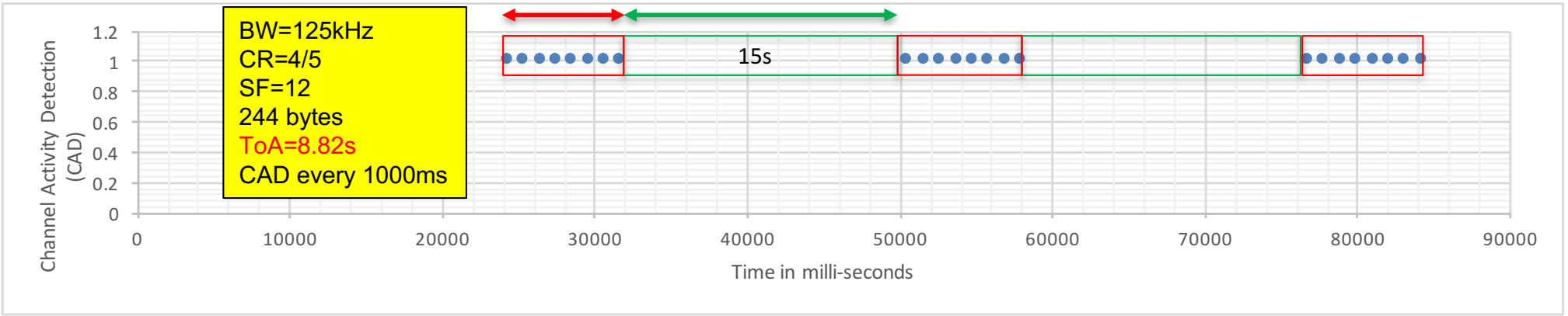


	LoRa mode	Tsym (ms)	CAD duration (Tsym)	CAD duration (ms)	Experimental measures min value	Experimental measures max value
BW125 SF12	1	32.768	1.86	60.948	60	62
BW250 SF12	2	16.384	1.86	30.474	29	31
BW125 SF10	3	8.192	1.77	14.500	14	16
BW500 SF12	4	8.192	1.86	15.237	15	16

Clear Channel Assessment with LoRa

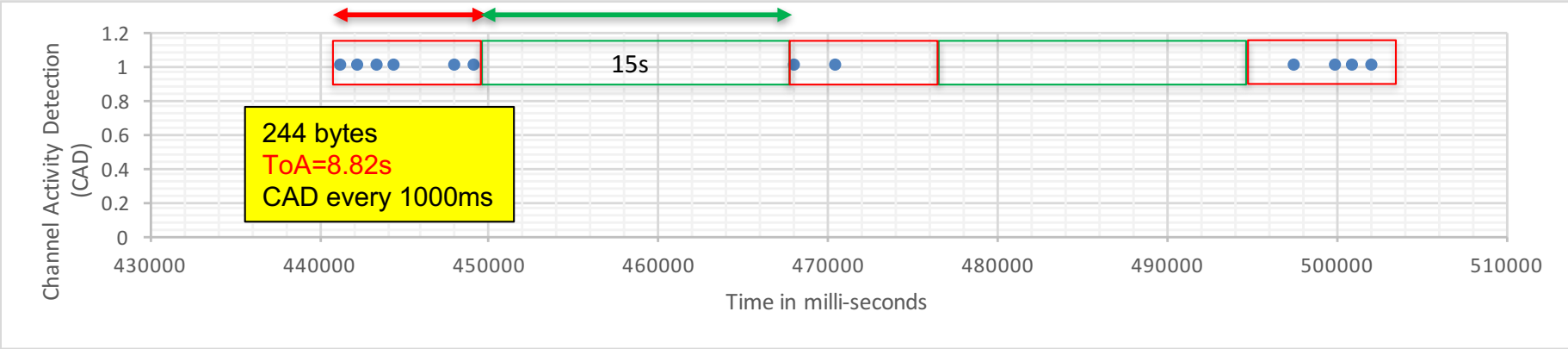
- CCA uses dedicated LoRa's Channel Activity Detection (CAD) as data reception can be done below the noise floor



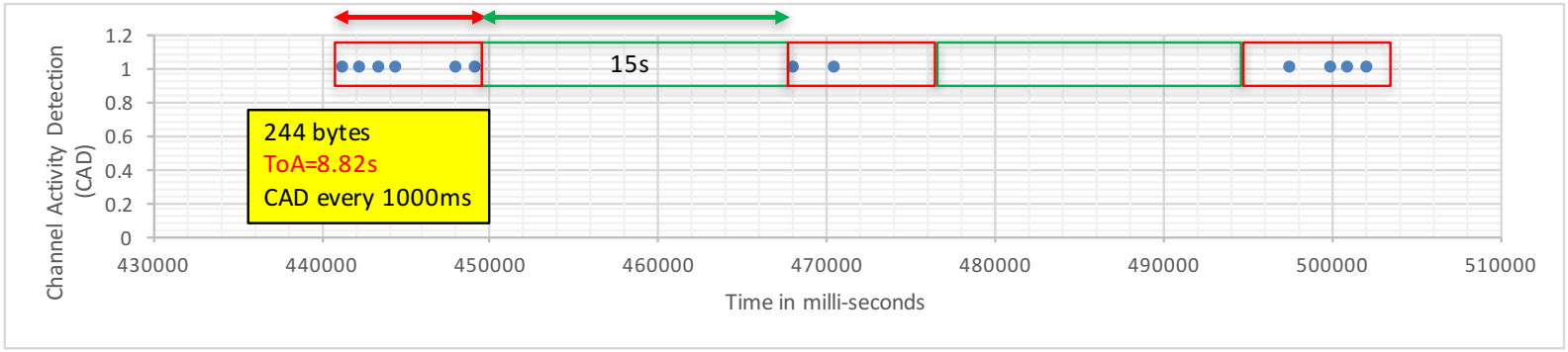


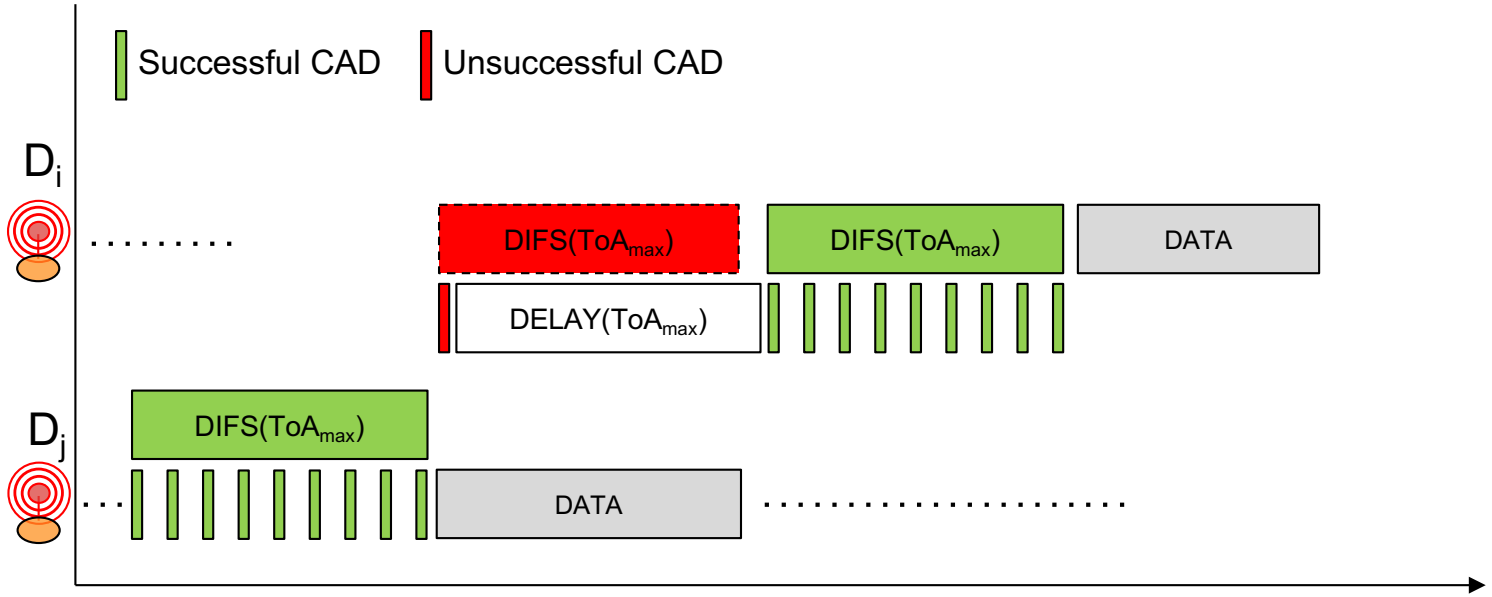
CAD reliability?

- CAD reliability decreases as distance increases
  - A CAD returning false does not mean that there is no activity!
- During a long transmission (i.e. several seconds), there is usually at least one CAD returning true

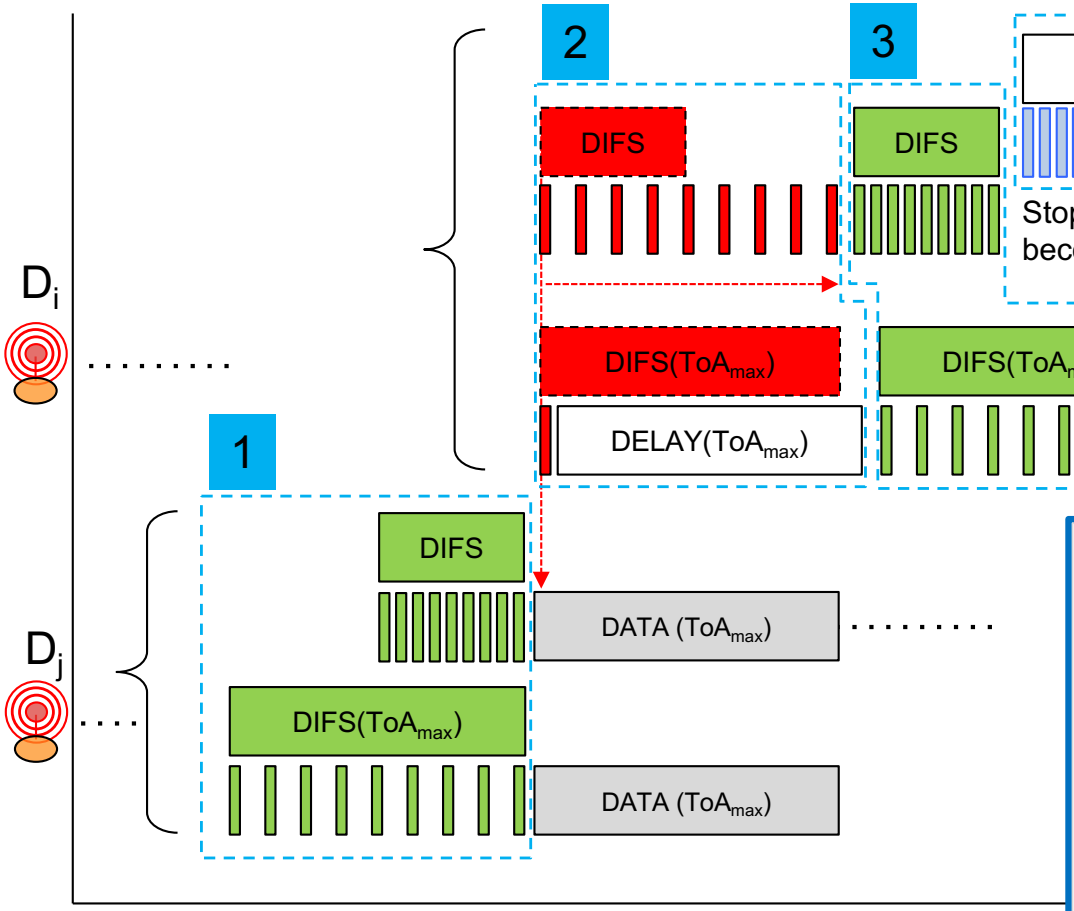


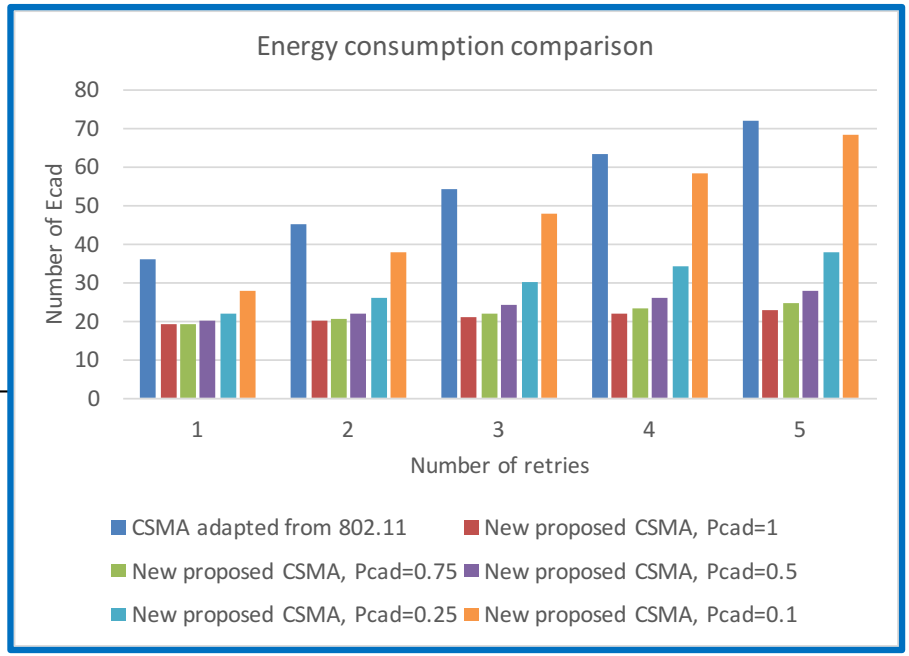
LoRa CSMA adapted to longer message





CSMA variants & comparison



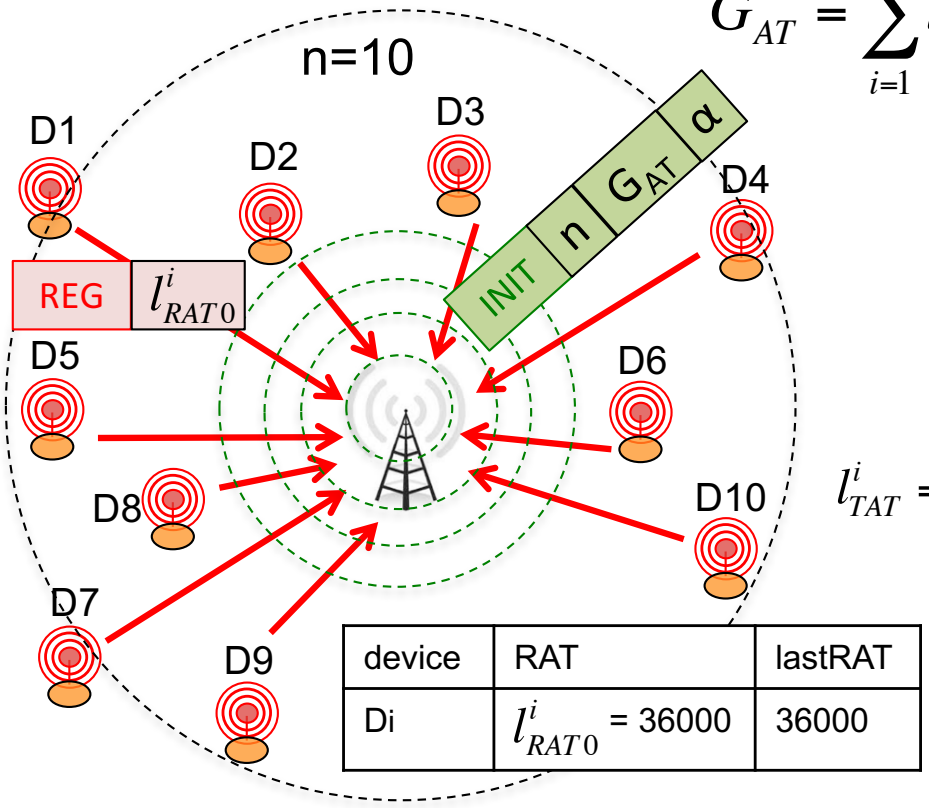


Select the CSMA variant

- Latency depends on maxToA, i.e. max packet length
- When maxToA is small (only traditional devices)
  - CSMA derived from 802.11 has lowest latency and is efficiently handling packet collisions
  - as maxToA is small, vulnerability time is small and…
  - …CAD reliability issue has little impact
- When maxToA is larger (e.g. image sensors)
  - CAD reliability is a concern
  - To improve robusteness, latency is directly linked to maxToA
  - **However, it is possible to decrease maxToA by not using the maximum packet size for image packet**
  - Overhead is 4 bytes per additional packet

				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	max thr. for 255B in bps
1	125	4/5	12	0.95846	2.59686	4.23526	5.87366	7.51206	9.15046	223
2	250	4/5	12	0.47923	1.21651	1.87187	2.52723	3.26451	3.91987	520

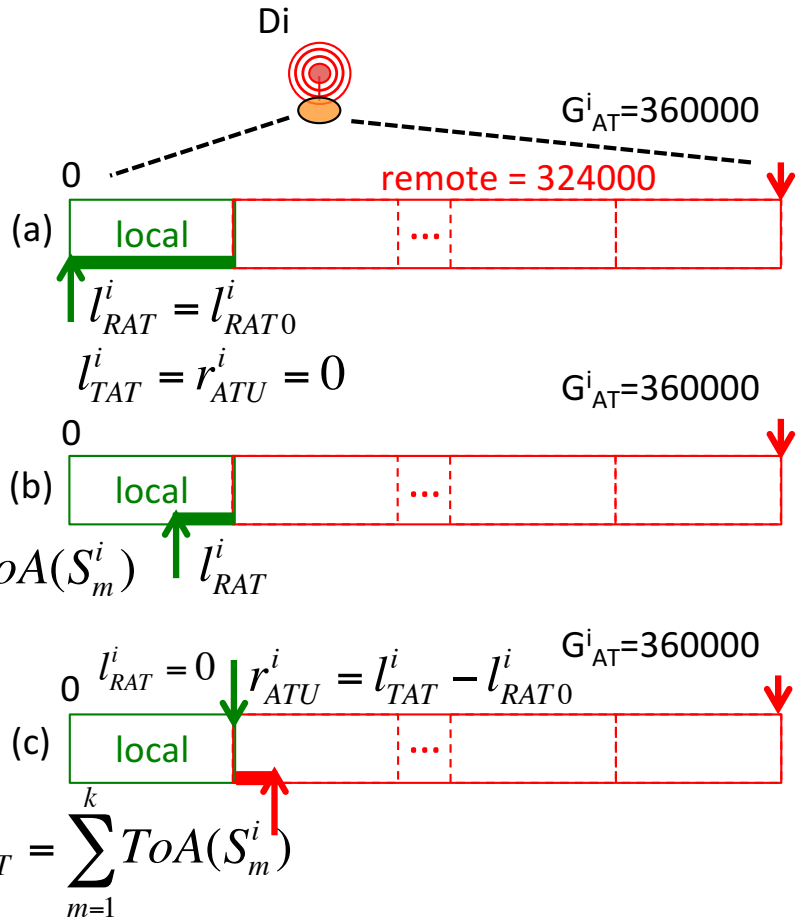
Long-range Activity Sharing (LAS)



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

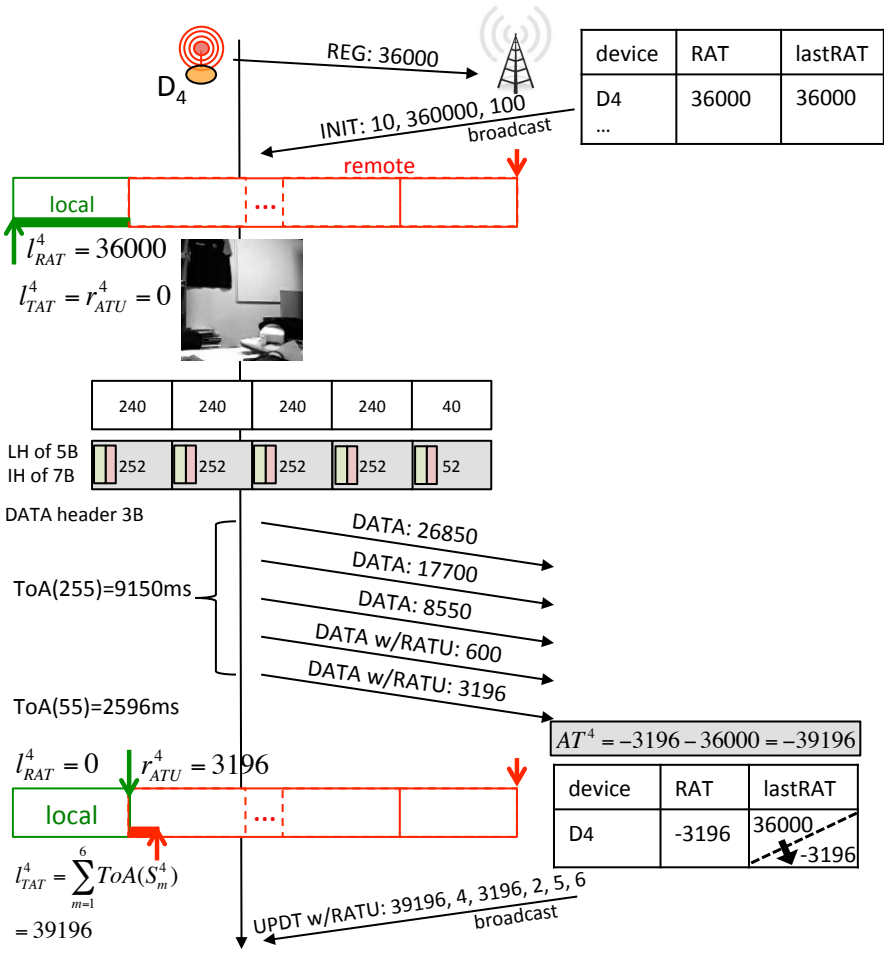
$$G_{AT} = \sum_{i=1}^{n} l^i_{RAT0}$$

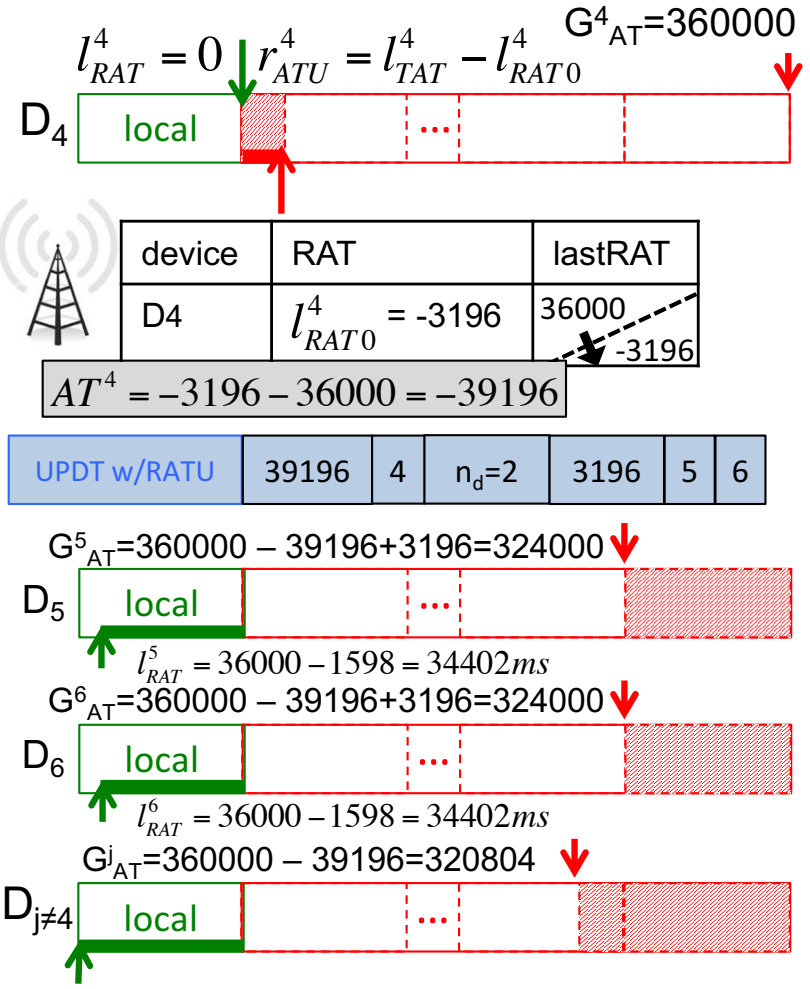
$$l^i_{TAT} = \sum_{m=1}^{k} ToA(S^i_m)$$



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

Distributing Remote Activity Time Usage



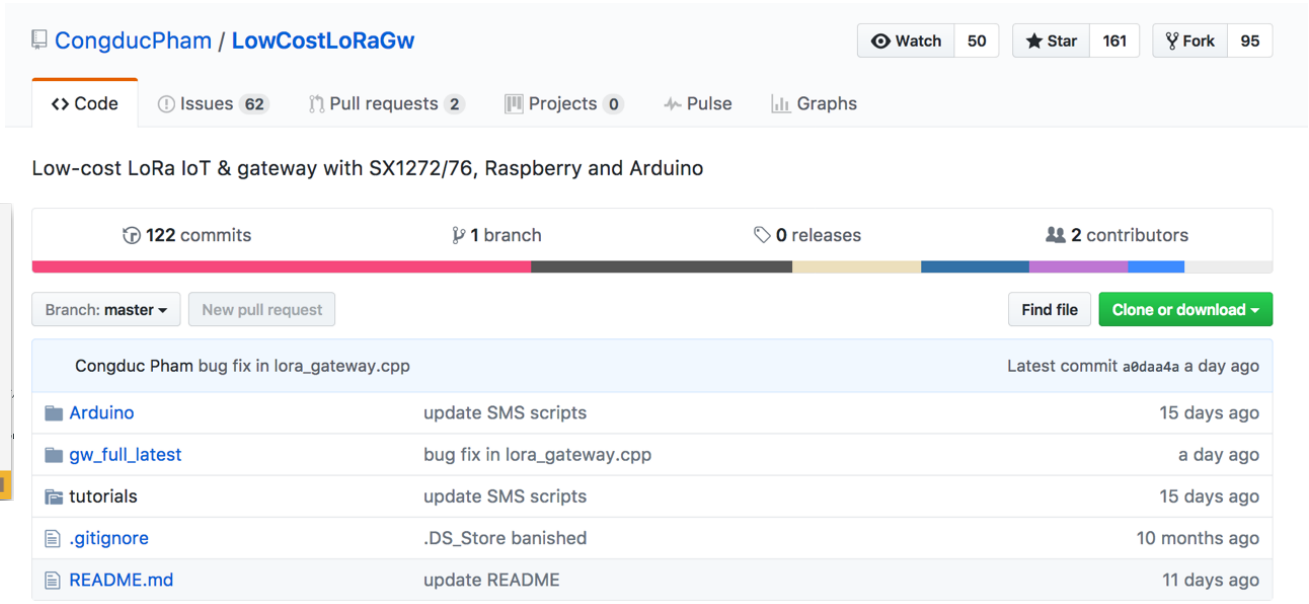


Other issues to take into account

- 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

Implemented in our IoT communication lib

- Image sensor code and tutorial available
- Communication lib runs on most of Arduino-compatible boards
- Support most of SPI-based LoRa radio modules



LowCostLoRaGw github has latest general distribution:
https://github.com/CongducPham/LowCostLoRaGw

Questions?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