

Experimental results on the coexistence of LoRa and Wi-Fi in the 2.4 GHz ISM band

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2. METHODOLOGY AND EXPERIMENT DESCRIPTION
3. COEXISTENCE EXPERIMENT RESULTS
4. PERSPECTIVES

PROBLEM STATEMENT

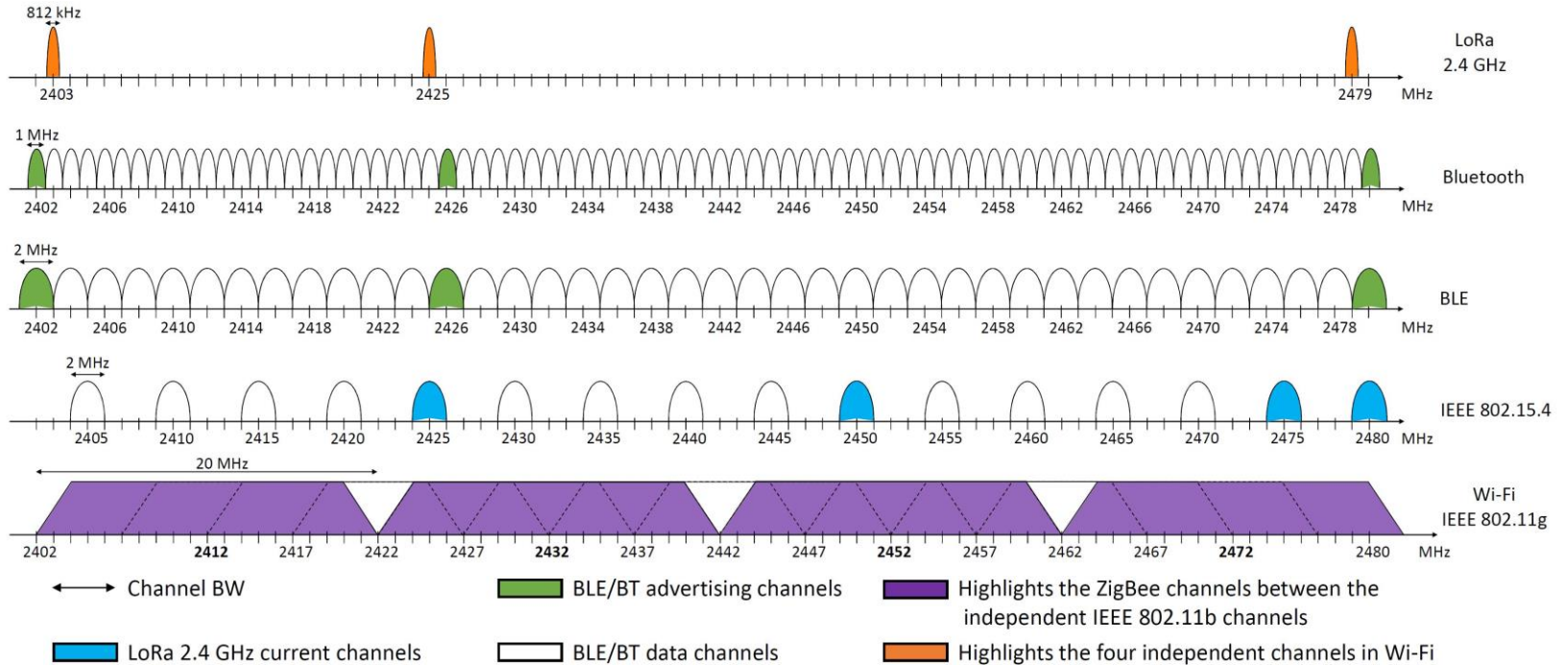


Figure 1 – Spectrum occupancy of LoRa and the main wireless technologies using the 2.4 GHz ISM band.



LORA IN THE 2.4 GHZ ISM BAND

→ no duty-cycle, worldwide available set of frequencies and common regional parameters

The 2.4 GHz ISM band is overcrowded (Wi-Fi, BT, microwave oven, etc)

→ How to manage interference between LoRa and other technologies working in the 2.4 GHz ISM band such as Wi-Fi?

Motivation for studying coexistence

→ Only few papers focus on the coexistence of LoRa with other technologies using the 2.4 GHz ISM band [1] [2]

→ Wi-Fi is the main wireless technologies of the 2.4 GHz ISM band and is deployed everywhere

METHODOLOGY FOR STUDYING THE COEXISTENCE BETWEEN LORA AND WI-FI

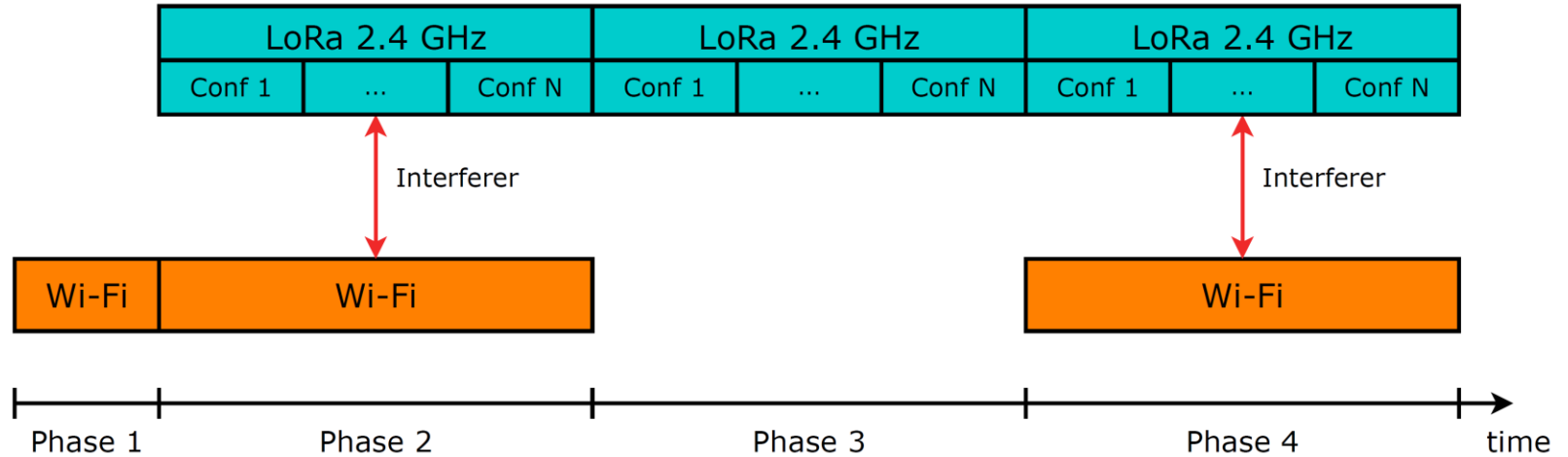


Figure 2 – Coexistence experiment timeline divided into four phases: (1) Wi-Fi only, (2) Wi-Fi + LoRa, (3) LoRa only, and (4) LoRa + Wi-Fi.



EXPERIMENTAL SETUP AND METRICS

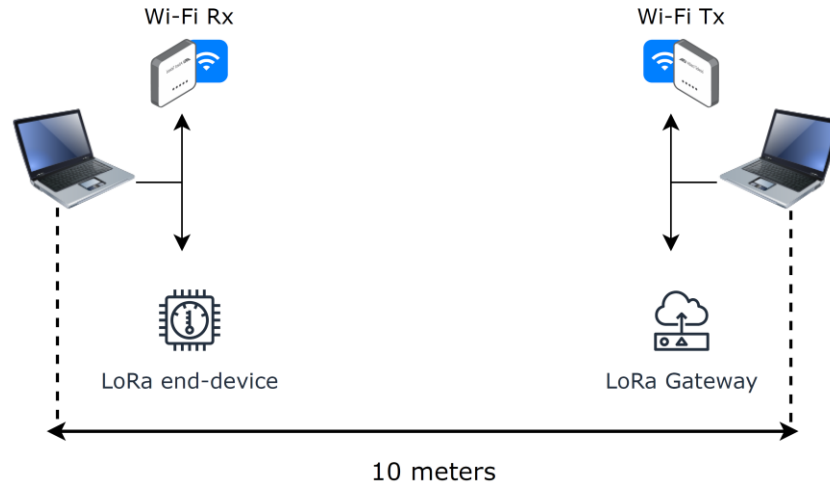


Figure 3 – Experimental setup.

- **Variable experiments parameters:** **LoRa configurations**, LoRa occupancy channel rate, IEEE 802.11 standard, **experiment topology**
- **Metrics:** frame delivery ratio (**FDR**), RSSI, SNR

EXPERIMENT SCENARIO AND CONFIGURATIONS

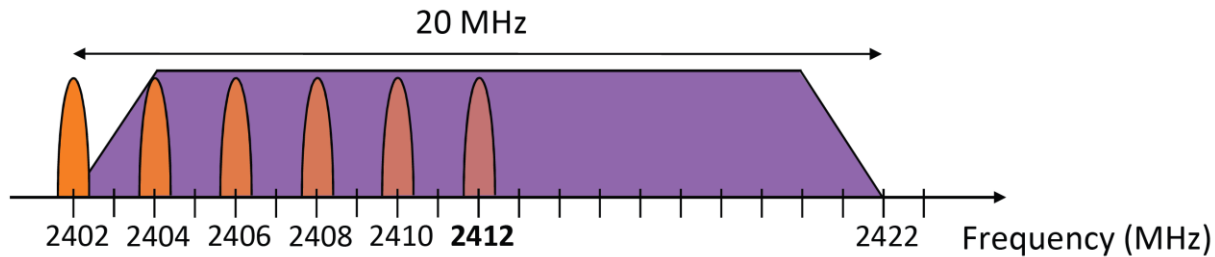
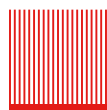


Figure 4 – Evaluated LoRa channels and Wi-Fi channel.

Technology	Configuration number	PHY Configuration	Center frequency (in MHz)	Payload size (in bytes)	Time on Air (in ms)
Wi-Fi	/	802.11g, BW 20 MHz	2412 (channel 1)	1400	1
LoRa	1 (highest reliability)	SF12, BW203, CR4/8	2402, 2404,	20	1054
	2 (intermediate)	SF9, BW812, CR4/8	2406, 2408,		38
	3 (highest data rate)	SF6, BW1625, CR4/5	2410, 2412		3

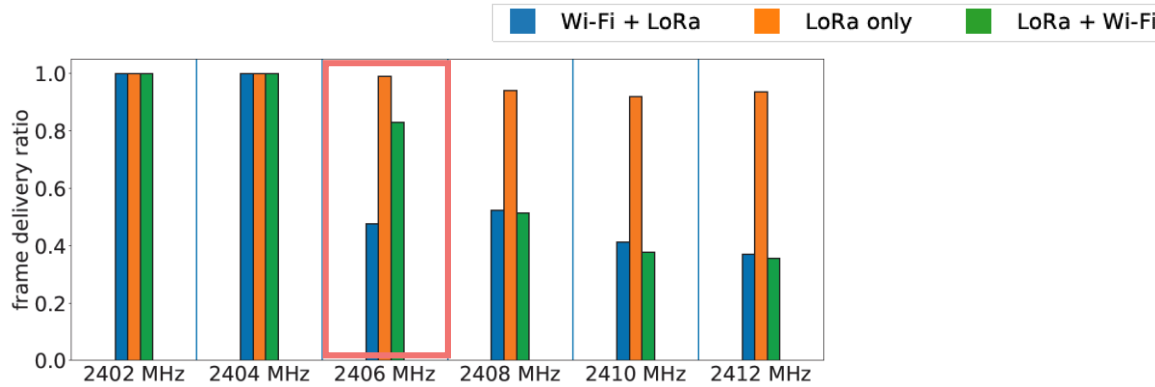
Table 1 – Parameters of the coexistence experiments.





IMPACT OF THE LORA CHANNEL (1/2)

How does LoRa channel impacts LoRa communication reliability in term of FDR?



a) LoRa FDR for configuration 2 (intermediate)

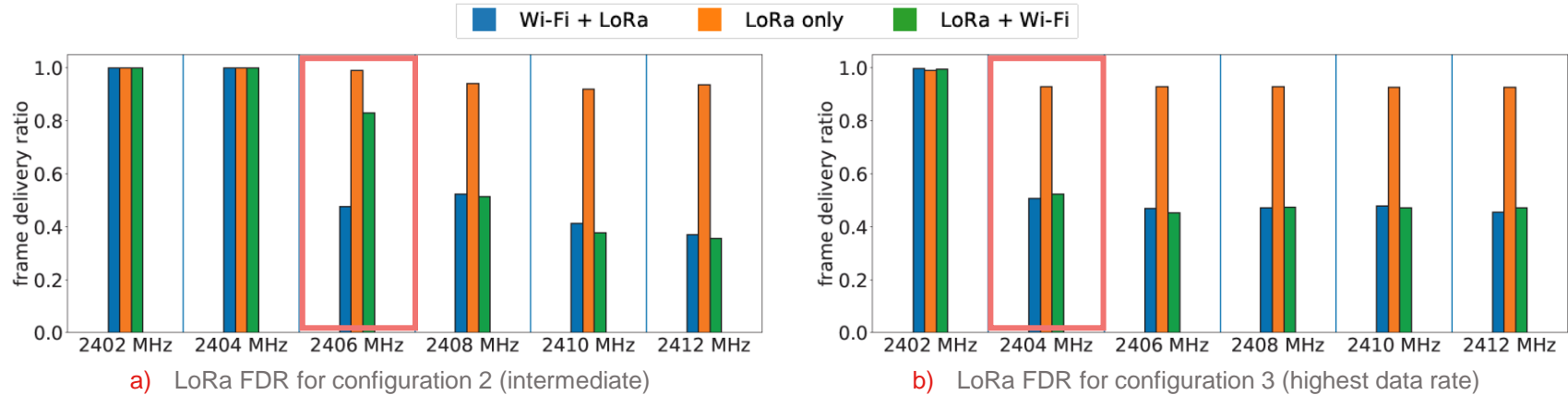
→ The LoRa FDR increases by decreasing the frequency offset between LoRa and Wi-Fi center frequency channels.



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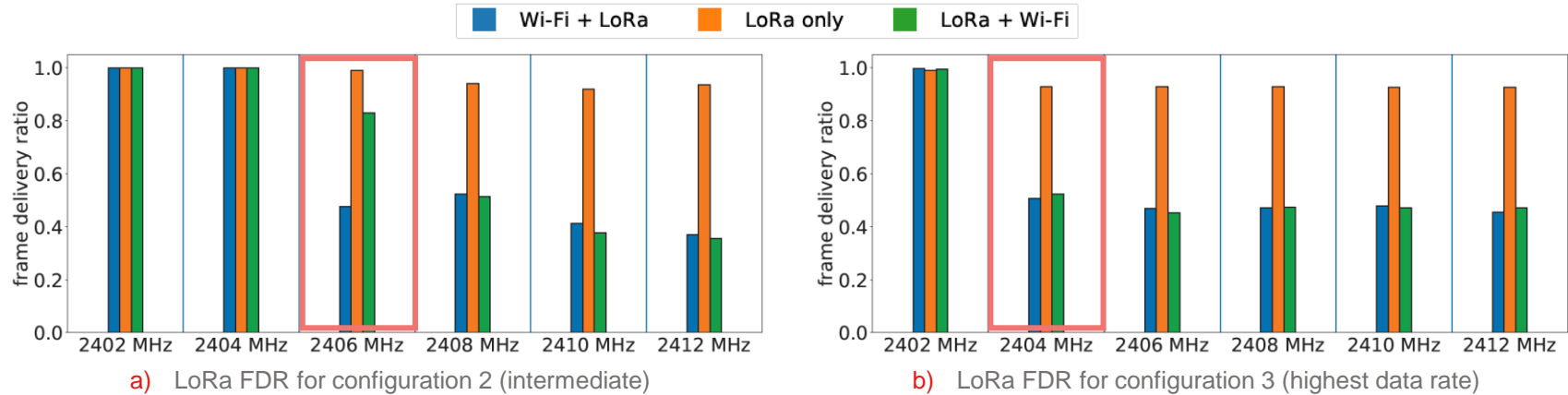


- The LoRa FDR increases by decreasing the frequency offset between LoRa and Wi-Fi center frequency channels.
- LoRa center frequency channel impacts more LoRa less robust configurations.

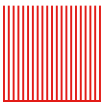
IMPACT OF THE LORA CHANNEL (1/2)



How does LoRa channel impacts LoRa communication reliability in term of FDR?



- The LoRa FDR increases by decreasing the frequency offset between LoRa and Wi-Fi center frequency channels.
- LoRa center frequency channel impacts more LoRa less robust configuration.
- LoRa configuration 1 always provides a FDR of 100% independently of the channel. **(not presented here)**
- LoRa channels have to be taken into account for future LoRa networks deployment in order to ensure a good coexistence with Wi-Fi.





IMPACT OF THE LORA CHANNEL (2/2)

How does LoRa channel impacts Wi-Fi communication reliability in term of FDR?

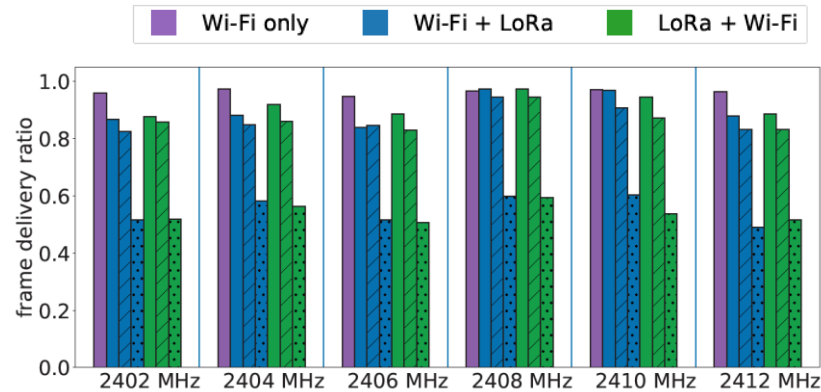
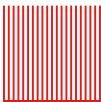


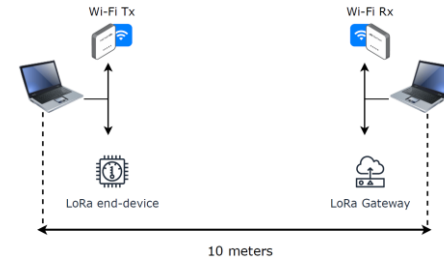
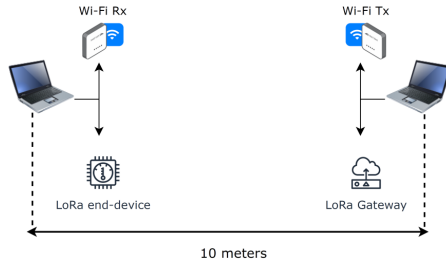
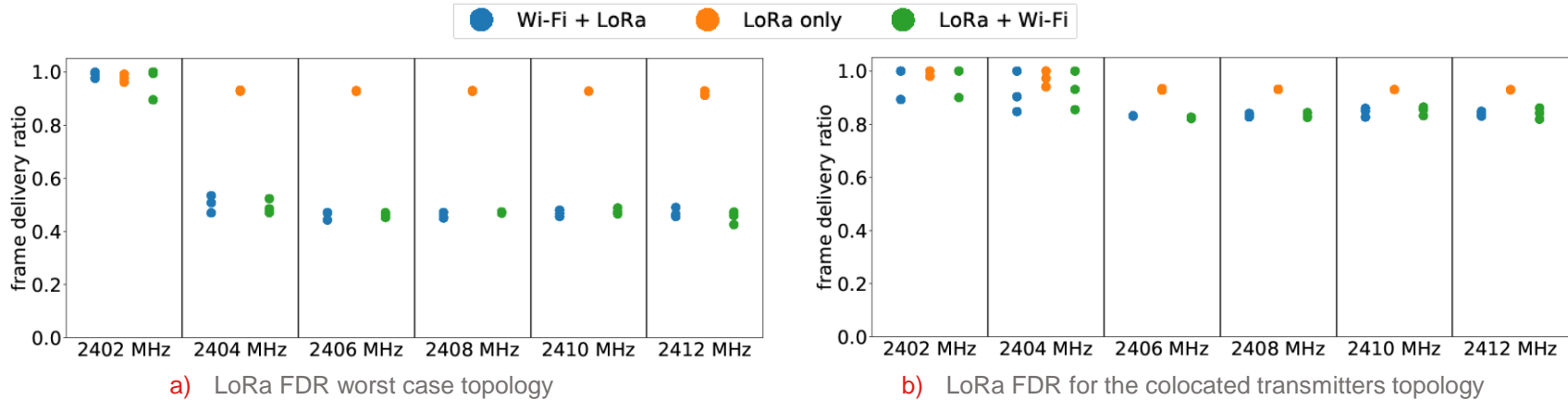
Figure 4 – Wi-Fi FDR depending on LoRa center frequency and configuration

- The Wi-Fi FDR is on average:
 - 91% when LoRa configuration 1 (highest reliability) is interfering.
 - 87% when LoRa configuration 2 (intermediate) is interfering.
 - 55% when LoRa configuration 3 (highest data rate) is interfering.
- LoRa frames with short time-on-air interfere more frequently with Wi-Fi traffic.
- The center frequency of the LoRa channel has no significant impact on Wi-Fi performance.



IMPACT OF EXPERIMENT TOPOLOGY (1/2)

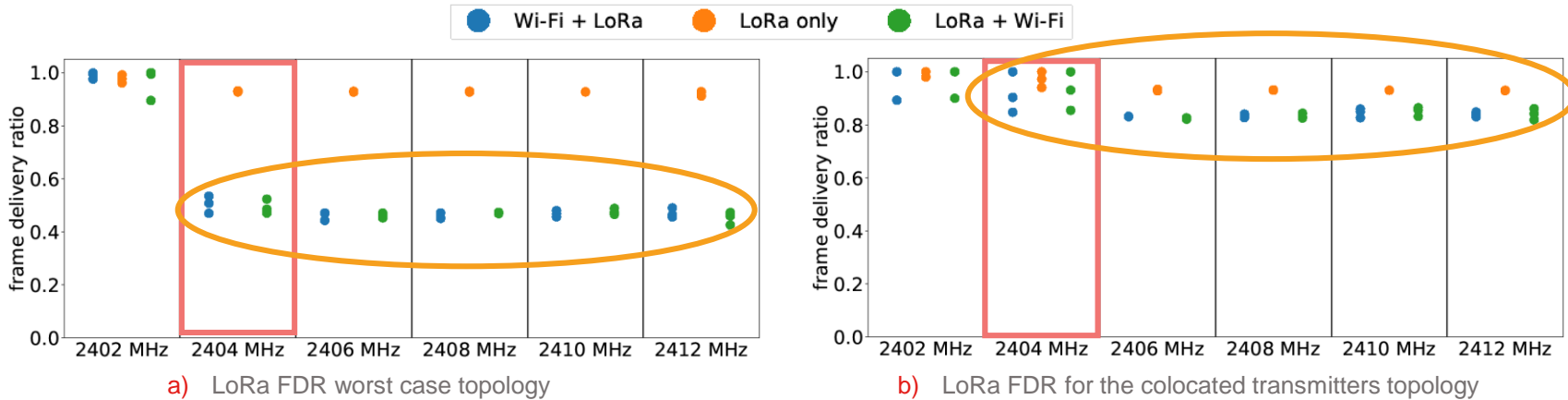
How does the distance between LoRa and Wi-Fi equipments impacts LoRa FDR?



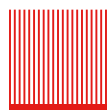


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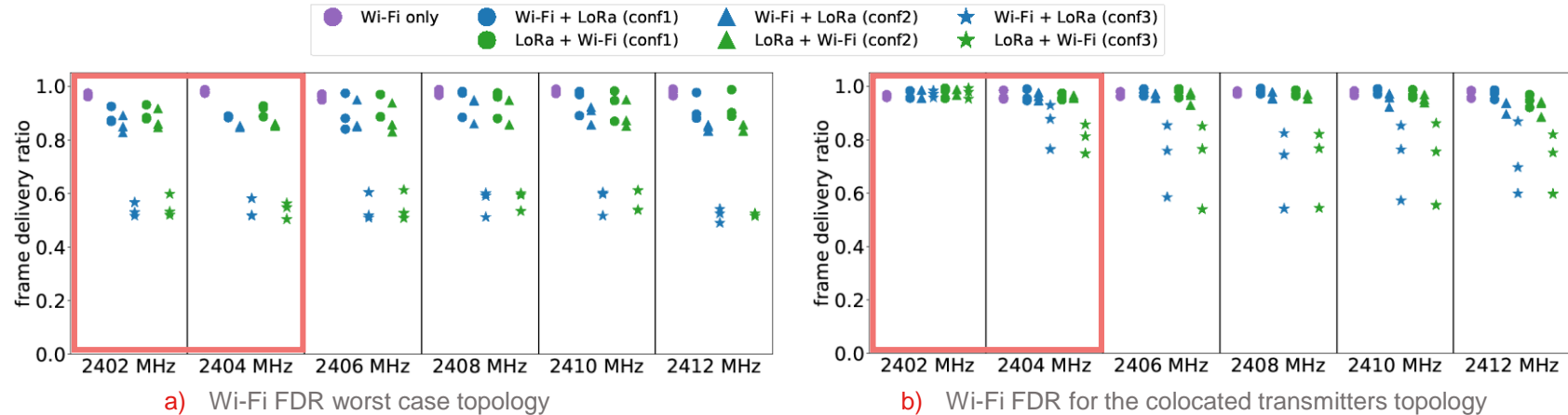


- Changing the topology reduces the interference between LoRa and Wi-Fi:
 - **Configuration 3 (highest data rate):** LoRa FDR increases from 47% to 84%.
- LoRa configuration 1 always provides a FDR of 100% independently of the experiment topology. (**not presented here**)
- LoRa FDR configuration 2 increases from 36% to 90%.



IMPACT OF EXPERIMENT TOPOLOGY (2/2)

How does the distance between LoRa and Wi-Fi equipments impacts Wi-Fi FDR?



- The FDR improvement of changing the experiment topology is only noticeable for LoRa traffic centered at 2402 MHz and 2404 MHz.
- The topology of the experiments has more impact on the Wi-Fi FDR than the center frequency of the LoRa channel.



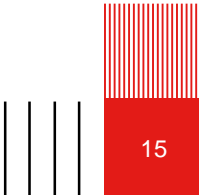
COEXISTENCE EXPERIMENT TAKEAWAY

What is the impact when there are LoRa and Wi-Fi concurrent transmissions on both technologies' communication reliability, in terms of FDR?

LoRa:

- LoRa configuration 1 always provides a FDR of 100% regardless of the parameter that varies.
- LoRa channels centered at 2402 and 2404 MHz provide a FDR of 100% at least for configurations 1 and 2.
 - The Semtech proposal of a LoRa channel centered at 2403 MHz is a good option.
- Maximising the distance between LoRa gateways and Wi-Fi Aps increases LoRa FDR.

Wi-Fi:





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Wi-Fi:

- Wi-Fi FDR decreases according to the time-on-air of LoRa frames.
- The center frequency of the LoRa channel has no significant impact on Wi-Fi performance.
- For a fixed LoRa occupancy channel rate the Wi-Fi FDR depends on (1) the LoRa configuration, (2) the LoRa topology deployment, and (3) the LoRa center frequency channel.
- The higher the LoRa occupancy channel rate, the lower the Wi-Fi FDR. (**not presented here**)

These results are under submission [\[1\]](#).





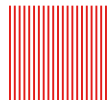
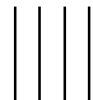
WHAT'S NEXT?

Coexistence experiments extension:

- Evaluate other IEEE 802.11 standards
 - IEEE 802.11b which uses the same type of modulation as LoRa (spread spectrum)
 - IEEE 802.11ax which is the most recent IEEE 802.11 standard and uses an OFDM modulation
- Evaluate other wireless technologies of the 2.4 GHz ISM band such as Bluetooth

How to improve the coexistence of LoRa and Wi-Fi in the 2.4 GHz ISM band?

- Implementing interference mitigation mechanisms such as frequency hopping



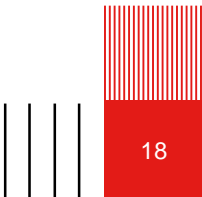


REFERENCES

[1] L. Polak and J. Milos, “Performance analysis of LoRa in the 2.4 GHz ISM band: coexistence issues with Wi-Fi,” *Telecommunication Systems*, vol. 74, no. 3, pp. 299–309, Jul. 2020.

[2] L. Polak, F. Paul, M. Simka, R. Zedka, J. Kufa, and R. Sotner, “On the Interference between LoRa and Bluetooth in the 2.4 GHz Unlicensed Band,” in *2022 32nd International Conference Radioelektronika (RADIOELEKTRONIKA)*, Apr. 2022, pp. 1–4.

[*] **G. Hochet Derévia****ckine**, A. Guitton, O. Iova, B. Ning, and F. Valois, “Hate or Love in the 2.4 GHz ISM band: The Story of LoRa and IEEE 802.11g,” Nov. 2023. (under review)





Thanks for your attention
Questions?