Exploring the capture effect in LoRaWAN

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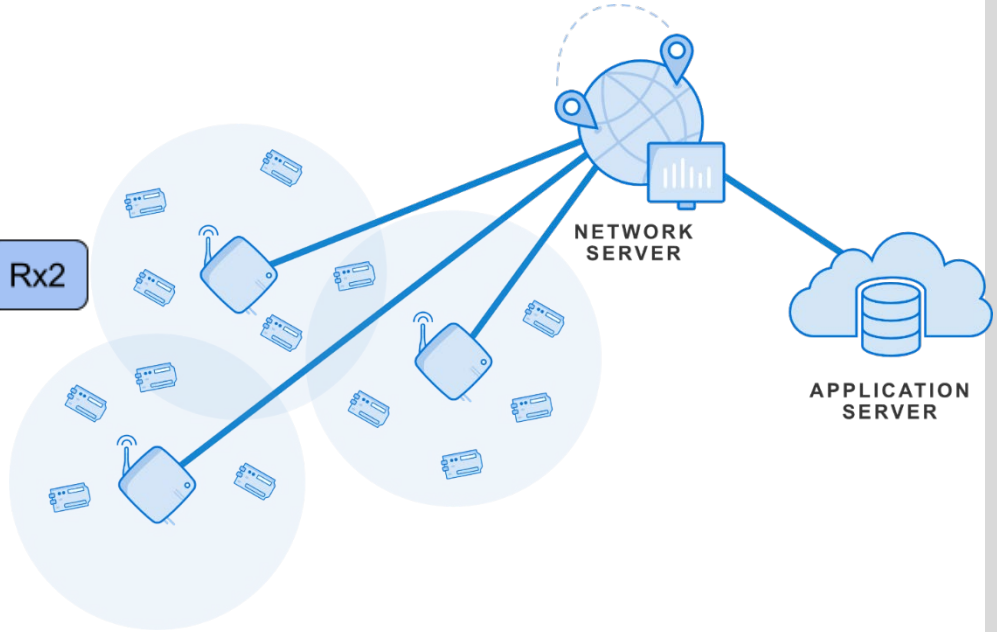
LoRaWAN: Aloha-based MAC

Class A

uplink transmission

Rx1

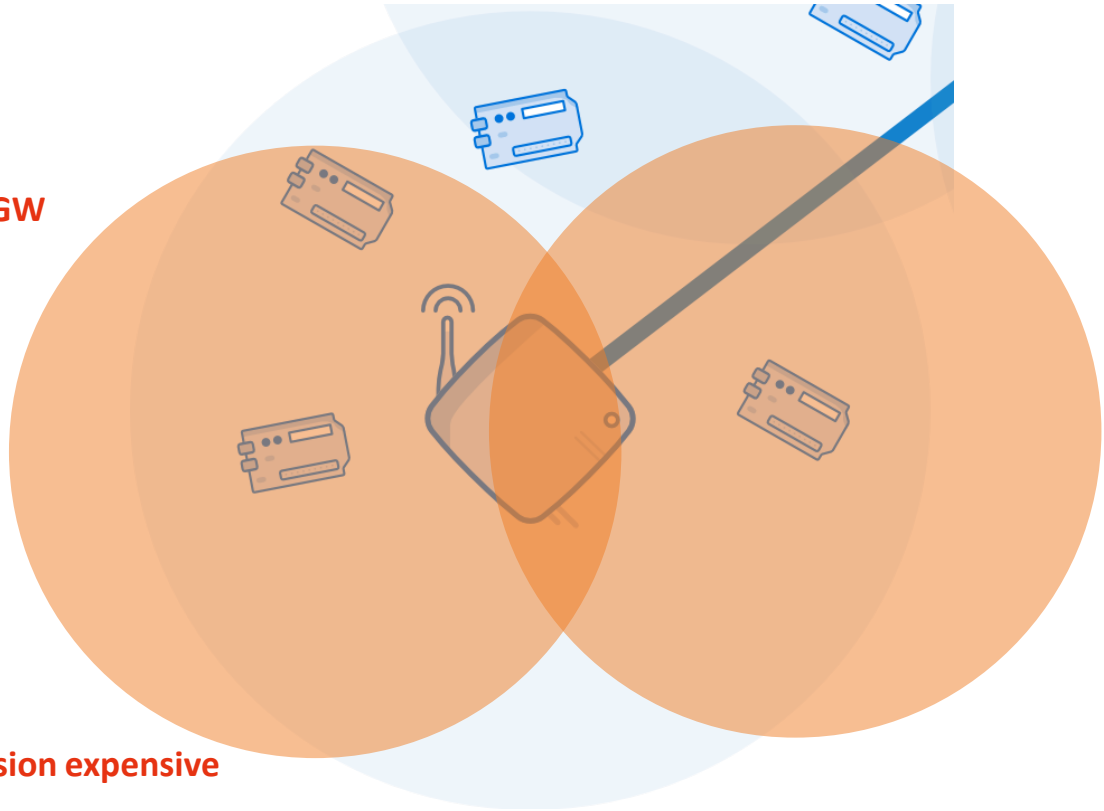
Rx2



- « Pure » Aloha*
- Random uplinks based on needs

LoRaWAN: Aloha-based MAC

- **Uplink Tx may collide at the GW**
- **Information gets lost**
- **Duty cycle makes retransmission expensive**



Collisions: What do they depend on?

- **Frequency: 863-870 MHz BW 125/250/500 KHz**
- **Spreading factor: SF 7 – 12**
- **Tx Power**

Collisions: Frequency-based

- **Frequency: 863-870 MHz BW 125/250/500 KHz**
  - Transmission possible in different frequencies

$$C_{freq}(x,y) = \begin{cases} 1 \; if \; |f_x - f_y| < f_{threshold} \\ 0 \; else \end{cases}$$ [1]

  - $f_{threshold}$=60Khz for BW125 / 120KHz for BW250 / 240KHz for BW500
  - Most gateways able to listen on multiple carriers

[1] - Bor, Martin C., et al. "Do LoRa low-power wide-area networks scale?." Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems. ACM, 2016.

Collisions: Spreading Factor-based

- **Spreading Factor: SF7 – SF12**
  - Different SF available

$$C_{SF}(x,y) = \begin{cases} 1 \; if \; SF_x = SF_y \\ 0 \; else \end{cases}$$ [1]

  - SF are orthogonal and allow successful decoding of simultaneous uplink frames

[1] - Bor, Martin C., et al. "Do LoRa low-power wide-area networks scale?." Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems. ACM, 2016.

Collisions: Transmission Power-based

- **Tx Power**
  - Transmission power can be set before uplink

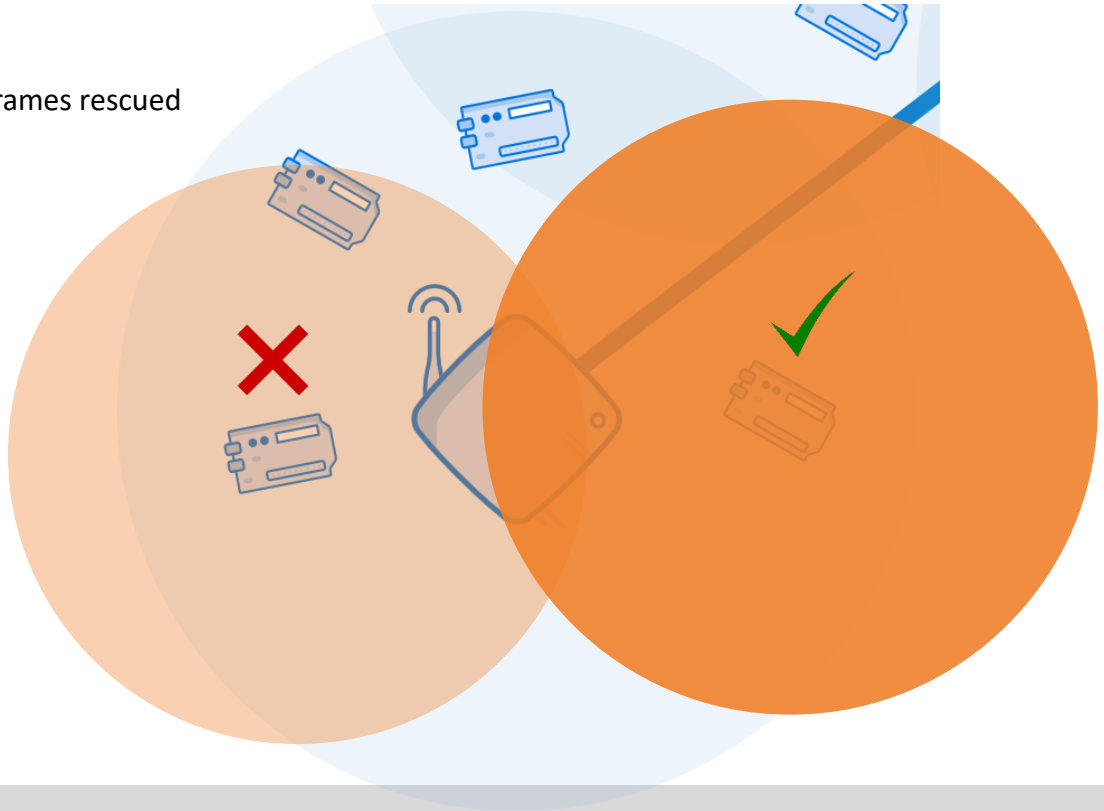
$$C_{pwr}(x,y) = \begin{cases} 1 \; if \; P_x - P_y < P_{threshold} \\ 0 \; else \end{cases}$$ [1]

- $P_{threshold}$ 

[1] - Bor, Martin C., et al. "Do LoRa low-power wide-area networks scale?." Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems. ACM, 2016.

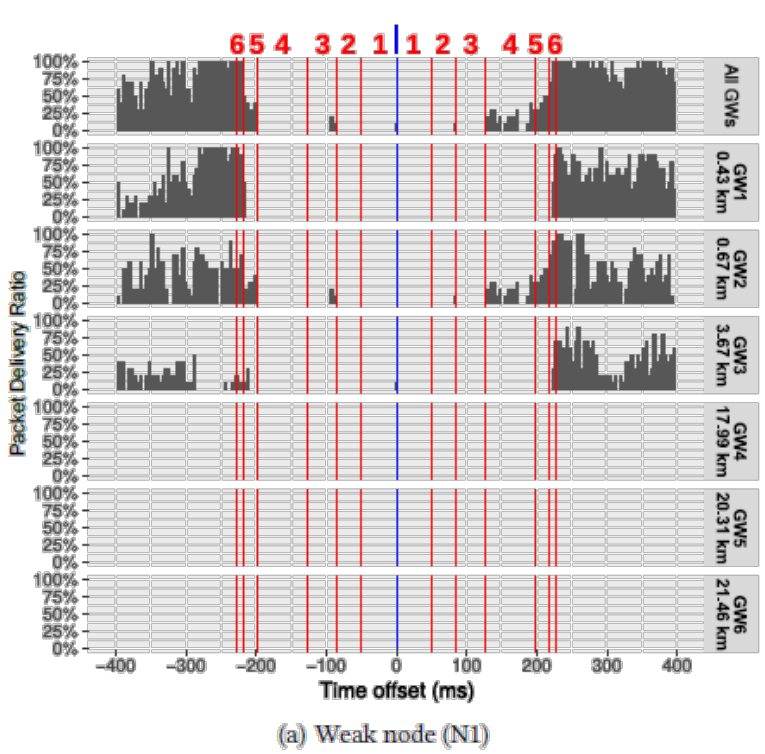
Bottom line

- **When two frames arrive simultaneously at the GW**
  - Collisions => Both frames lost
  - Capture effect => One of the frames rescued

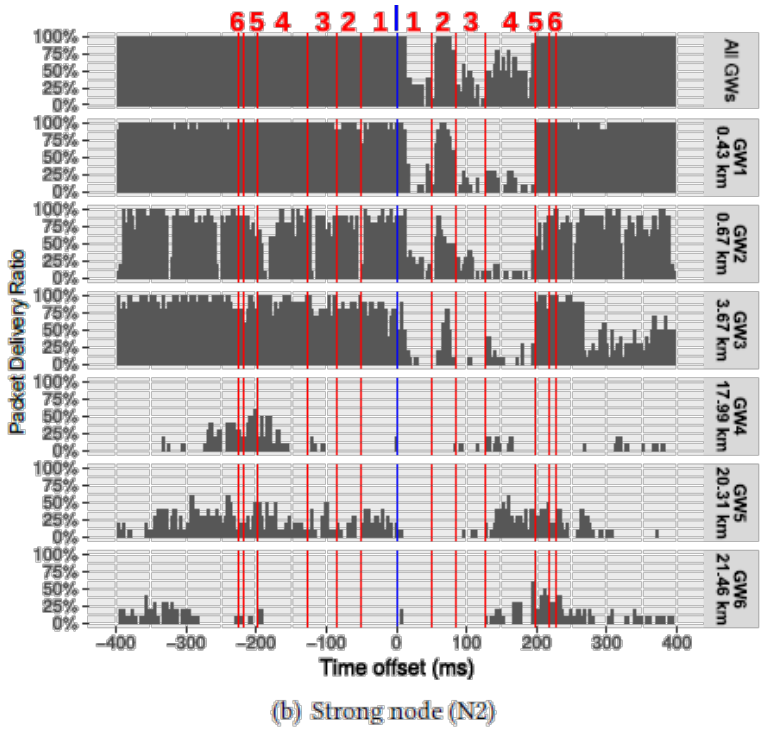


Capture effect in state-of-the-art

- **When frames arrive at the same time [2]**



(a) Weak node (N1)



(b) Strong node (N2)

All or nothing

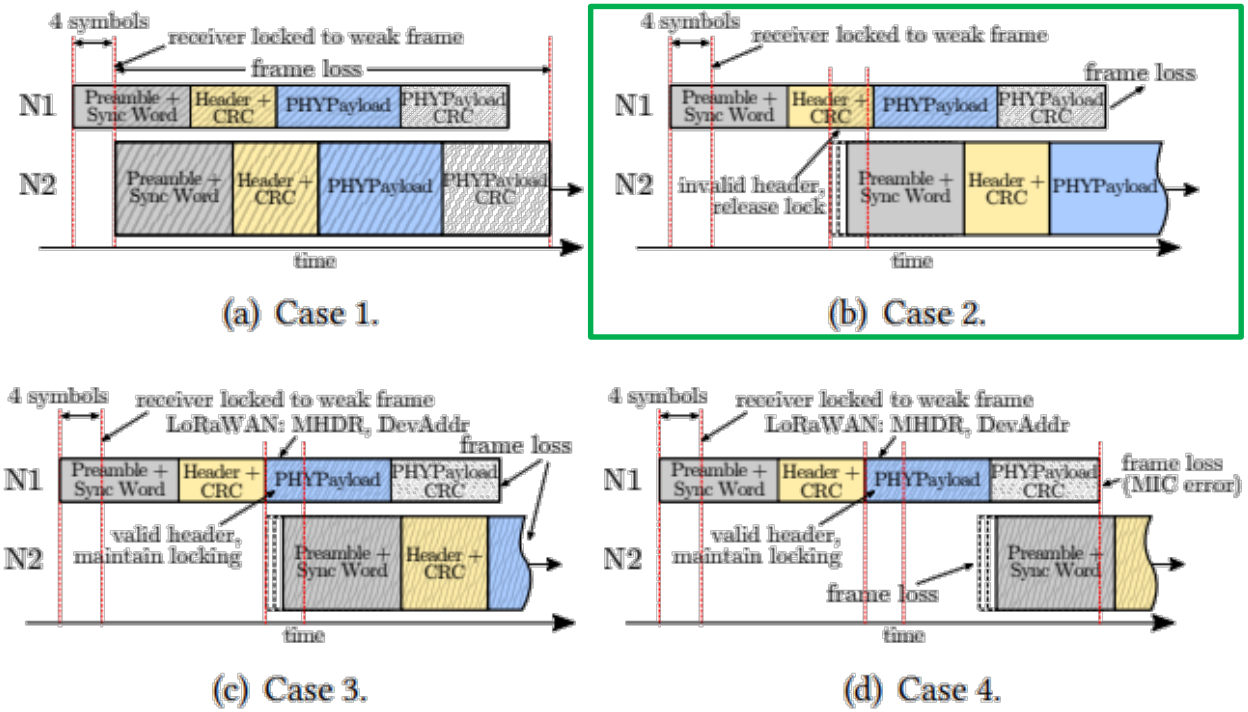
- Fixed set of parameters (TxPower 2dBm & 8dBm)[2]

[2] - Rahmadhani, Andri, and Fernando Kuipers. "When LoRaWAN Frames Collide." WiNTECH@ MOBICOM. 2018.

Capture effect in state-of-the-art

- **When frames arrive at different times [2]**

$TxPower_{N2} > TxPower_{N1}$



[2] - Rahmadhani, Andri, and Fernando Kuipers. "When LoRaWAN Frames Collide." WiNTECH@ MOBICOM. 2018.

Motivation

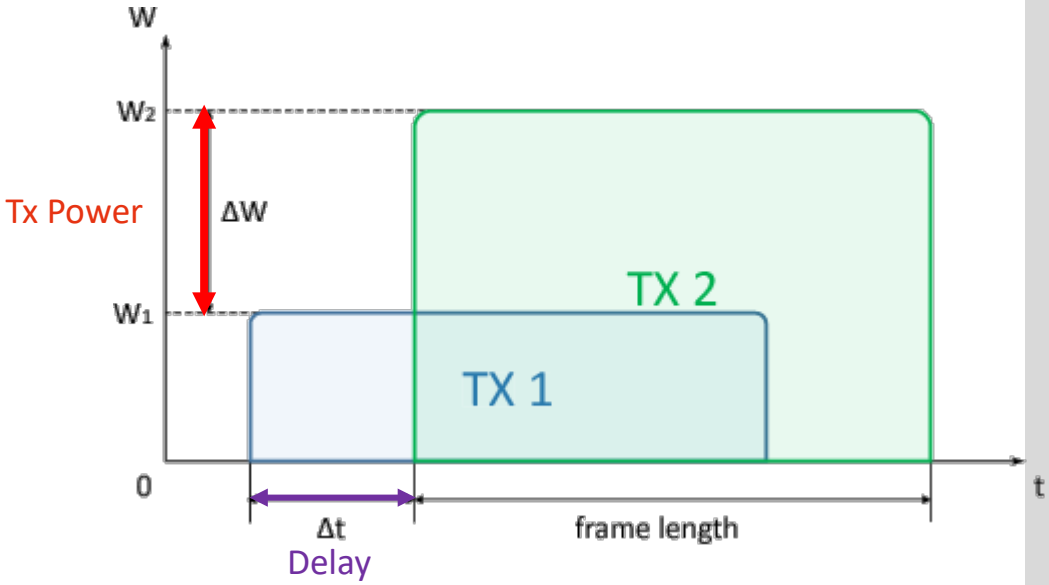
- **State-of-the-art is not enough**
  - Bor & al [1]
    - Same TX power between nodes
    - Different SF between nodes
  - Rahmadhani & al [2]
    - Only one set of TX power considered
    - Sync between nodes not adequate

[1] - Bor, Martin C., et al. "Do LoRa low-power wide-area networks scale?." Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems. ACM, 2016.

[2] - Rahmadhani, Andri, and Fernando Kuipers. "When LoRaWAN Frames Collide." WiNTECH@ MOBICOM. 2018.

Objectives

- **Verify assessments made in state-of-the-art**
- **Explore different paramaters**
  - Different SF
  - Different sets of Tx Power
  - Different types of GWs
  - All while different delays



[3] - Khorov, Evgeny, et al. "Testbed to Study the Capture Effect: Can We Rely on This Effect in Modern Wi-Fi Networks." 2018 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom). IEEE, 2018.

Experiments setup

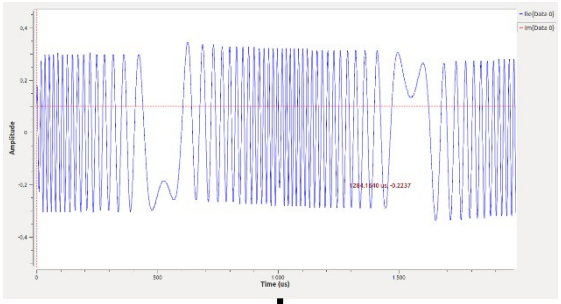
- 2 USB dongles
  - ARM-N8-LW
  - SX1272
  - LoRaWAN 1.0
  - TX Power range 2 <-> 14 dBm
  - Serial connect

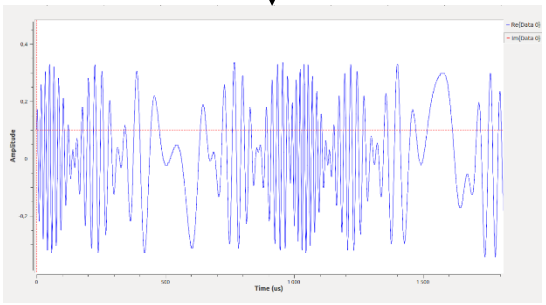
- USRP used to ensure synchronization

- TheThingsNetwork as Network server

THE THINGS NETWORK

Normal single TX





Colliding TXs

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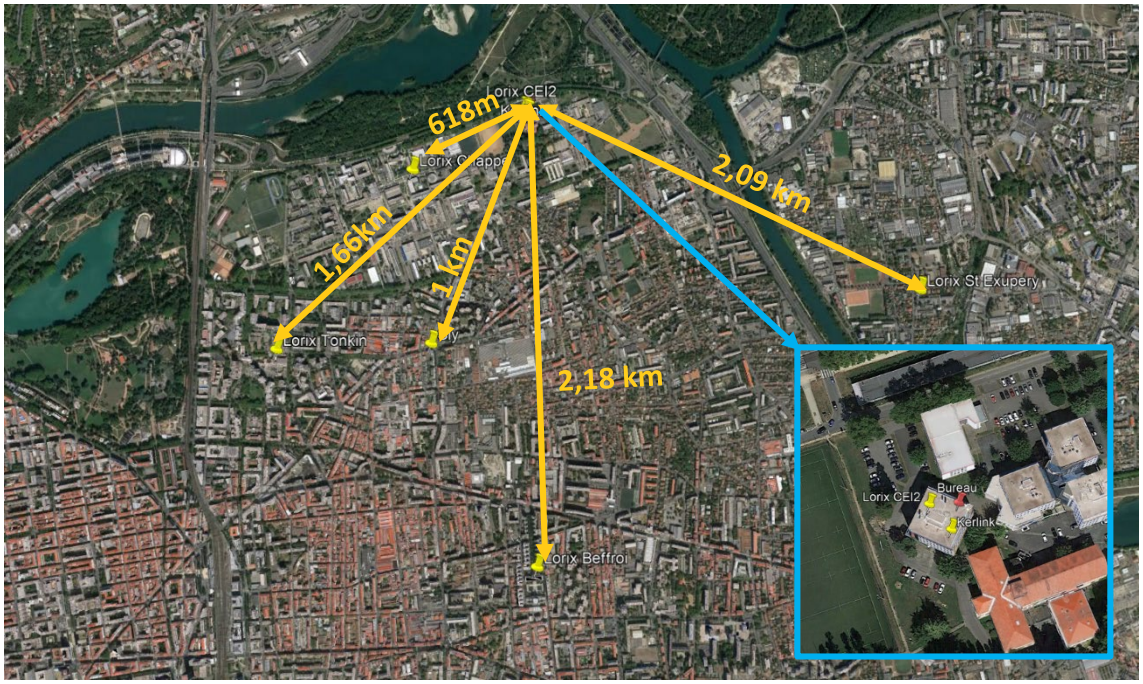
Experiments setup

- 7 GW in range
  - 5 Lorix One
    - SX1257
  - 1 Kerlink
    - SX1257
  - 1 unknown



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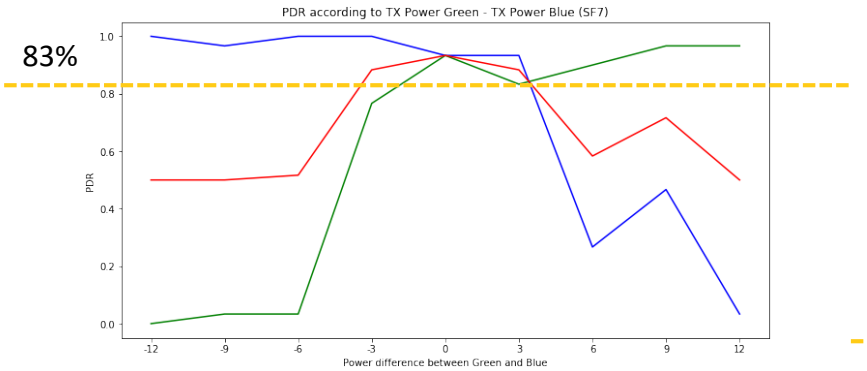
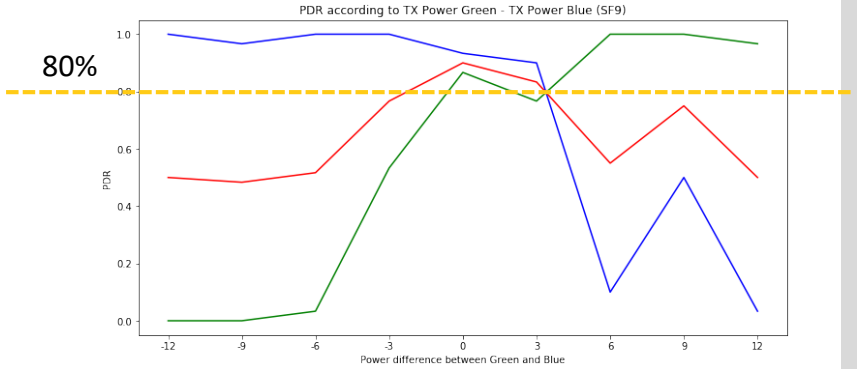
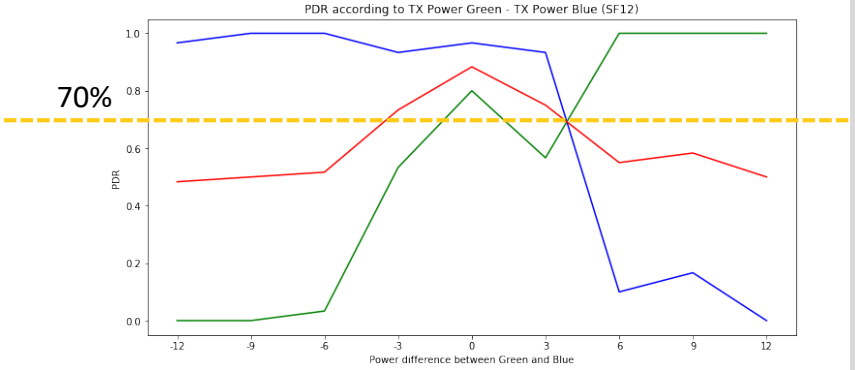
Simultaneous TX results



Overall PDR for SF7



Overall PDR for SF9



Overall PDR for SF12

Node Green
Node Blue
Overall

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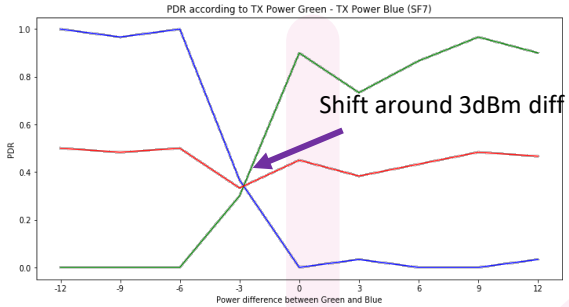
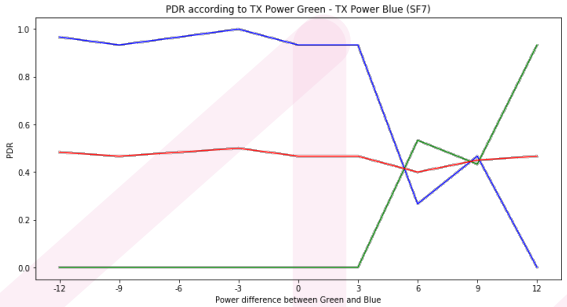
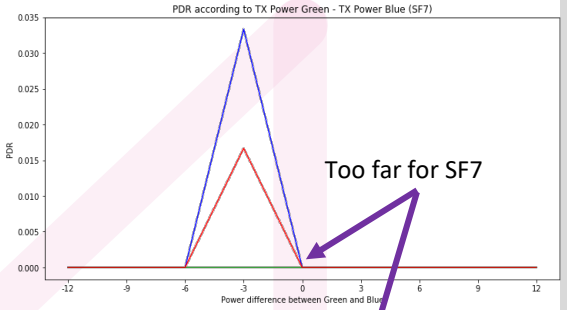
Simultaneous TX results (per GW – SF7)



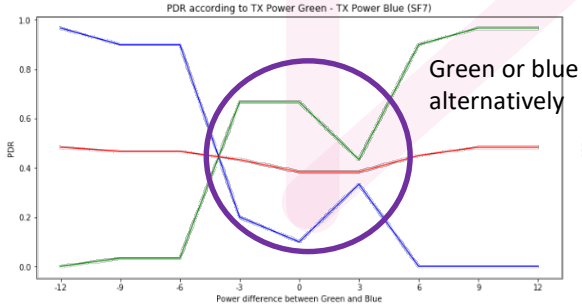
Kerlink (closest)



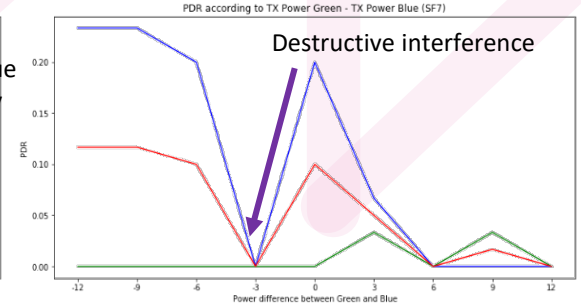
Chappe



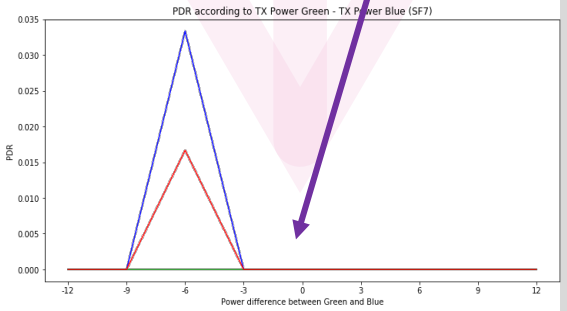
Tonkin



CEI2

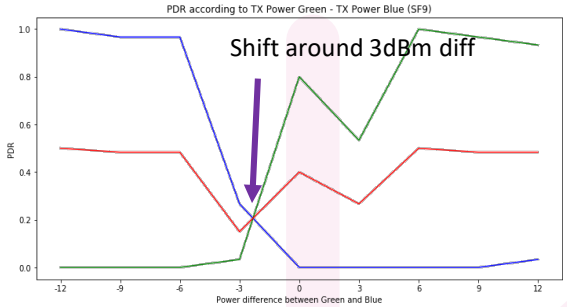


Beffroi

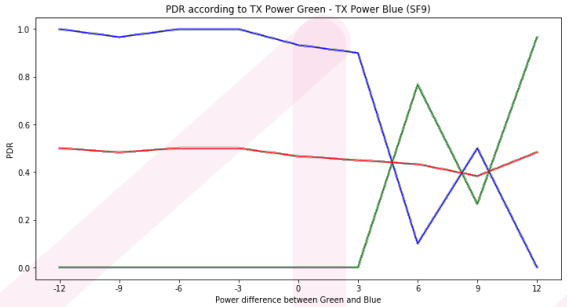


St Exupéry (furthest)

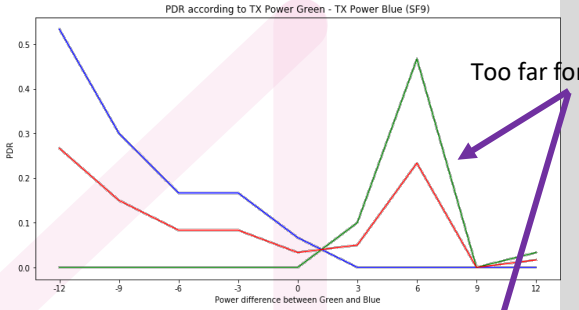
Simultaneous TX results (per GW – SF9)



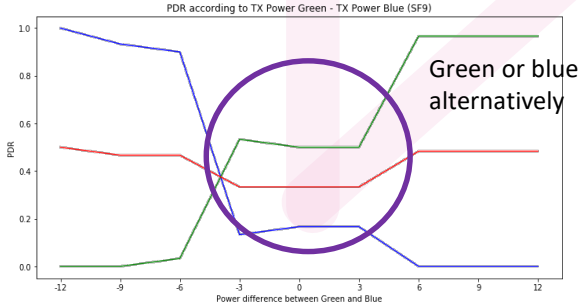
Kerlink (closest)



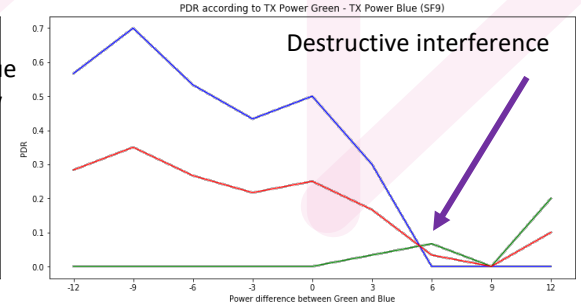
Chappe



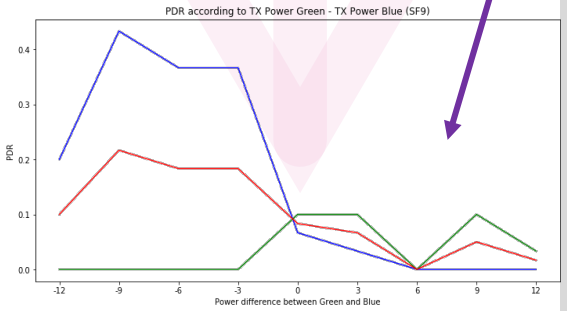
Tonkin



CEI2

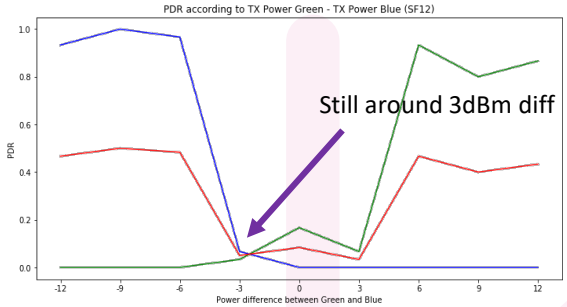


Beffroi

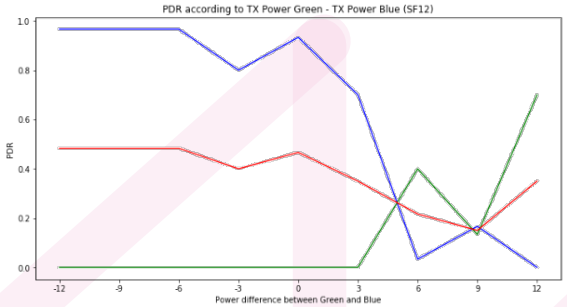


St Exupéry (furthest)

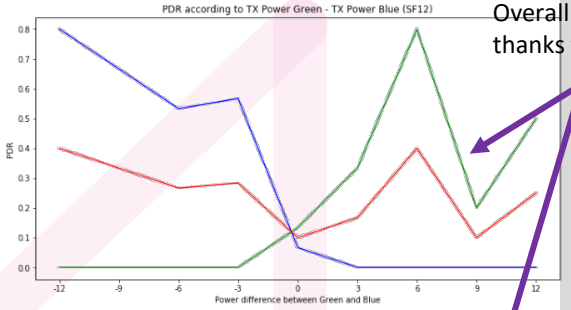
Simultaneous TX results (per GW – SF12)



Kerlink (closest)

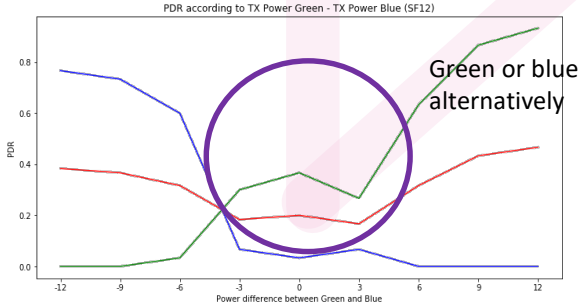


Chappe

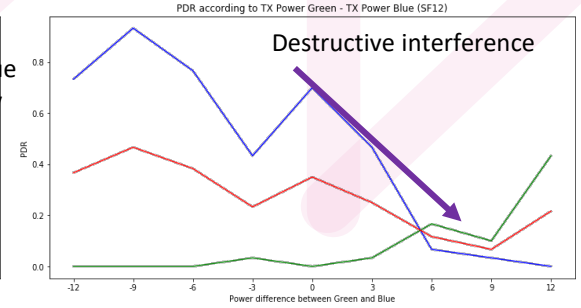


Tonkin

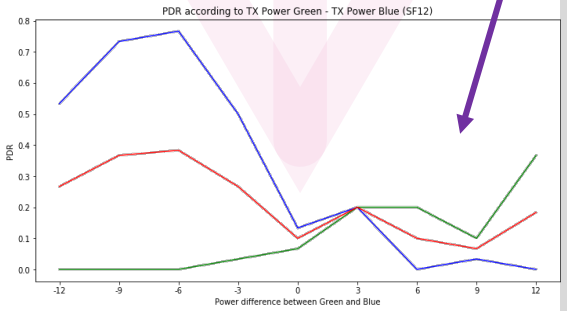
Overall better thanks to SF12



CEI2



Beffroi



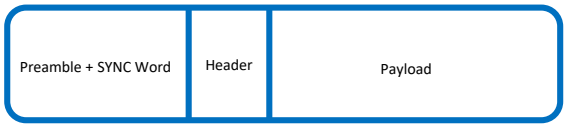
St Exupéry (furthest)

Simultaneous TX results (analysis)

- **Shift around 6 <-> 3 dBm difference**
  - Contrarily to 2dBm expected in Bor & al [1]
- **Results vary depending on various parameters:**
  - No « all or nothing » behavior
  - Gateway distance impacts SNR and decoding
    - The furthest from the GW, the more dependant on Tx power difference
  - Spreading factor impacts signal which in turn impacts capture effect
  - TX power as expected
- **Due to unconclusive results with furthest gateways, next results will focus on Chappe, CEI and Kerlink gateways**

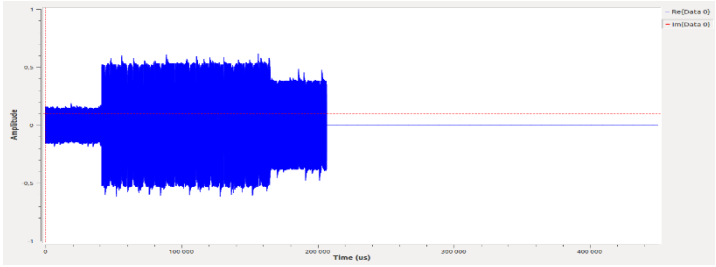
[1] - Bor, Martin C., et al. "Do LoRa low-power wide-area networks scale?." Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems. ACM, 2016.

Delayed TX experiments setup

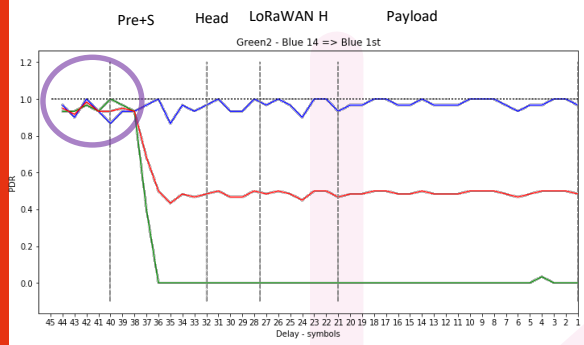


- **Same USB dongles**
- **LoRa parameters**
  - SF 9
  - CR 4/5
  - BW 125
  - 868,1 MHz
- **LoRaWAN frame**
  - Preamble + Sync word: 8 symbols
  - LoRaWAN header: 13 bytes
  - Payload: 4 bytes
  - Total: 40,25 symbols

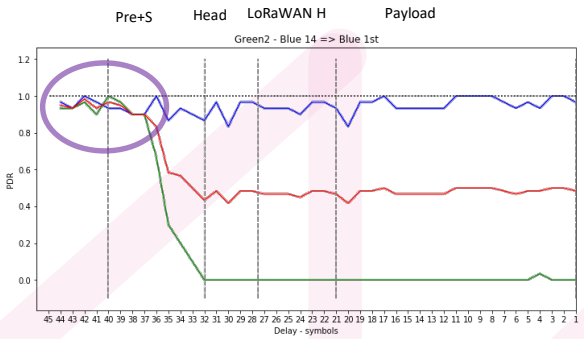
- **Delay**
  - Delay in symbols
  - SF9 => T_{sym} = 4,096ms
  - $-45T_{sym}$ <-> $+45\ T_{sym}$
- **Tx power**
  - Ranging from 2 <-> 14dBm



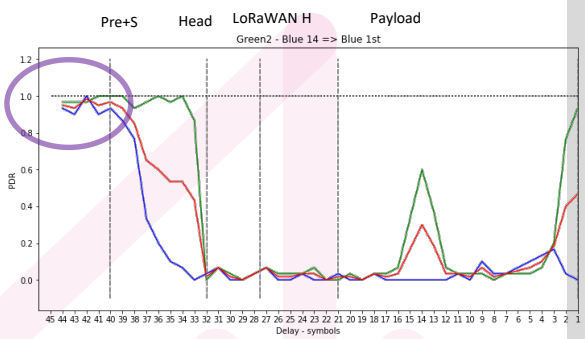
Delayed TX results (Blue 14dBm – Green 2dBm)



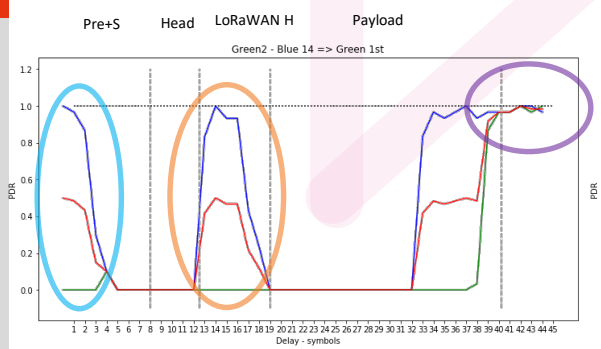
Kerlink

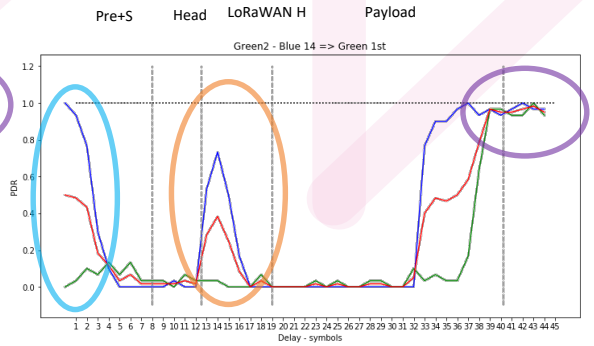


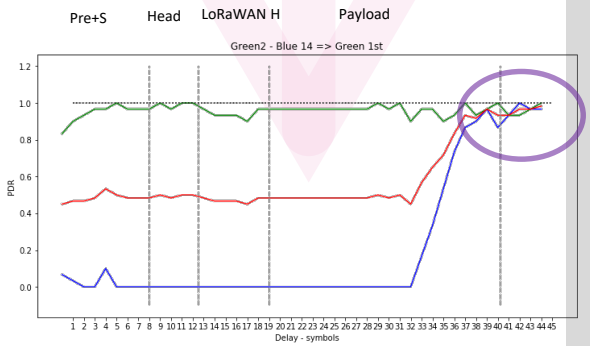
CEI 2



Chappe







Frame A after end of Frame B

Frame B before and after SYNC word of Frame A

Frame B Payload/CRC during header of Frame A

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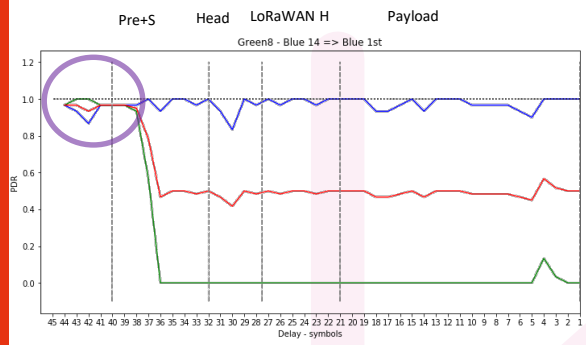
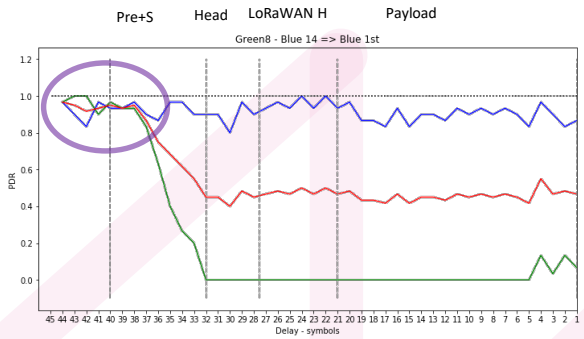
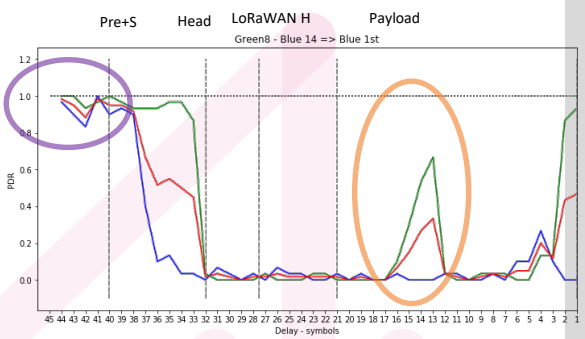
Delayed TX results (Blue 14dBm – Green 8dBm)



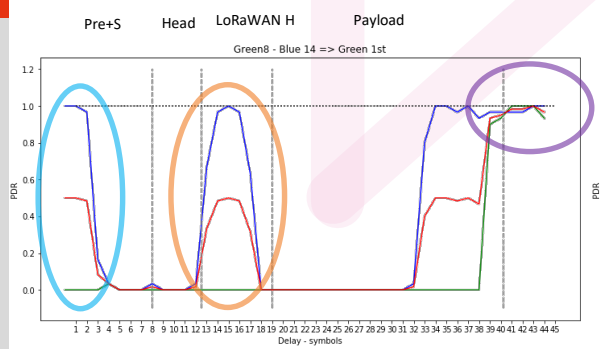
Kerlink

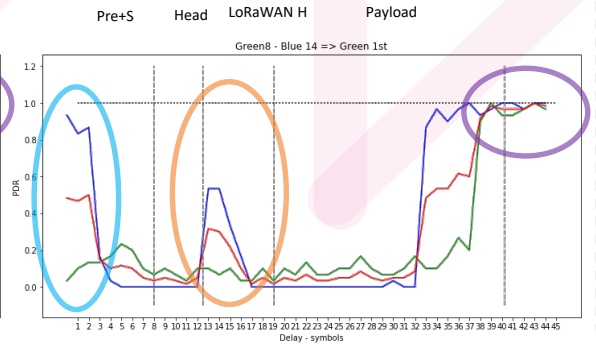


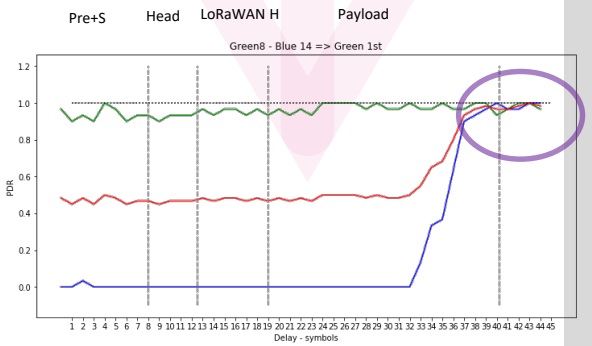
CEI 2



Chappe







Frame B after end of Frame A

Frame B before and after SYNC word of Frame A

Lower power difference => lower PDR

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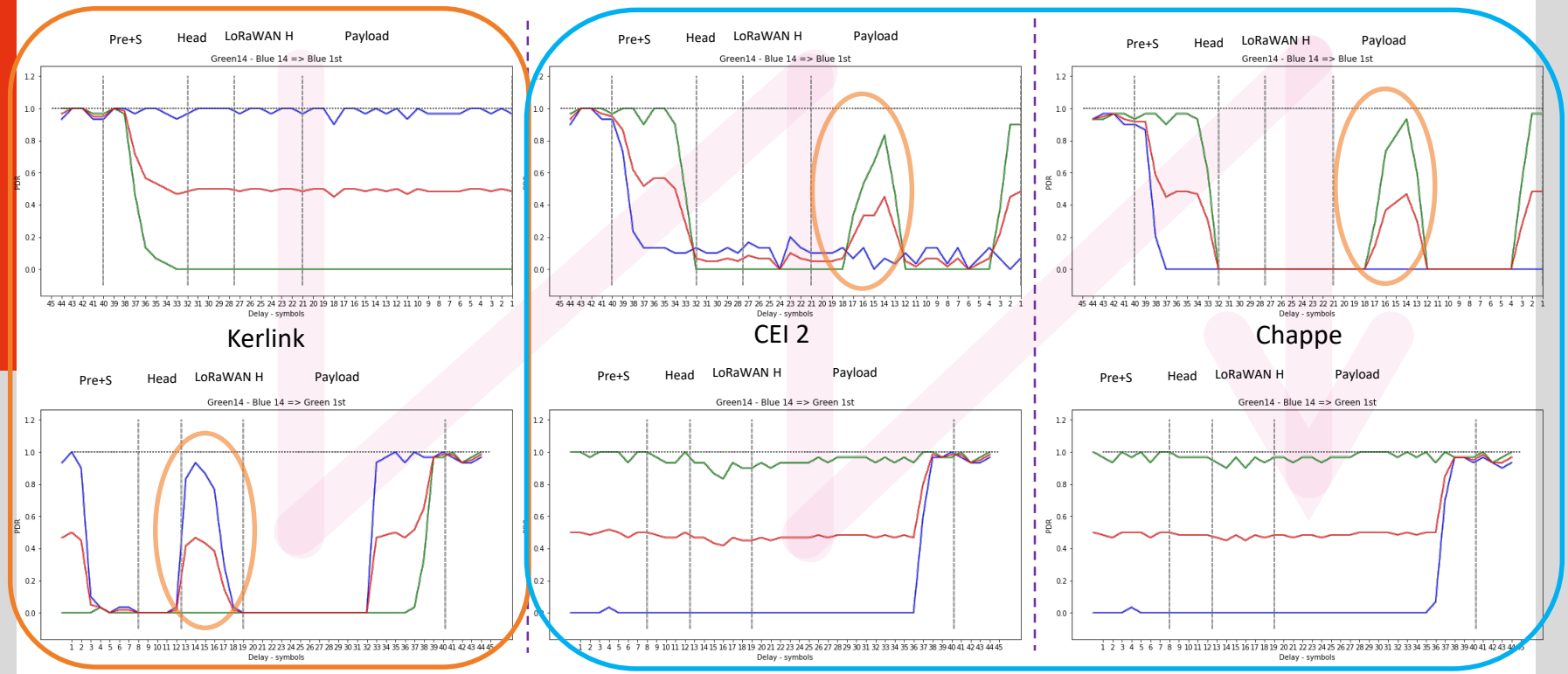
Delayed TX results (Blue 14dBm – Green 14dBm)



Green node sensed as stronger than Blue

Blue node sensed as stronger than Green

Delayed TX results (analysis)

- **Results vary depending on various parameters:**
  - Gateway distance
    - RSSI/SNR values dictates the behavior of the capture effect
  - TX power
    - Stronger signal when sent first is always received
  - Delay
    - Main switch points
    - LoRaWAN header
    - Preamble and before SYNC word
    - Payload / CRC

Future works & Perspectives

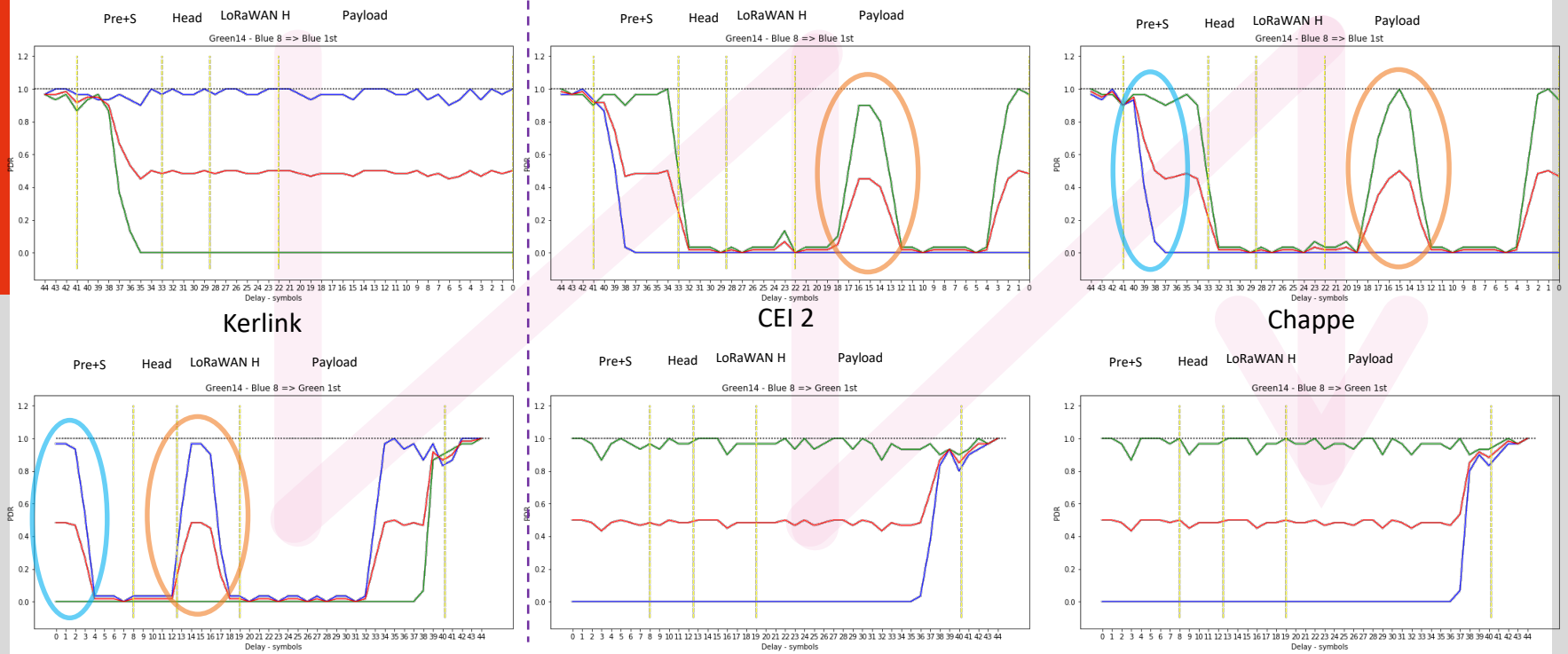
- **Run experiments from different locations**
  - Have node at different locations simultaneously sending uplink
  - Main issue => microsecond level synchronization needed
  - Already looking into PTP
- **Have more than 2 nodes involved**
- **Heterogeneous sources**
- **Take advantage of the capture effect to improve capacity of LoRa cells**

Thanks !

BTW currently looking for a postdoc position

aziz.mbacke@inria.fr

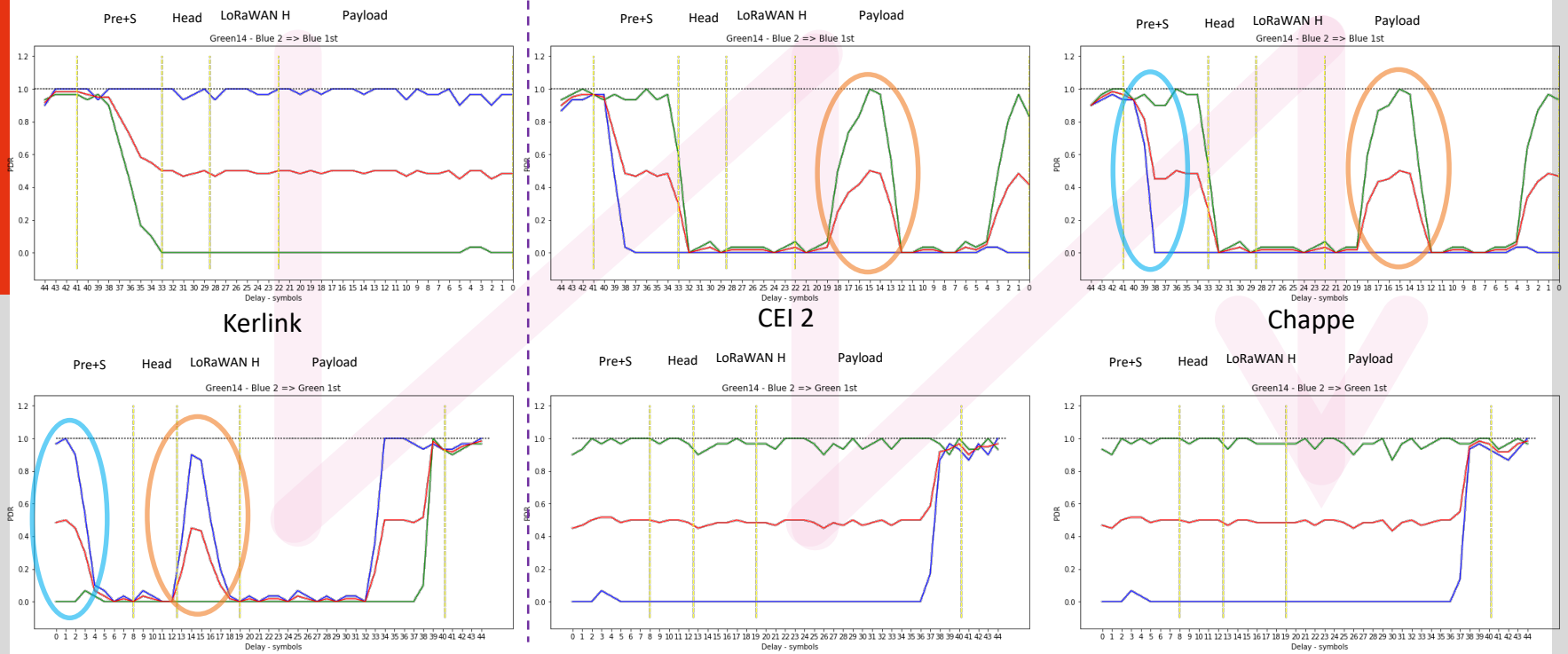
Delayed TX results (Blue 8dBm – Green 14dBm)



Frame B before and after SYNC word of Frame A

Frame B during header of Frame A

Delayed TX results (Blue 2dBm – Green 14dBm)



Frame B before and after SYNC word of Frame A

Frame B Payload/CRC during header of Frame A

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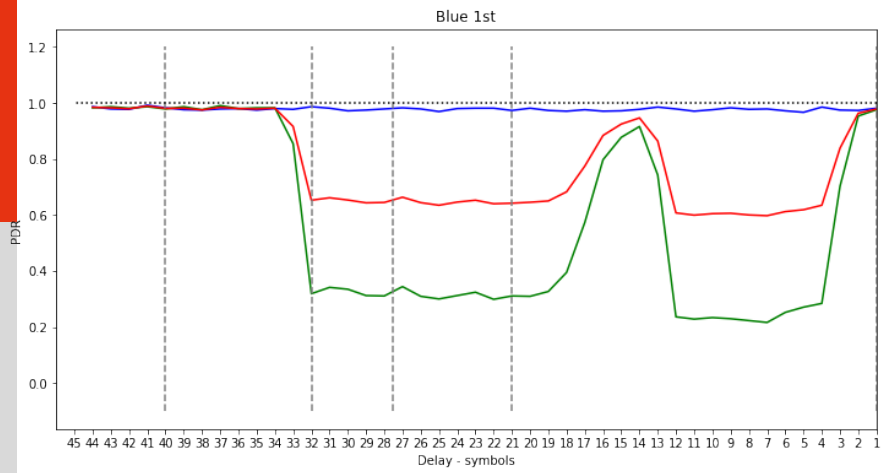
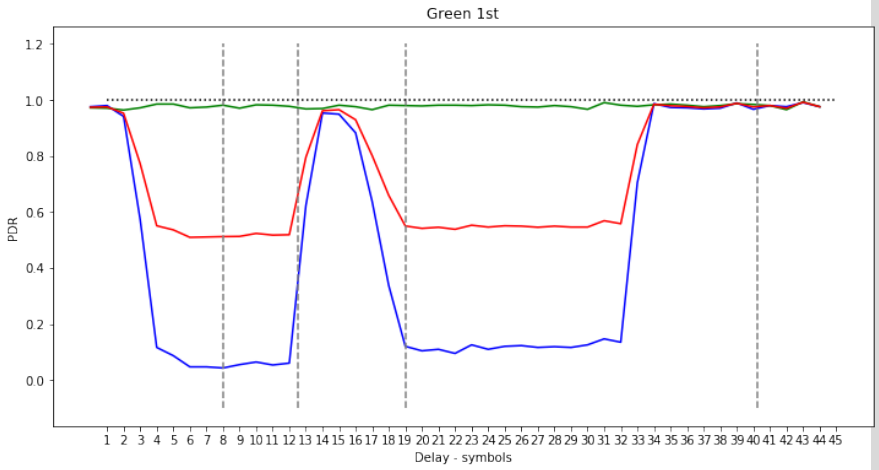
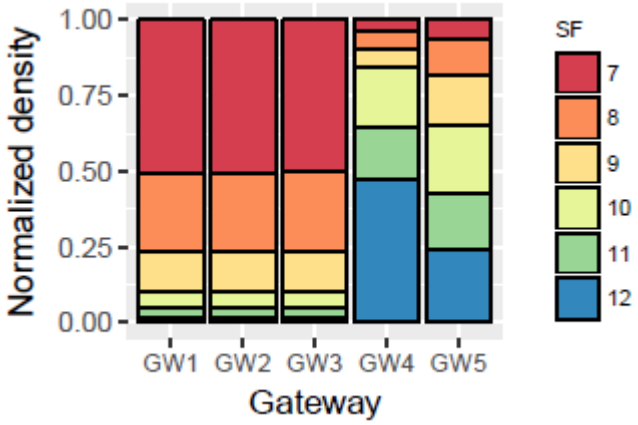
Delayed TX overall results

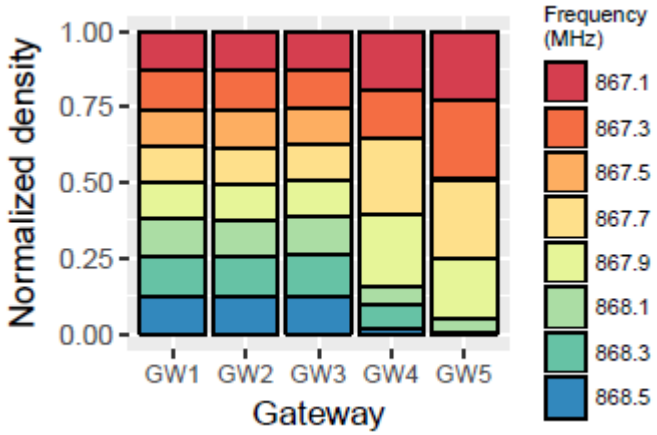




Influence of different LoRa parameters

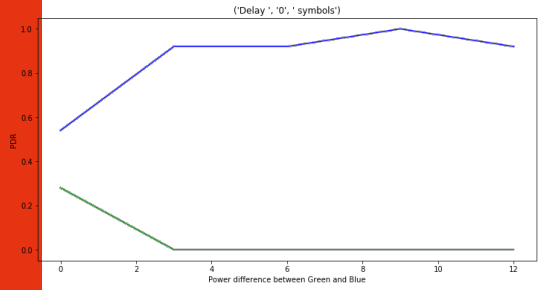


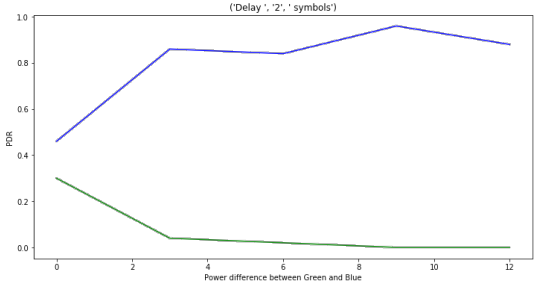
Influence of SF depending on distance

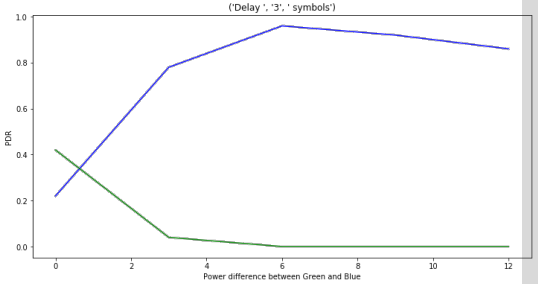


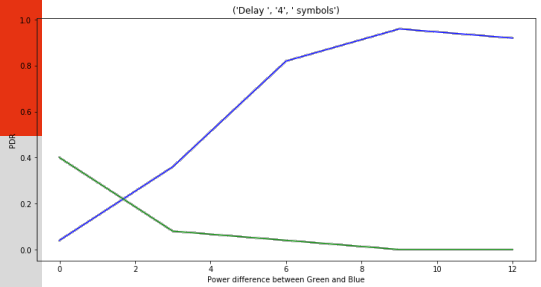
Influence of Freq depending on distance

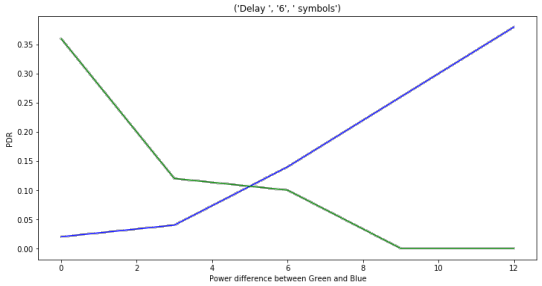
For GW Chappe

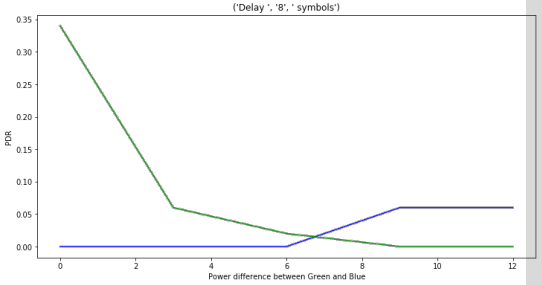


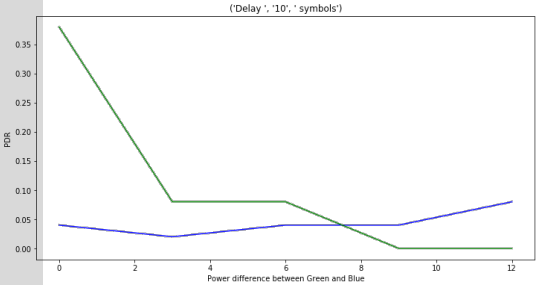


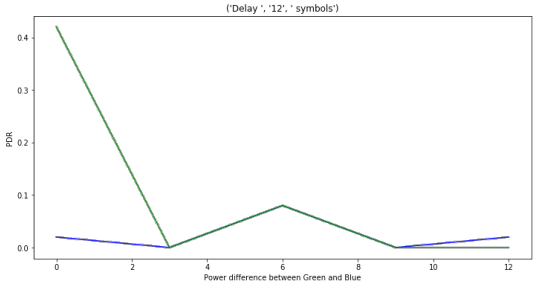


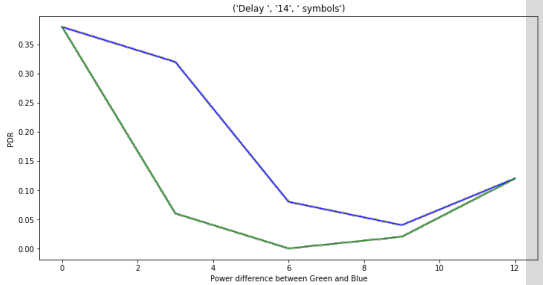












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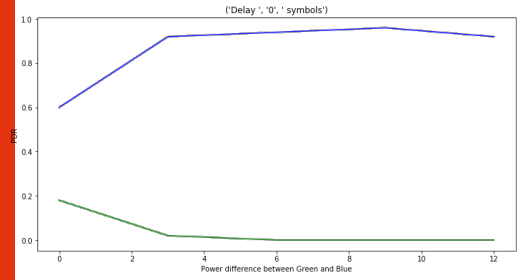
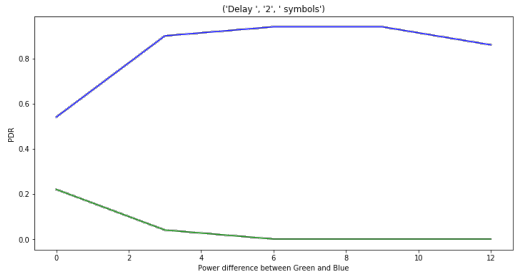
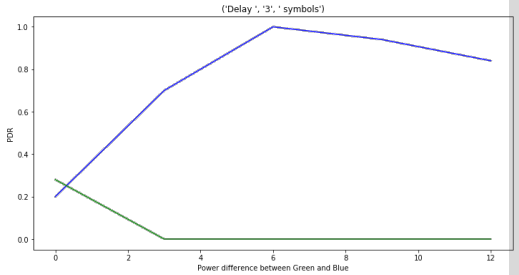
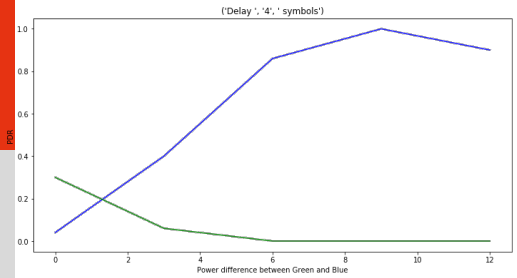
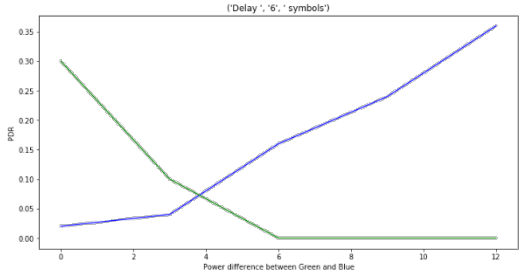
For GW CEI2

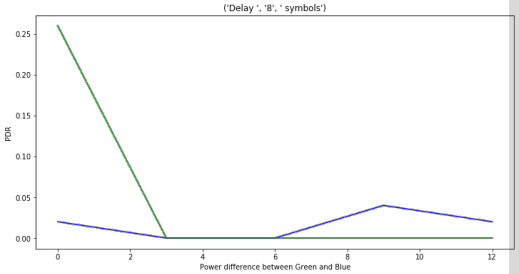


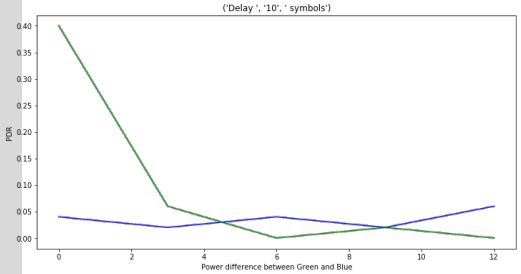


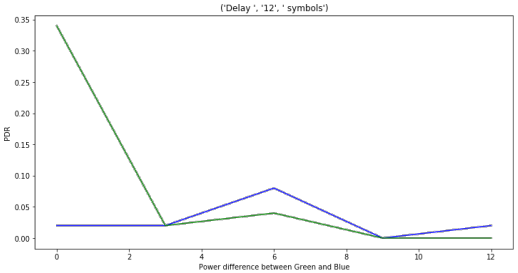


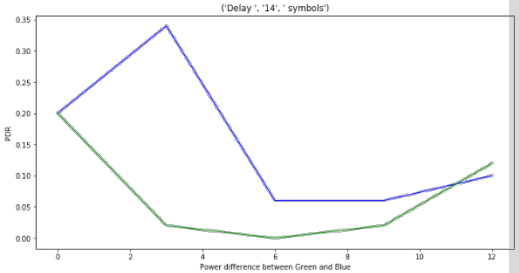












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