How to better share the radio channel in LoRa LPWAN?

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PRIMA PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

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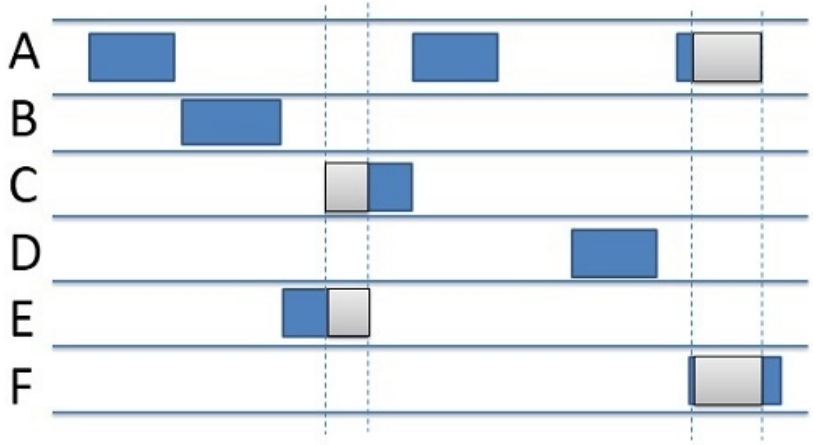
What MAC in LoRa networks?

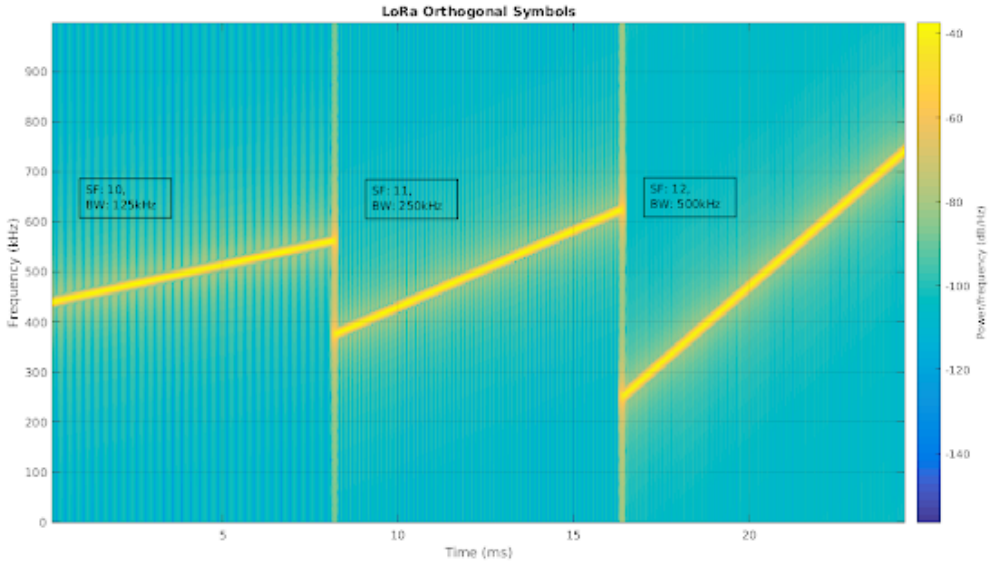
- LoRa networks are basically ALOHA system!



- So, if ALOHA efficiency is low, how can LoRa scalability be improved?

Low-level LoRa interference mitigation techniques

- Orthogonal "chirpyness"
- Different chirp rate can be achieved by different spreading factors and/or by different bandwidths
- LoRa symbols can by simultaneously transmitted and received on a same channel without interference
- LoRa has 7 spreading factors (SF6 - SF12) and 10 different bandwidths in kHz (7.8, 10.4, 15.6, 20.8, 31.2, 41.7, 62.5, 125, 250, 500). 125kHz, 250kHz & 500kHz most used



SF=10 BW=125kHz | SF=11 BW=250kHz | SF=12 BW=500kHz

Figure from "All About LoRa and LoRaWAN", https://www.sghoslya.com

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Not always orthogonal!

- Symbol rate Rs = BW/2^{SF} and Symbol period Ts = 1/Rs
- Chirp rate = BW*(Symbol rate)
- So Chirp rate = $BW^2/2^{SF}$
- i.e. slope = $(f_{max}-f_{min})/Ts = BW/(2^{SF}/BW) = BW^2/2^{SF}$

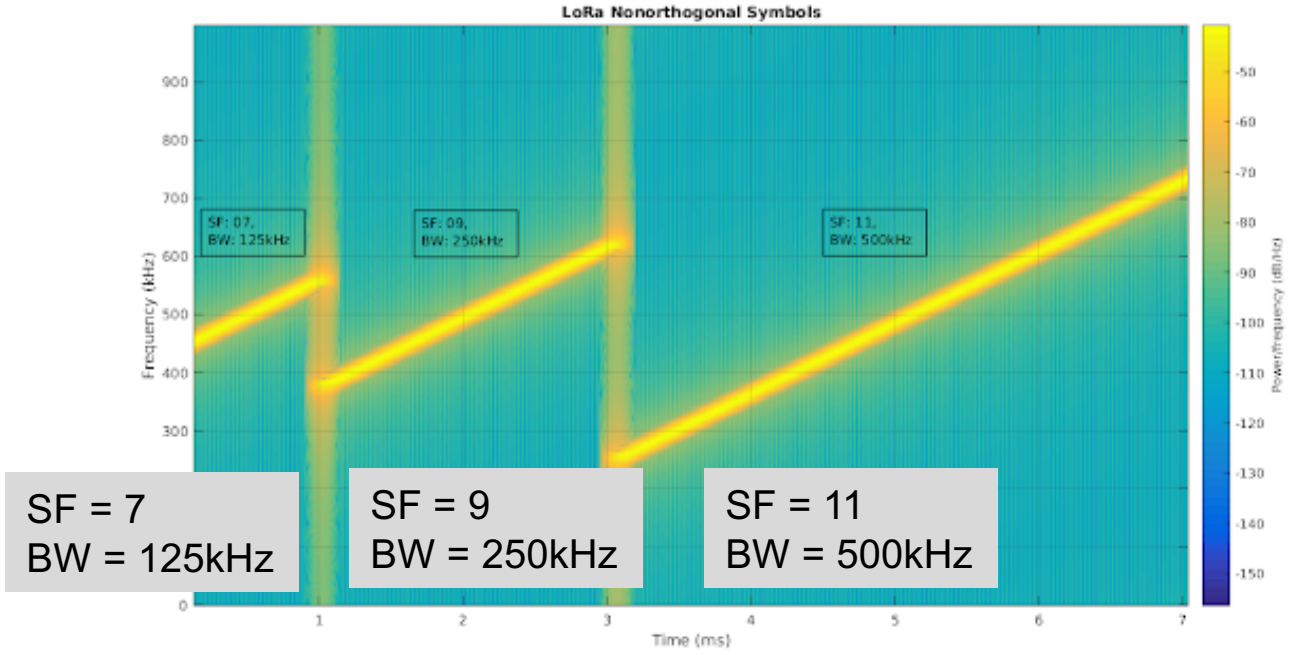


Figure from "All About LoRa and LoRaWAN", https://www.sghoslya.com

Orthogonal combinations

SF		7	8	9	10	11	12	7	8	9	10	11	12	7	8	9	10	11	12
	BW	125	125	125	125	125	125	250	250	250	250	250	250	500	500	500	500	500	500
7	125	x								x								x	
8	125		x								x								x
9	125			x								x							
10	125				x								x						
11	125					x													
12	125						x												
7	250							x								x			
8	250								x								x		
9	250	x								x								x	
10	250		x								x								x
11	250			x								x							
12	250				x								x						
7	500													x					
8	500														x				
9	500							x								x			
10	500								x								x		
11	500	x								x								x	
12	500		x								x								x

Unlicensed ≠Unregulated

- LoRa currently works in unlicensed band (sub-GHz & 2.4GHz)
- Unlicensed = possible usage free of charge
  - Example: WiFi in the 2.4GHz ISM band
  - Shared between a large variety and number of users
- For sub-GHz band, ETSI's regulations
  - Limit duty-cycle (<1%, i.e. 36s/h),
  - Limit transmit power (i.e. 14dBm),
- For sub-GHz band, FCC's regulations
  - Mandatory frequency hopping,
  - Minimum number of frequency sub-channels
  - limited dwell time (400ms),
- **GOAL = limit radio activity for a "reasonable" usage**

Frequency diversity

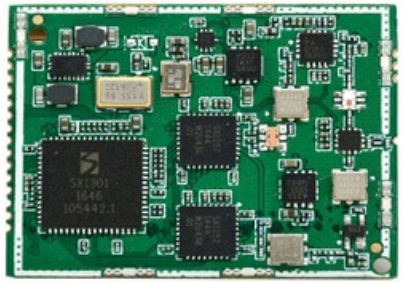
- A full LoRaWAN gateway should be able to listen on multiple channels (x8) and spreading factors (SF7-SF12)

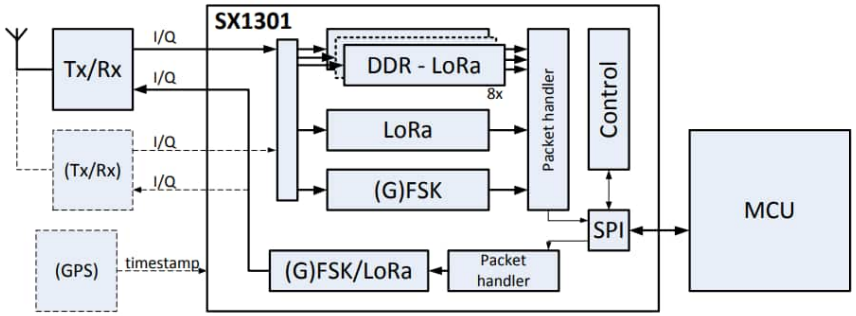
EU863-870

Uplink:

1. **868.1** - SF7BW125 to SF12BW125
2. **868.3** - SF7BW125 to SF12BW125
3. **868.5** - SF7BW125 to SF12BW125
4. **867.1** - SF7BW125 to SF12BW125
5. **867.3** - SF7BW125 to SF12BW125
6. **867.5** - SF7BW125 to SF12BW125
7. **867.7** - SF7BW125 to SF12BW125
8. **867.9** - SF7BW125 to SF12BW125
9. **868.8** - FSK

- They are mostly based on the Semtech SX1301 radio concentrator





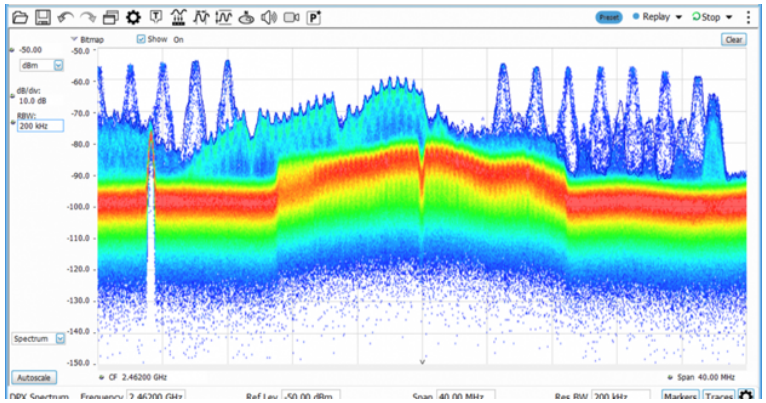
Towards more frequency diversity

- 8 channels is standard
- 16 channels is now becoming available and affordable
- Not unrealistic to foreseen 24 & 32 channels gateways

Part Number	8 Channel SX1301	16 channel SX1301	Cat4 Cellular	GPS	WIFI	Battery Backup
RAK7249-0x-14x	√		√	√	√	
RAK7249-1x-14x		√	√	√	√	
RAK7249-2x-14x	√		√	√	√	√
RAK7249-3x-14x		√	√	√	√	√
RAK7249-0x	√			√	√	
RAK7249-1x		√		√	√	
RAK7249-2x	√			√	√	√
RAK7249-3x		√		√	√	√

Large-scale IoT deployment

- More devices: more traffic, more interferences & collisions!
- 1 msg/20min = 3 msg/h. For 1000 devices = almost 1 msg/s!



- More gateways increases coverage & SF diversity BUT there are still many devices on same collision domain!

Side effect of frequency plans

EU863-870 (THE THINGS NETWORK)

Uplink:

1. **868.1** - SF7BW125 to SF12BW125
2. **868.3** - SF7BW125 to SF12BW125
3. **868.5** - SF7BW125 to SF12BW125
4. **867.1** - SF7BW125 to SF12BW125
5. **867.3** - SF7BW125 to SF12BW125
6. **867.5** - SF7BW125 to SF12BW125
7. **867.7** - SF7BW125 to SF12BW125
8. **867.9** - SF7BW125 to SF12BW125
9. **868.8** - FSK

LoRa Alliance

Frequency plan means common adoption for uplink frequencies which will increase interference level

AS923-925

Used in Brunei, Cambodia, Hong Kong, Indonesia, Laos, Taiwan, Thailand, Vietnam

Uplink:

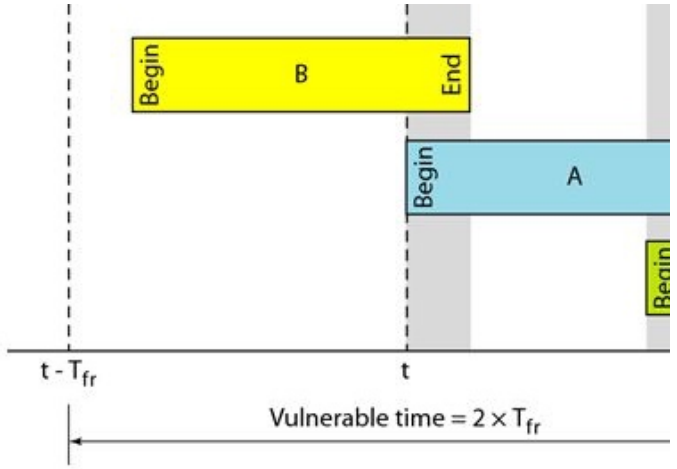
1. **923.2** - SF7BW125 to SF12BW125
2. **923.4** - SF7BW125 to SF12BW125
3. **923.6** - SF7BW125 to SF12BW125
4. **923.8** - SF7BW125 to SF12BW125
5. **924.0** - SF7BW125 to SF12BW125
6. **924.2** - SF7BW125 to SF12BW125
7. **924.4** - SF7BW125 to SF12BW125
8. **924.6** - SF7BW125 to SF12BW125
9. **924.5** - SF7BW250
10. **924.8** - FSK

(THE THINGS NETWORK)

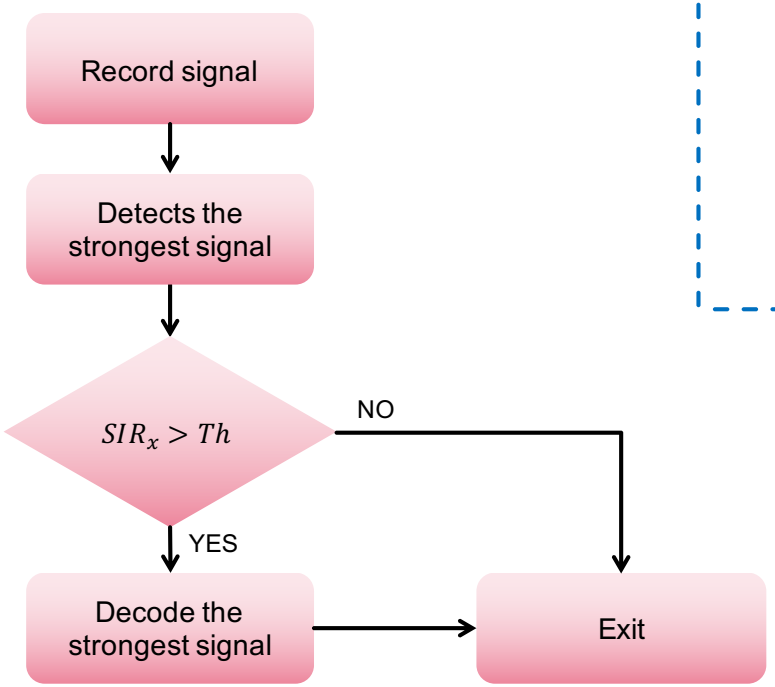
- At some point, there will be be so many nodes that even with frequency and SF diversity, there will still be hundreds of nodes in the same frequency/SF combination!

LoRa = ALOHA?

- LoRa uses a kind of frequency modulation (Chirp Spead Spectrum) so capture effect is possible
- "*In telecommunications, the capture effect, or FM capture effect, is a phenomenon associated with FM reception in which only the stronger of two signals at, or near, the same frequency or channel will be demodulated*." [Wikipedia]
- Capture effect can in some case allow for correct reception of a packet even with concurrent transmissions in the vulnerable time



Capture effect in LoRa



Signal to Interference Ratio > Threshold

$$SIR_x = \frac{P_x}{P_i} > Th$$

P_x: Received power of stronger signal
P_i: Received power of 2nd stronger signal

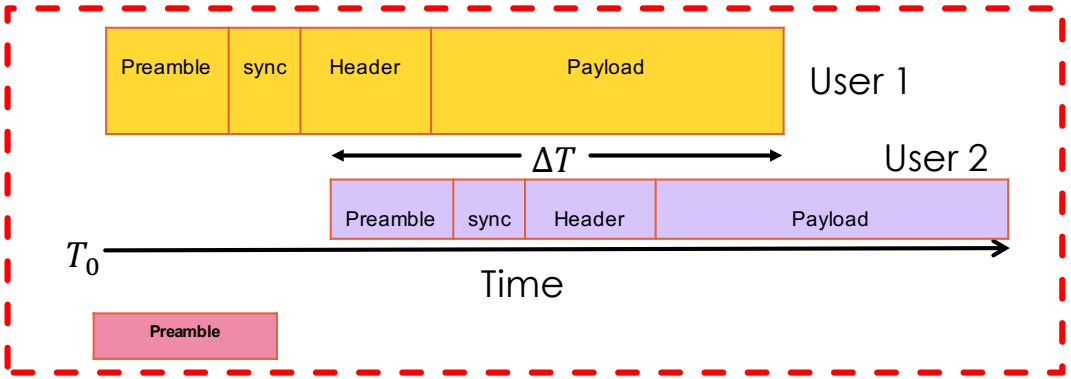
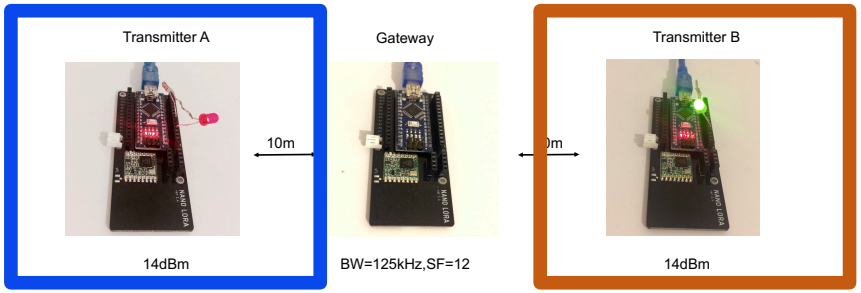


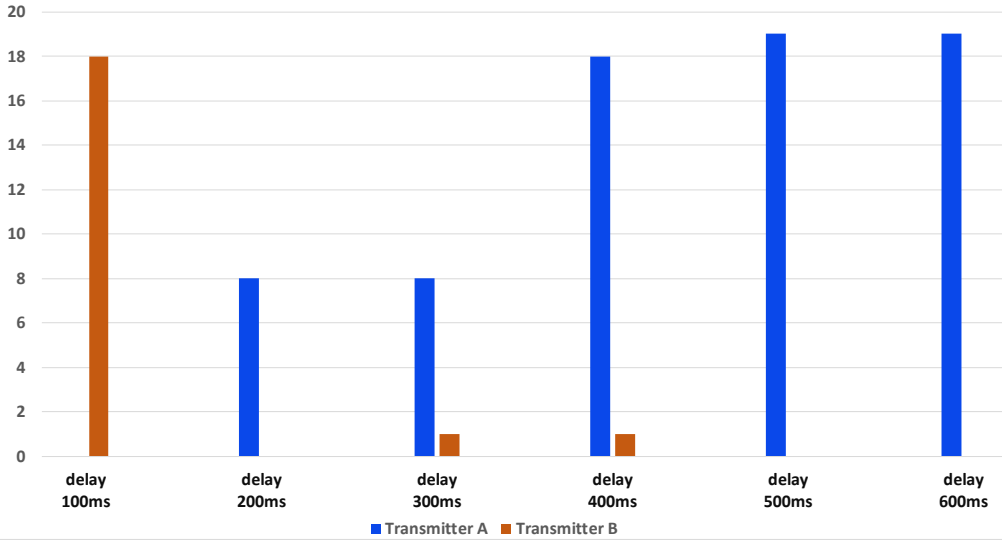
Figure from Umber Noreen, Ahcène Bounceur and Laurent Clavier. LoRa-like CSS-based PHY layer, Capture Effect and Serial Interference Cancellation (24th European Wireless 2018, Catania Italy).

In practice: with 2 nodes

- SF12BW125: preamble duration is about 401ms
- If interferer (B) transmit during A's preamble (100ms-400ms)
  - 100ms: B takes over A's transmission
  - 200ms: A can be successful
  - 300ms: A can be successful
  - 400ms: A is mostly successful
- After A's preamble
  - A is always successful

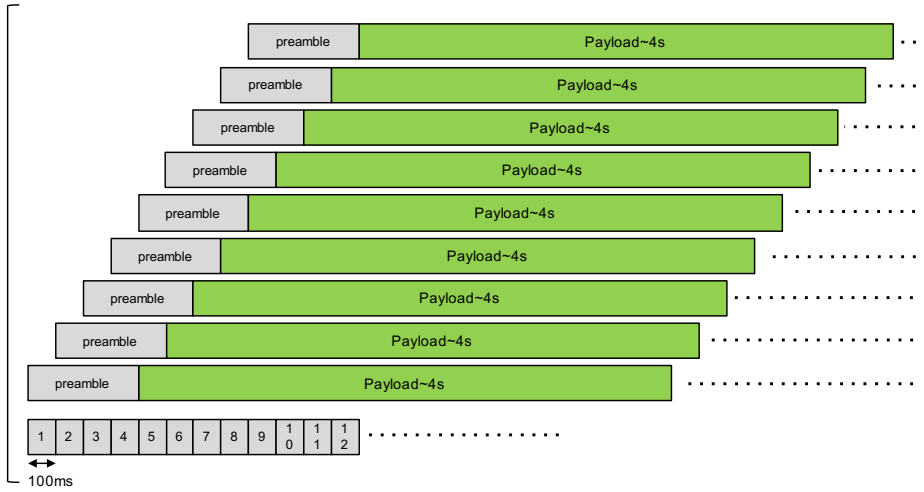


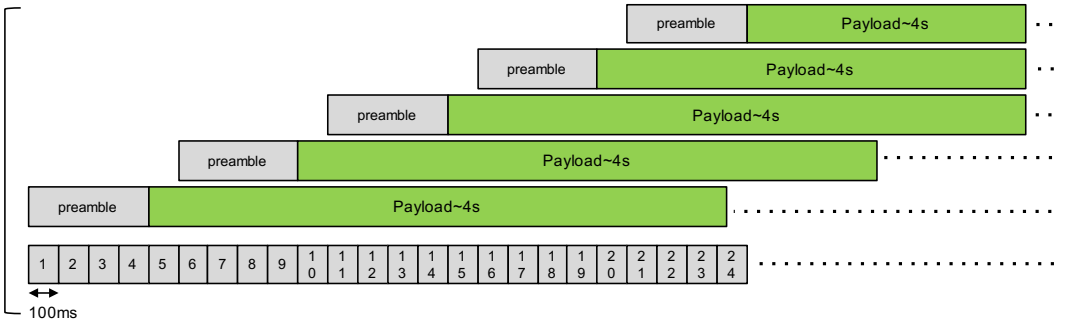
Concurrent transmission during preamble should be avoided
Concurrent transmission after preamble is inefficient but not that harmful



In practice: with high traffic load

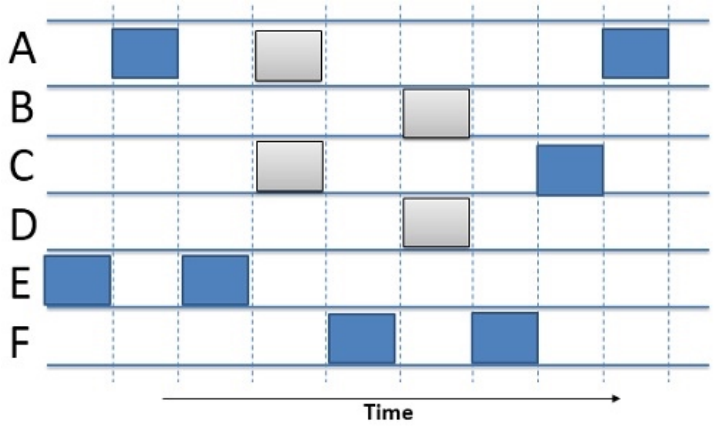
- When there are many overlapping transmissions, Capture Effect is not able to help ☹
- Most of packets are corrupted!
- Neither first nor last packet seems to have higher reception probability!

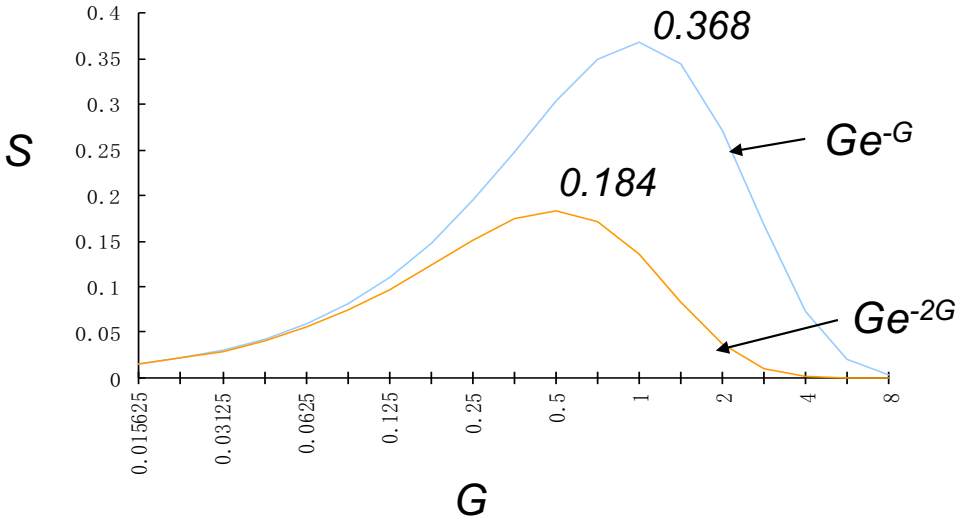




Slotted ALOHA

- Can only send at the beginning of a slot
- Reduces the vulnerable time
- Max efficiency is known to increase to about 37%

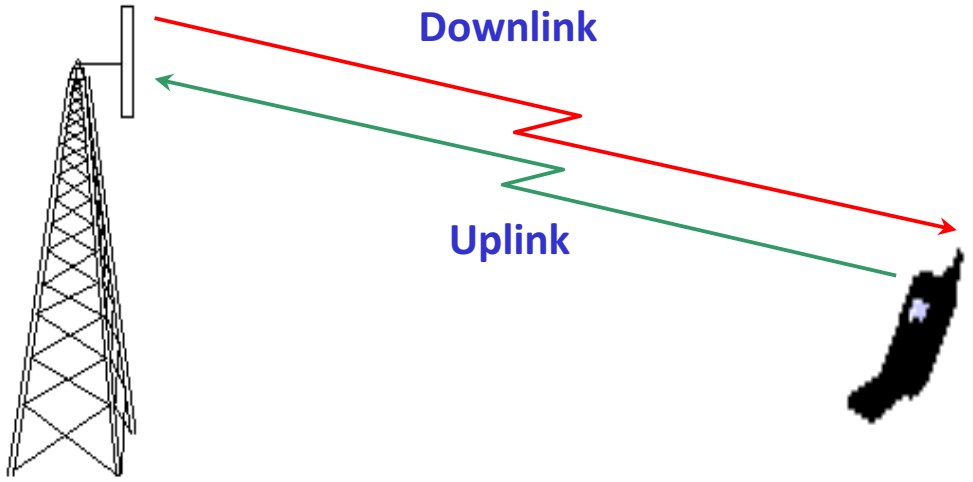


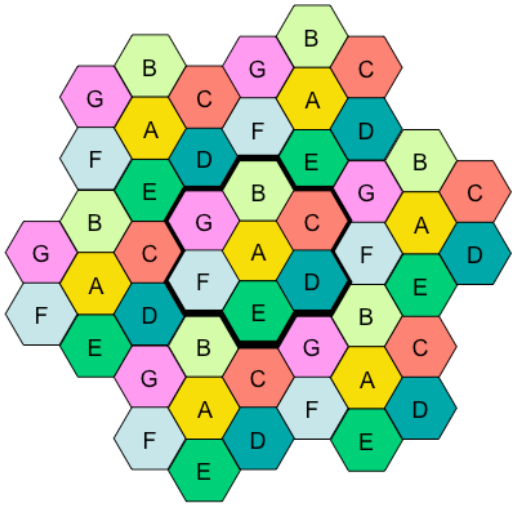


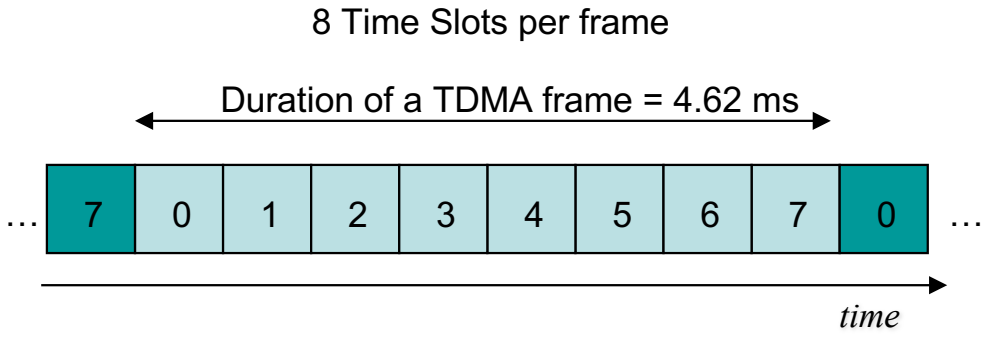
- But slotted mode needs higher level of coordination that is costly in LoRa

TDMA: e.g. GSM (2G)

Channels



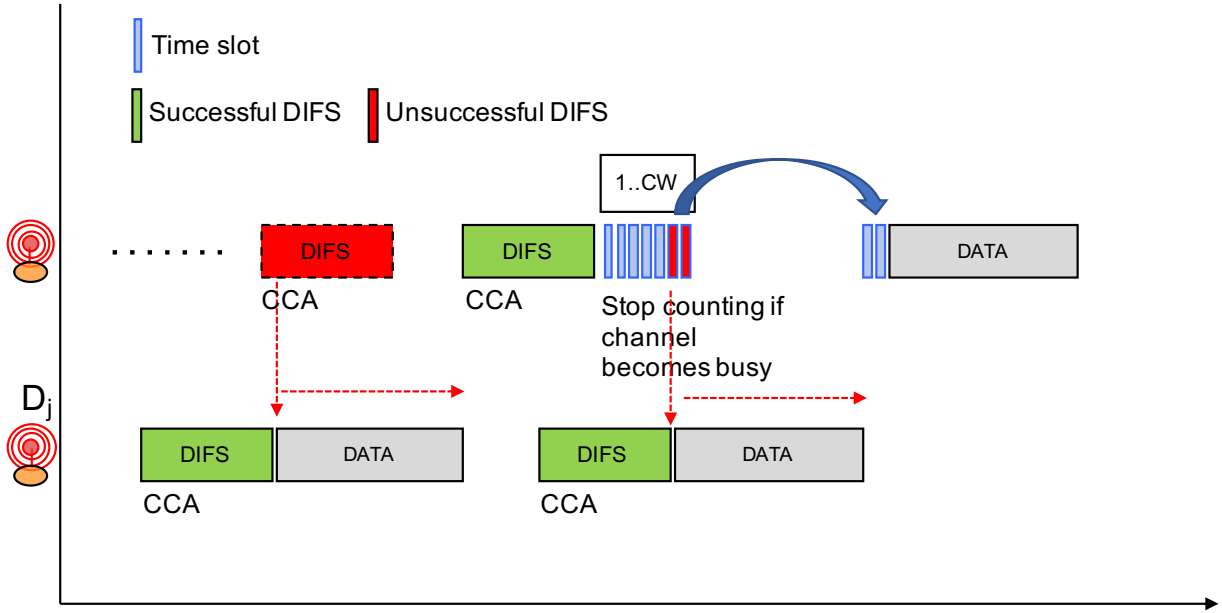




⊙ TDMA also needs a higher level of coordination ☹

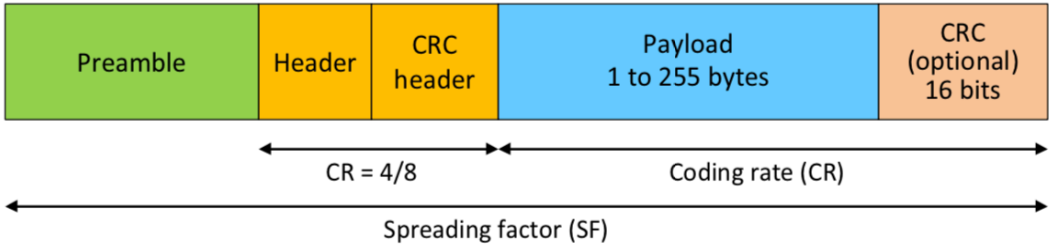
What about Carrier Sense approach?

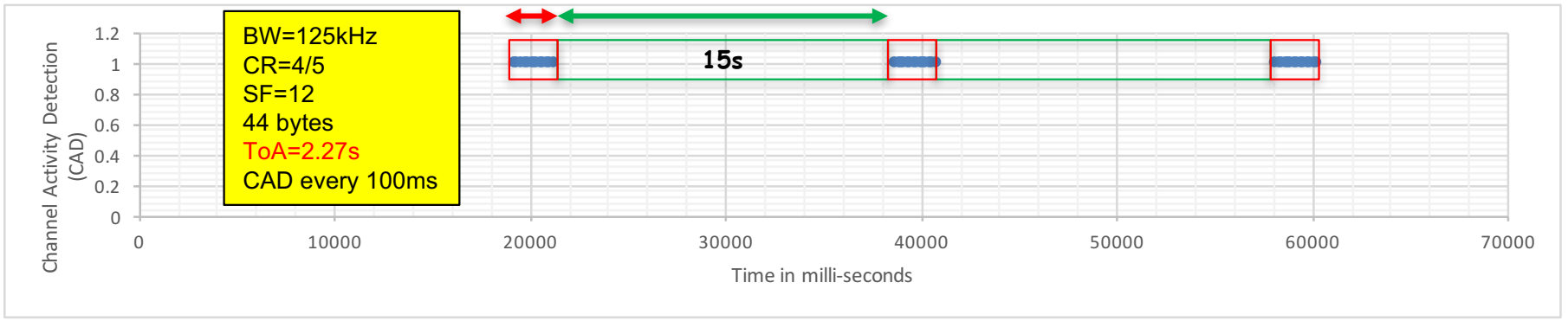
- Can we implement Listen-Before-Talk or Carrier Sense?
- Ex: Carrier Sense Multiple Access/Collision Avoidance in WiFi
  - CSMA/CA in DCF mode with DIFS, SIFS
  - Clear Channel Assessment: is radio channel free?
  - Random backoff [0..W[

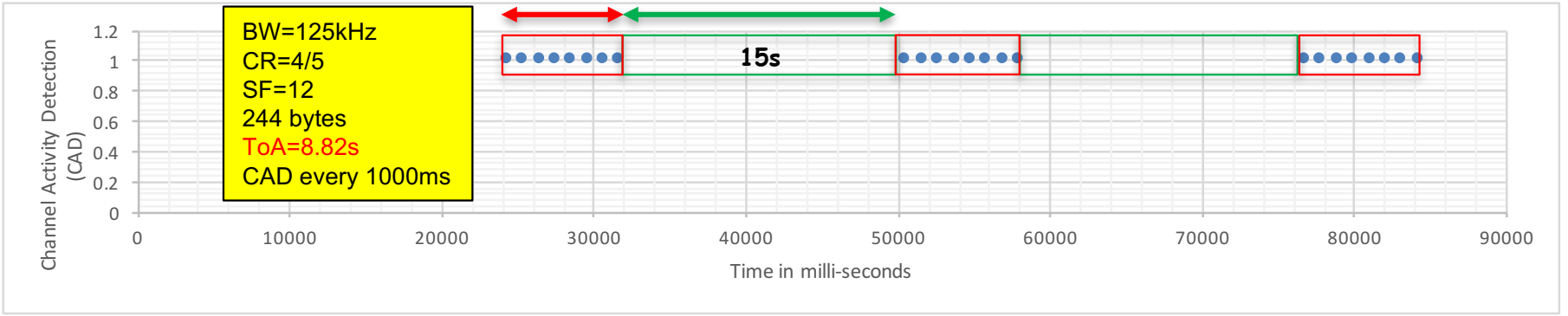


CCA with LoRa

- LoRa's Channel Activity Detection (CAD)

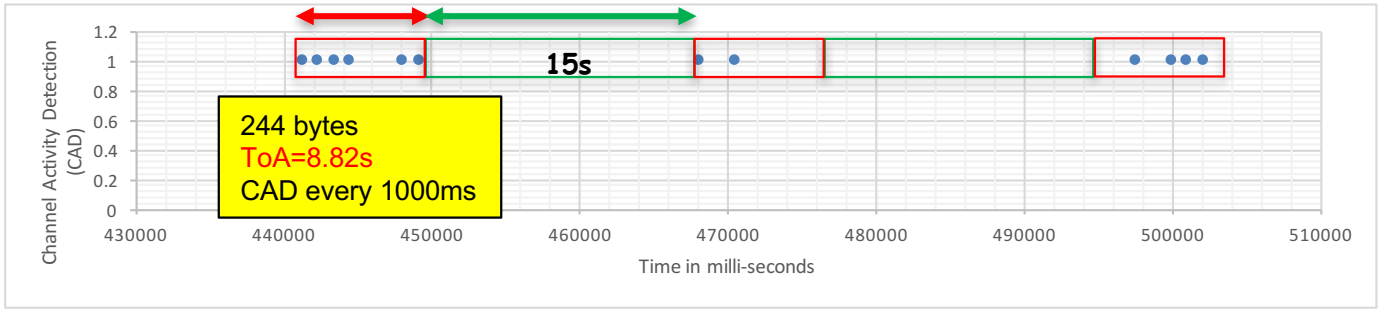




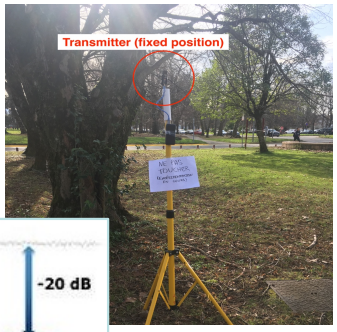


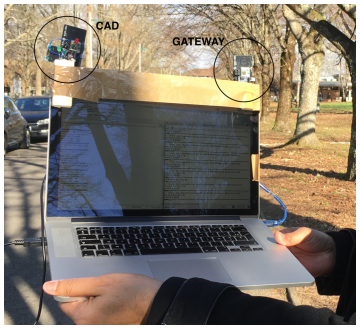
CAD reliability?

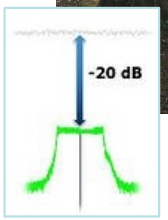
- CAD reliability decreases as distance increases
  - A CAD returning false does not mean that there is no activity! ☹
  - Similar to hidden terminal issue

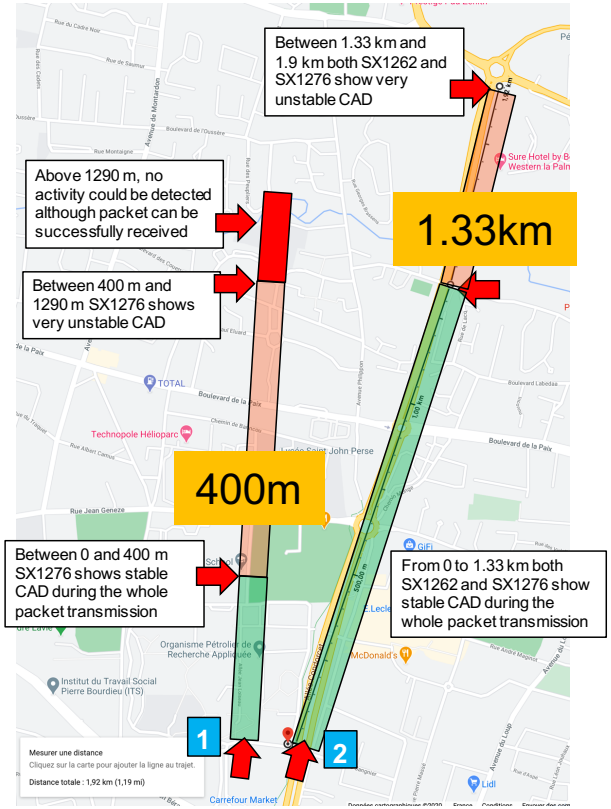


- CAD sensitivity not as good as full reception sensitivity
- CAD returns "no activity" but packet can be received!
- Because LoRa can receive below noise flow!

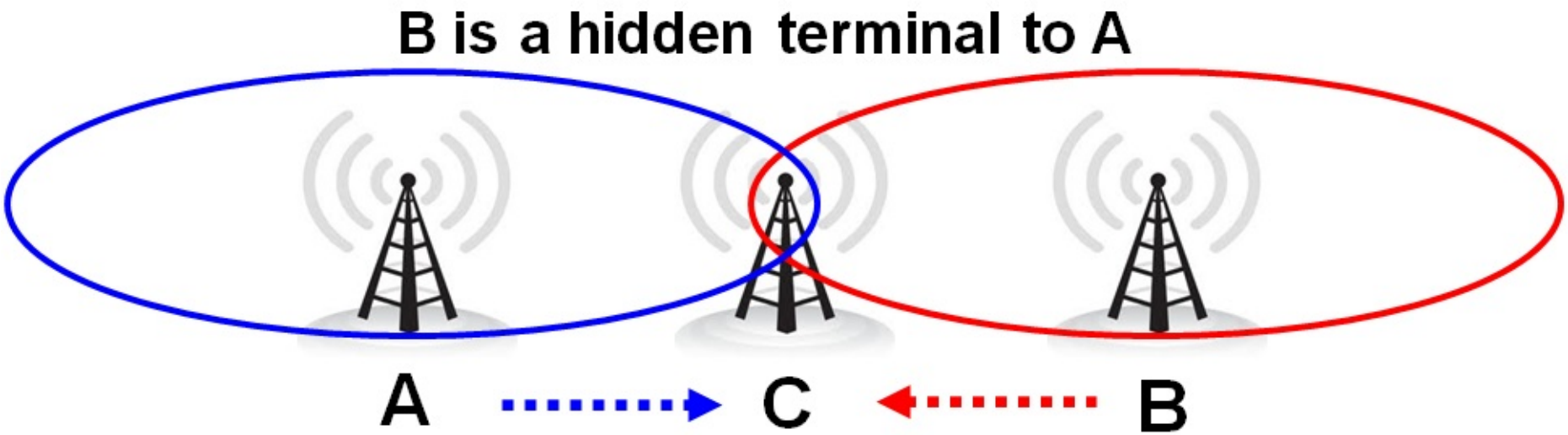






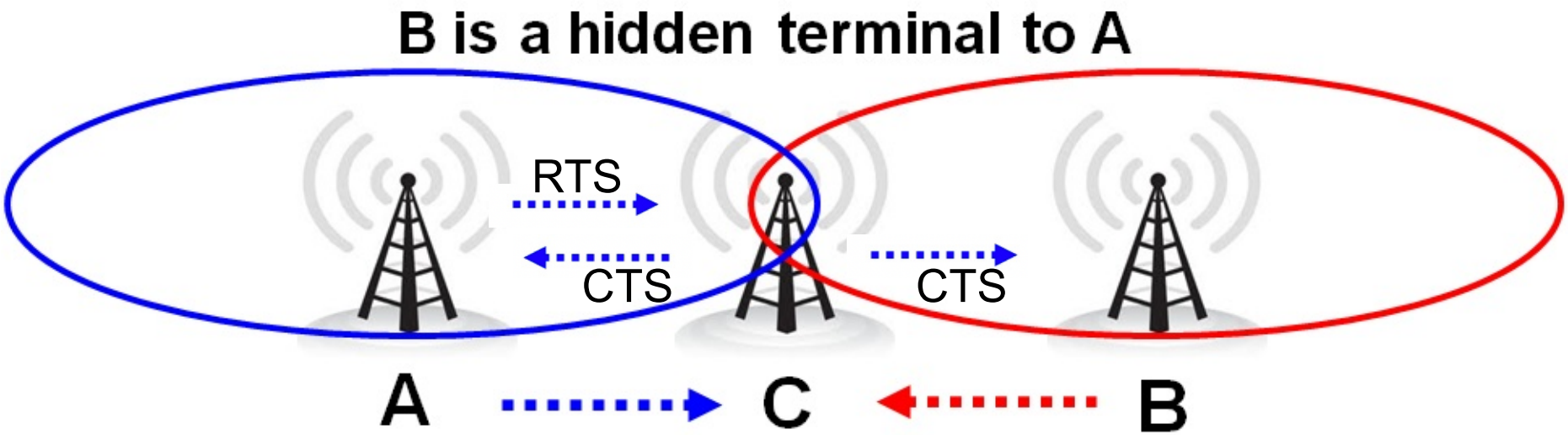


Hidden terminal



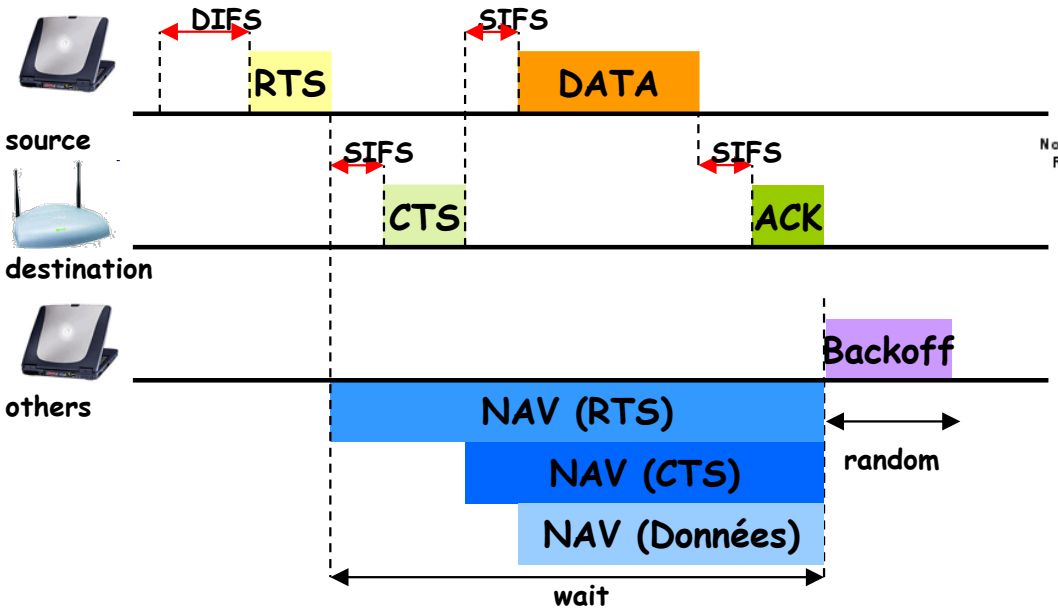
How can we solve hidden terminal?

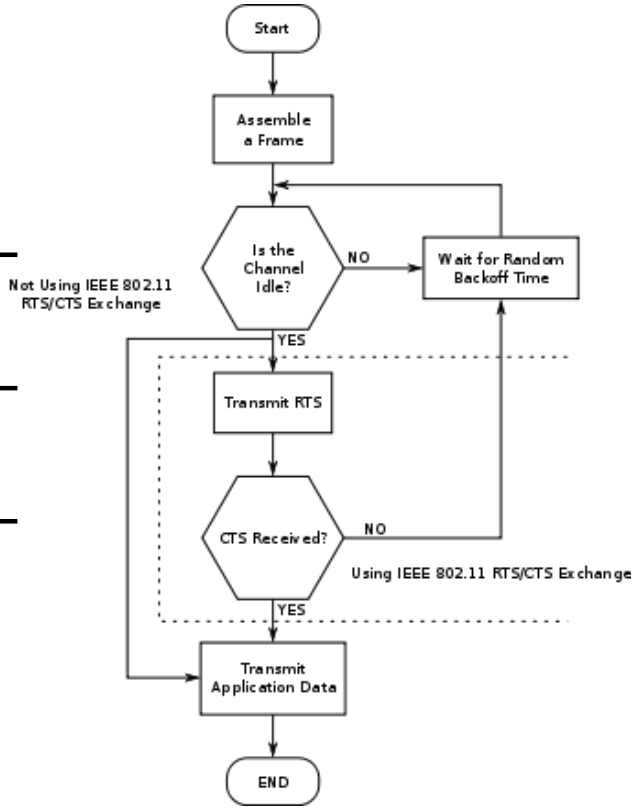
- Use RTS/CTS
  - RTS: Request to Send
  - CTS: Clear to Send



CSMA/CA with RTS/CTS in WIFI

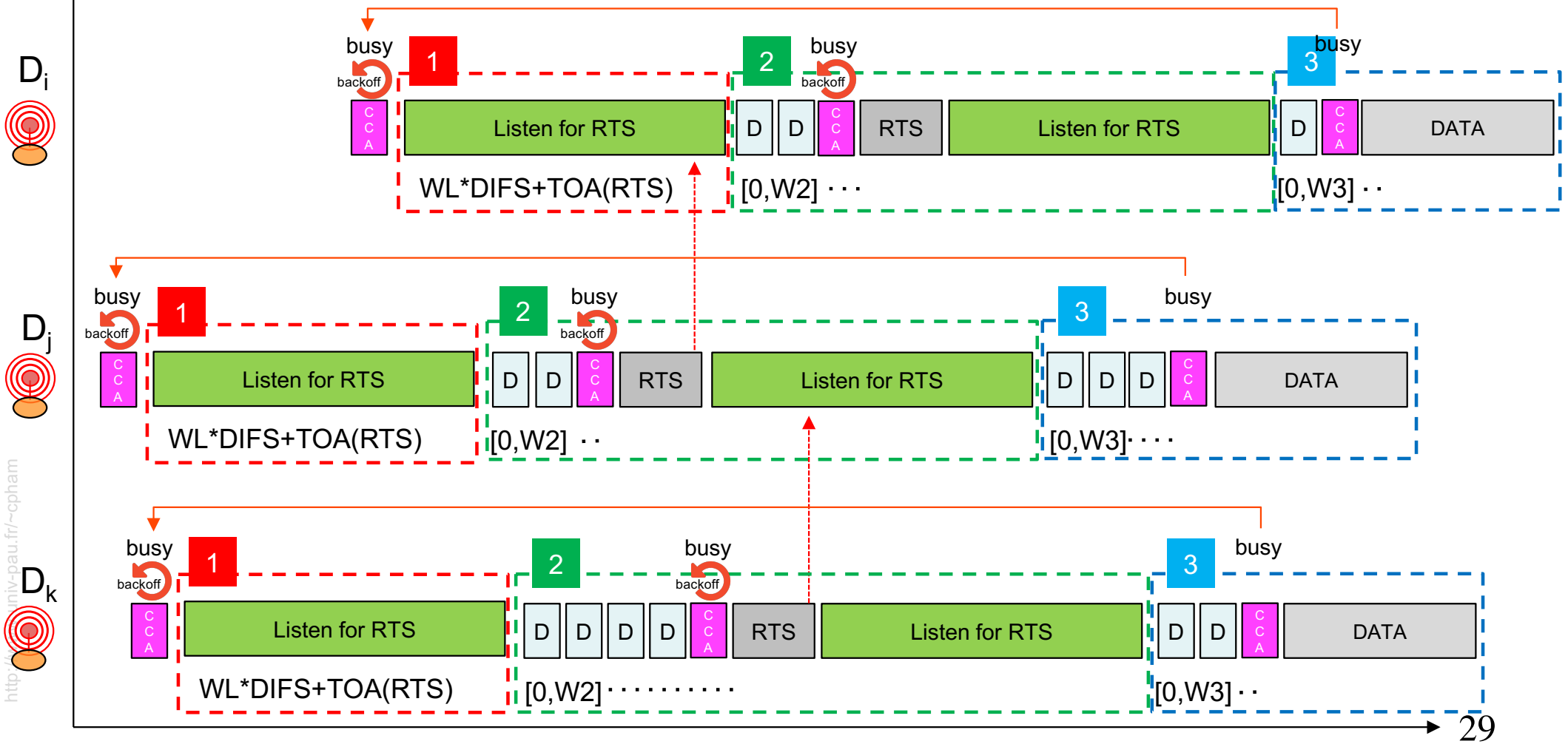
- Collision Avoidance with RTS/CTS to limit the hidden terminal problem
- DCF (Distributed Coordination Function)



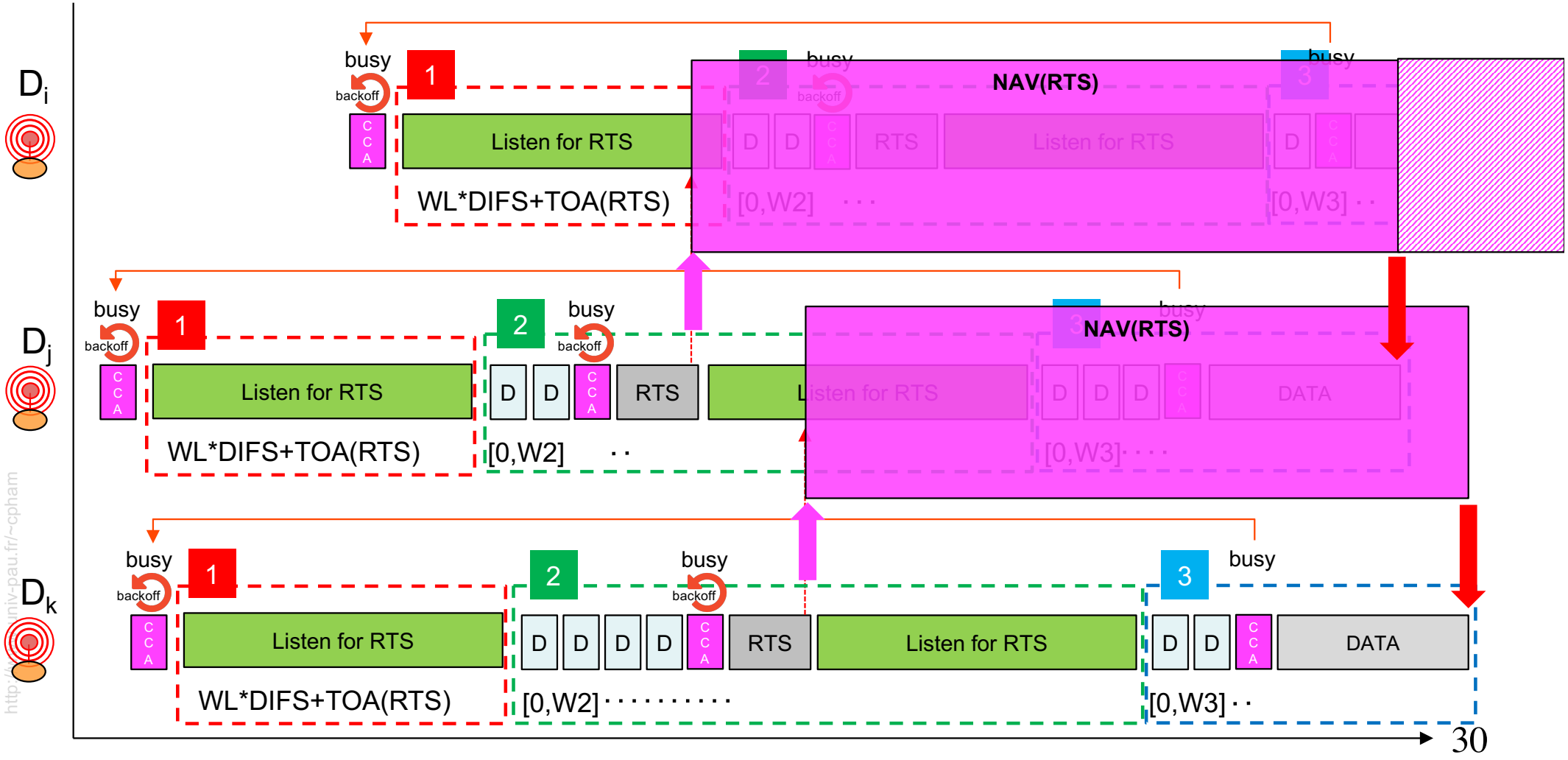


RTS/CTS for LoRa? CA_{lora}

DIFS can be defined as preamble duration, e.g. 400ms for datarate SF12BW125
TOA(RTS)=TOA(1-byte packet), e.g. 827ms for datarate SF12BW125

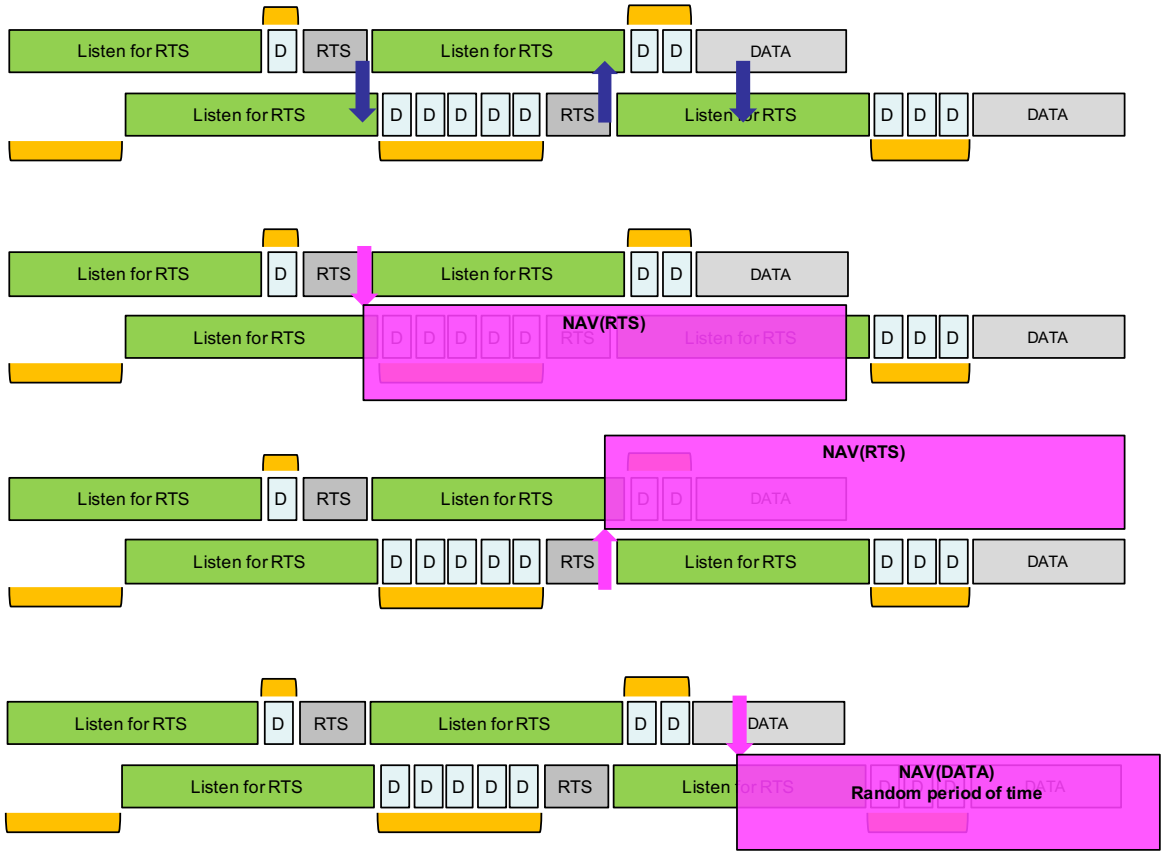


CA_{lora}: NAV period with RTS



Maximizing transmit/listen overlap

- Random timers (orange blocks) to maximize overlap
- Somehow similar to neighbor discovery or schedule-sharing



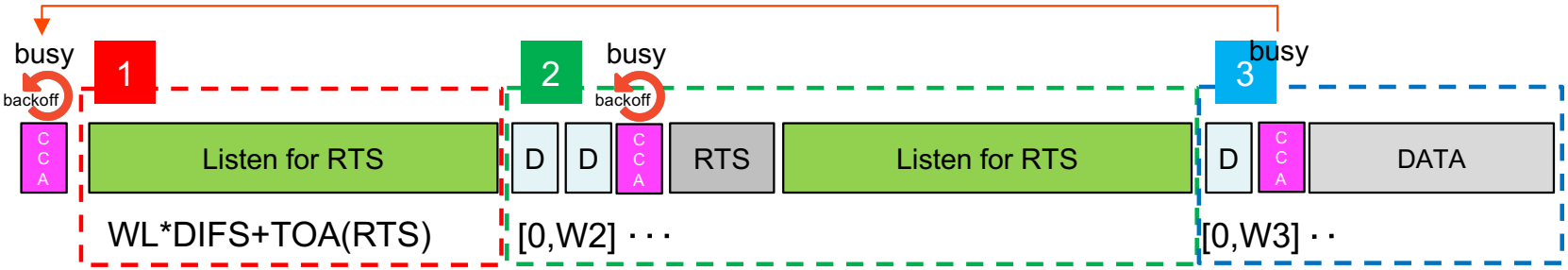
Simulation setting

- Based on LoRaSim (ALOHA), but improved with CSMA & CA

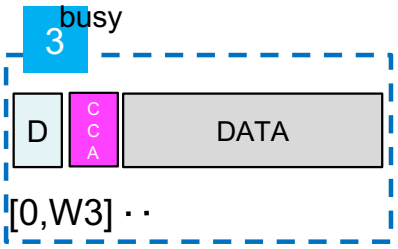
Common parameters – CA & Carrier Sense			
frequency	868.1 MHz	DATA pkt length	104 bytes
TX power	14 dBm	ToA(DATA)	4.104 s
TX current	44 mA	max pkt length	120 bytes
RX current	5 mA	ToA(120 bytes)	4.59 s
voltage	3.3 V	$Wbusy_{min}$	1
LoRa datarate	SF12BW125	$Wbusy_{BE}$	3
Tsym	32.76 ms	$Wbusy_{maxBE}$	6
DIFS duration	401.40 ms	CCA_{prob}	30%, 50%, 80%
#devices	20	n_{retry}	40
#pkt sent/node	2000	pkt inter-arrival	5 s .. 220 s
Only for CA			
$n_{retry-rts}$	20	RTS pkt length	5 bytes
WL	7	ToA(RTS)	827.3 ms
$W2$	10	P1 (WL=7)	3.630 s
$W3$	7	P2 (W2=10)	4.46 s .. 8.46 s

What do we compare?

- wCA: CA_{lora} = CA+CCA+backoff

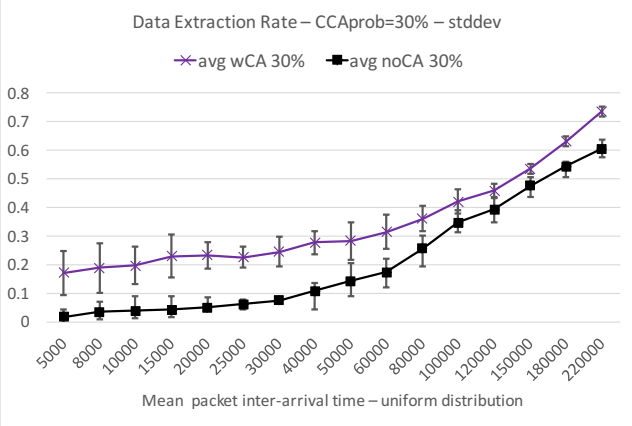


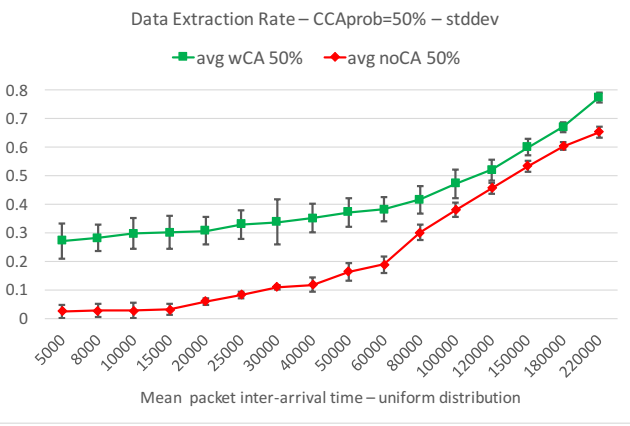
- noCA: CSMA=CCA+backoff

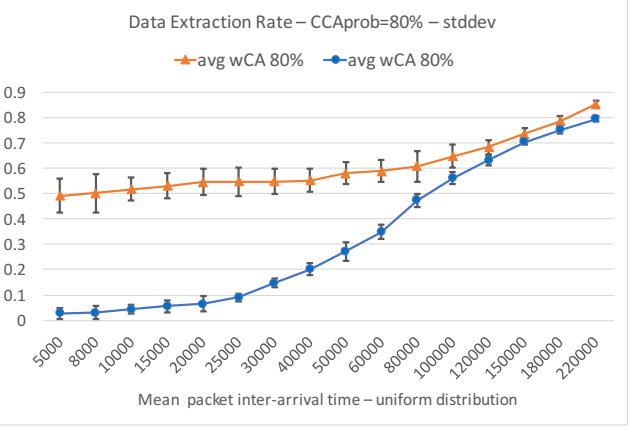


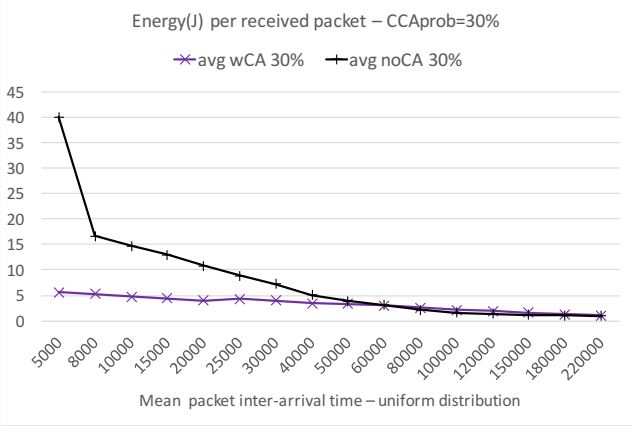
Data Extraction Rate: CA vs CSMA

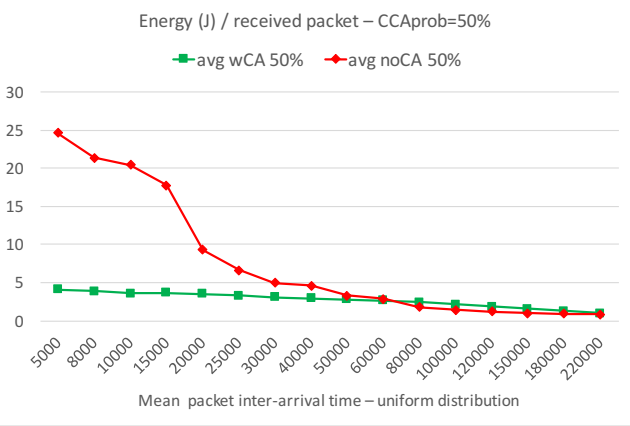
- CCAprob=30%, 50% or 80% (ability to detect radio activity)
- 20 nodes, T_{pkt}=4s, packet inter-arrival time [5s, 220s], DER

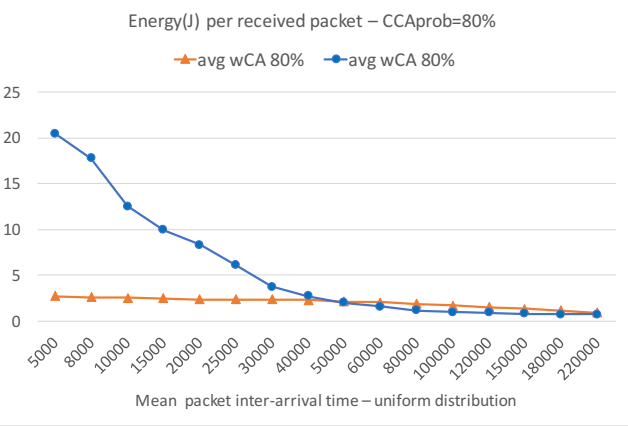






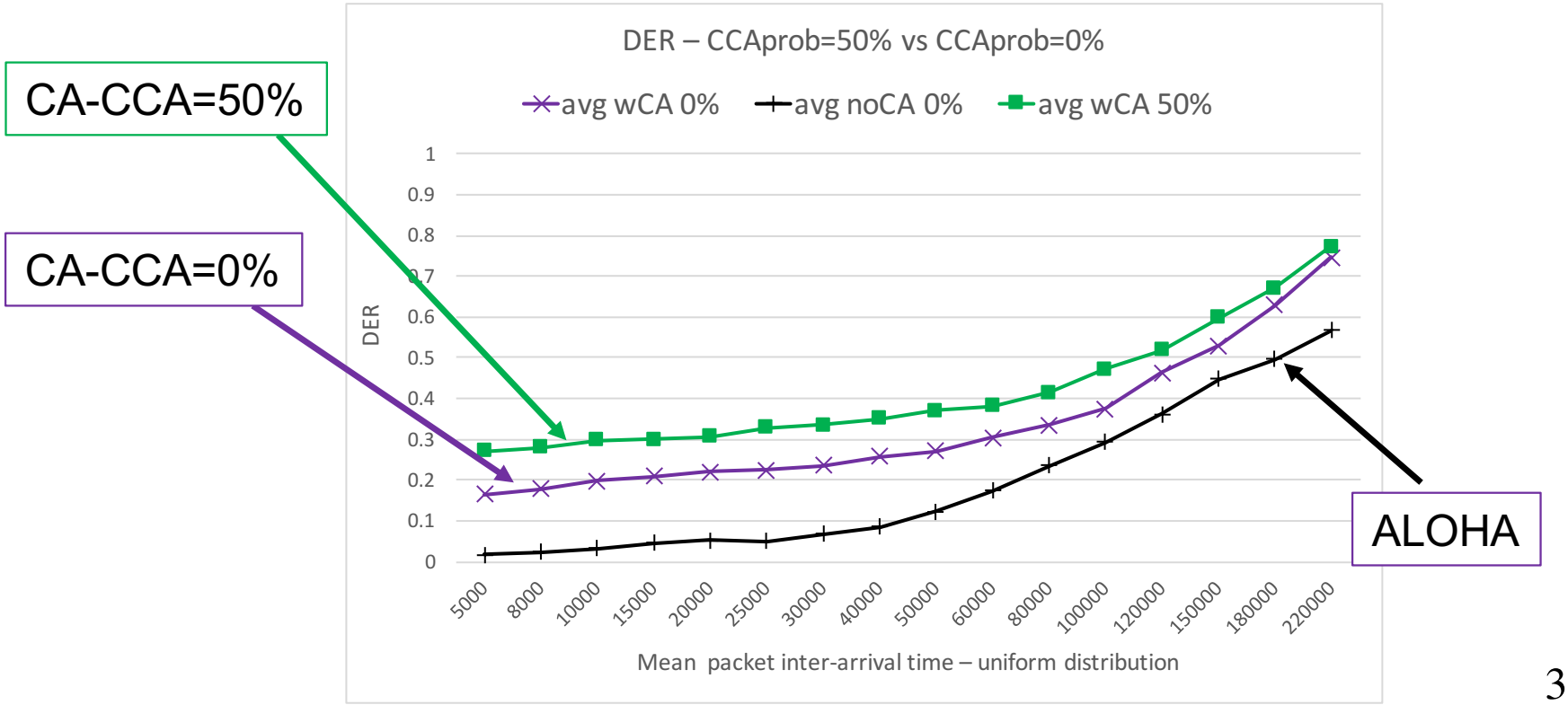






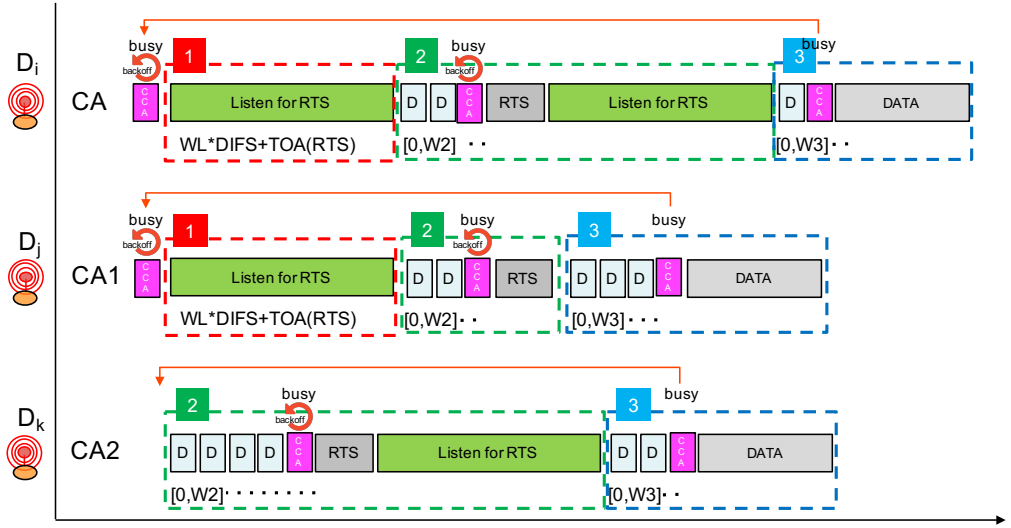
Completely disabling CCA

- Proposed CA when disabling CCA (purple) can still maintain a higher DER
- 20 nodes, T_{pkt}=4s, packet inter-arrival time [5s, 220s],

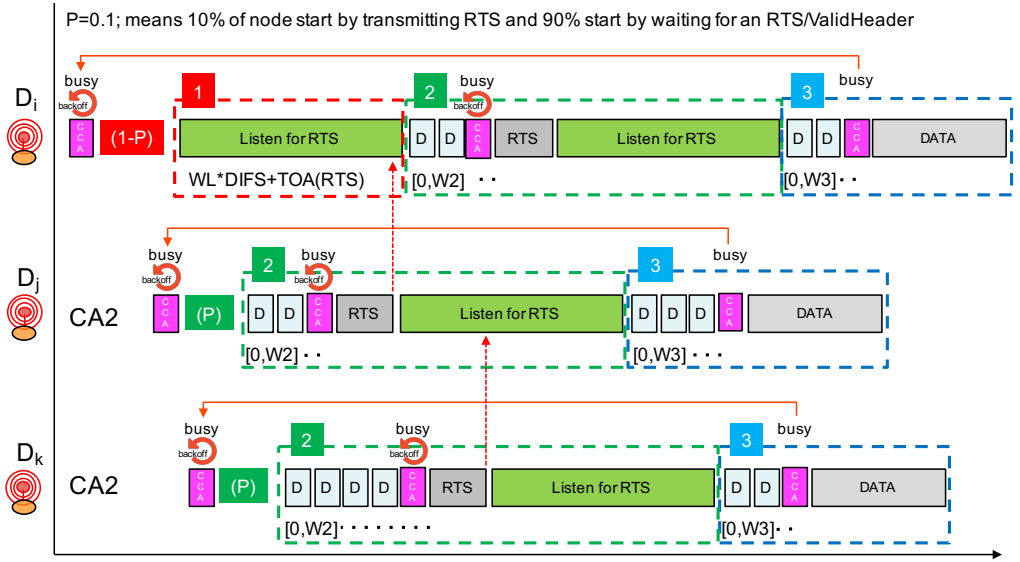


Future studies and improvements

- Impact of listening periods?
- Increasing listening period duration?



- Hybrid mode?
- Dynamically select CA parameters?



Conclusions

- LoRa networks are deployed world-wide is unlicensed bands
  - Telco operators, Communities, Private, ad-hoc infrastructures
  - LoRa 2.4GHz is also available with range of about 3kms
- Tremendous community-based gateway deployment initiatives
  - No other radio technologies (apart from WiFi) have similar involvement from community and citizens!
  - Density of LoRa gateway is expected to be high in cities
  - Frequency diversity is also expected to be high (x16, x24, x32 GW?)
- Efficient channel access is challenging
  - Due to LPWAN PHY modulations, CCA is unreliable
  - Difficulty to go beyond ALOHA system
- But, new perspectives in
  - Novel Collision Avoidance approaches
  - Adapting Neighbor Discovery protocols?

How to better share the radio channel in LoRa LPWAN?

Presented on July 7th, 2022

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