On Practical Coexistence Gaps in Space for LTE-U/WiFi Coexistence

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Technische Universität Berlin

TKN

Motivation

- **Rapid growth** in the use of smart phones / tablets and appearance of **new applications** like multimedia streaming & cloud storage.

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- **5 GHz band** is spectrum of choice for next-gen WiFi as 2.4 GHz is already very crowded.

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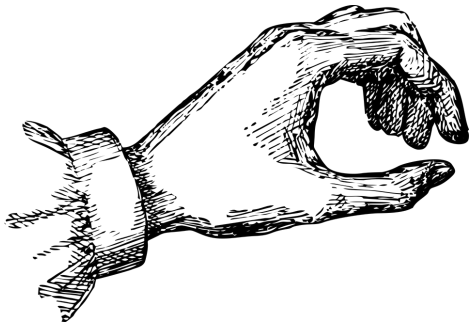
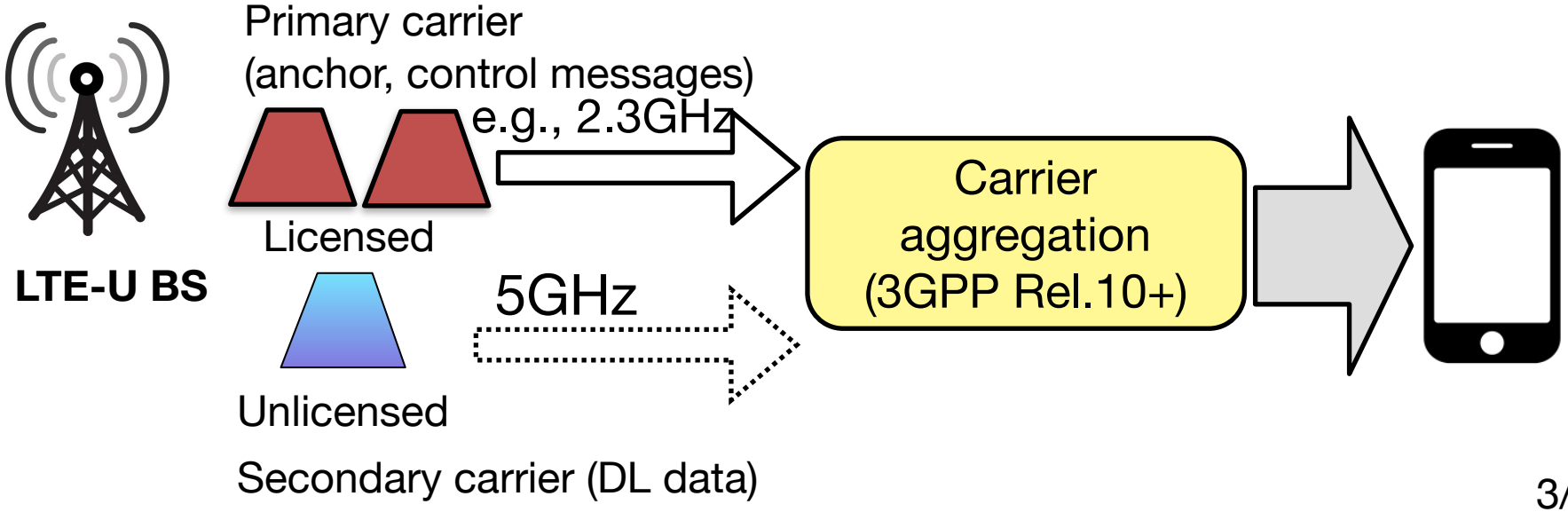
- To support rapid traffic growth cost-effective solutions for capacity expansion are needed,
  - Massive network densification using (small) cells with higher capacity per cell,
  - **Direct usage of unlicensed (free) spectrum**



LTE-Unlicensed Primer

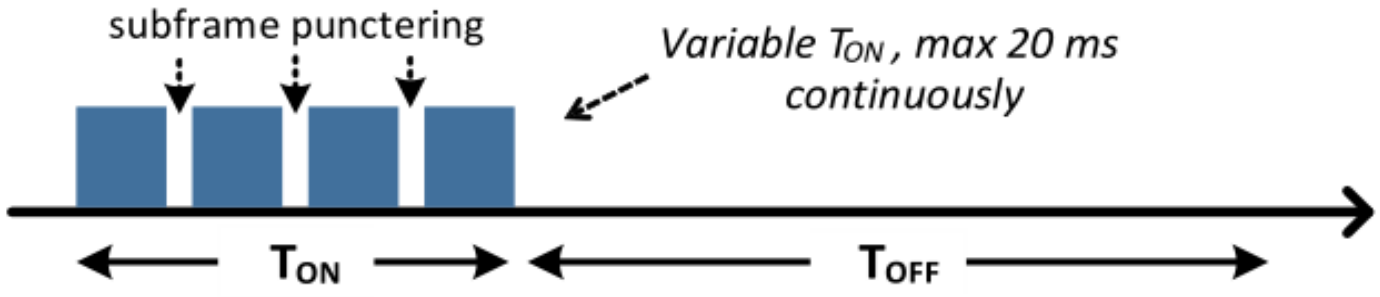
- First cellular solution for use of 5GHz unlicensed band
  - Channel bandwidth is 20MHz as in WiFi
- Two versions of LTE-Unlicensed:
  - LTE-LAA(LBT) and LTE-U(CSAT)



LTE-U CSAT

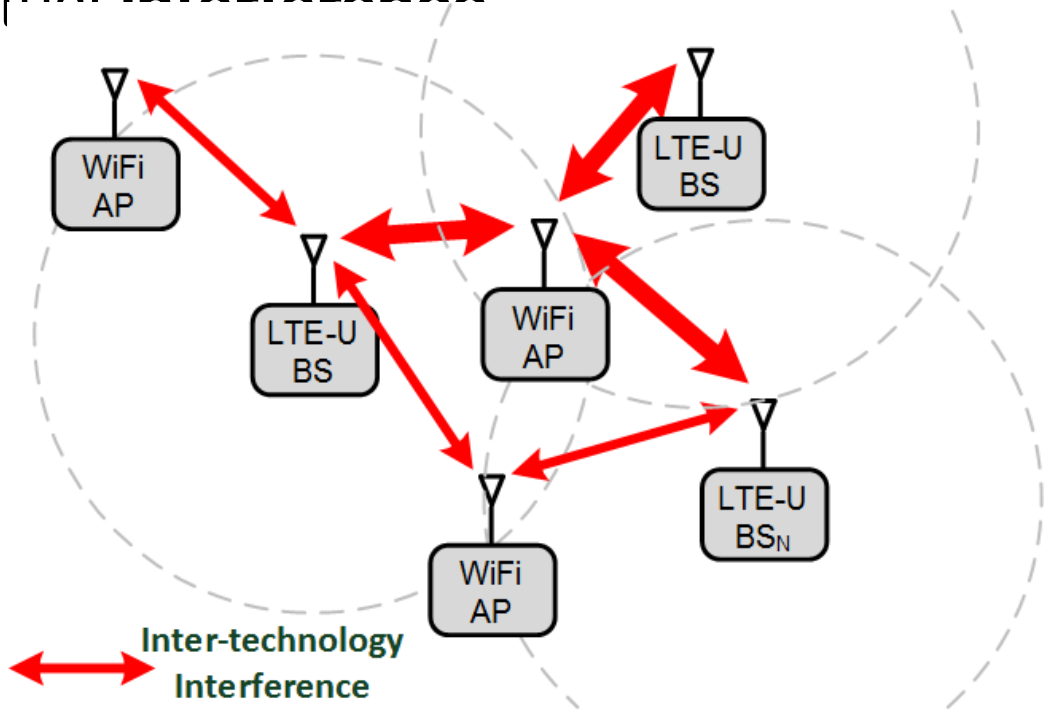
- Carrier Sense Adaptive Transmission (CSAT):
  - No Listen-Before Talk, but duty cycled channel access
  - Period: 40, 80, 160ms
  - Duty cycle adaptation based on number of WiFi and LTE nodes, max 50%

- Puncturing for low-latency WiFi traffic



Coexistence Issues

- LTE and WiFi compete for **shared radio resources** leading to performance degradation in both NWs due to:
  - *i)* increased **contention**,
  - *ii)* mutual **interference**



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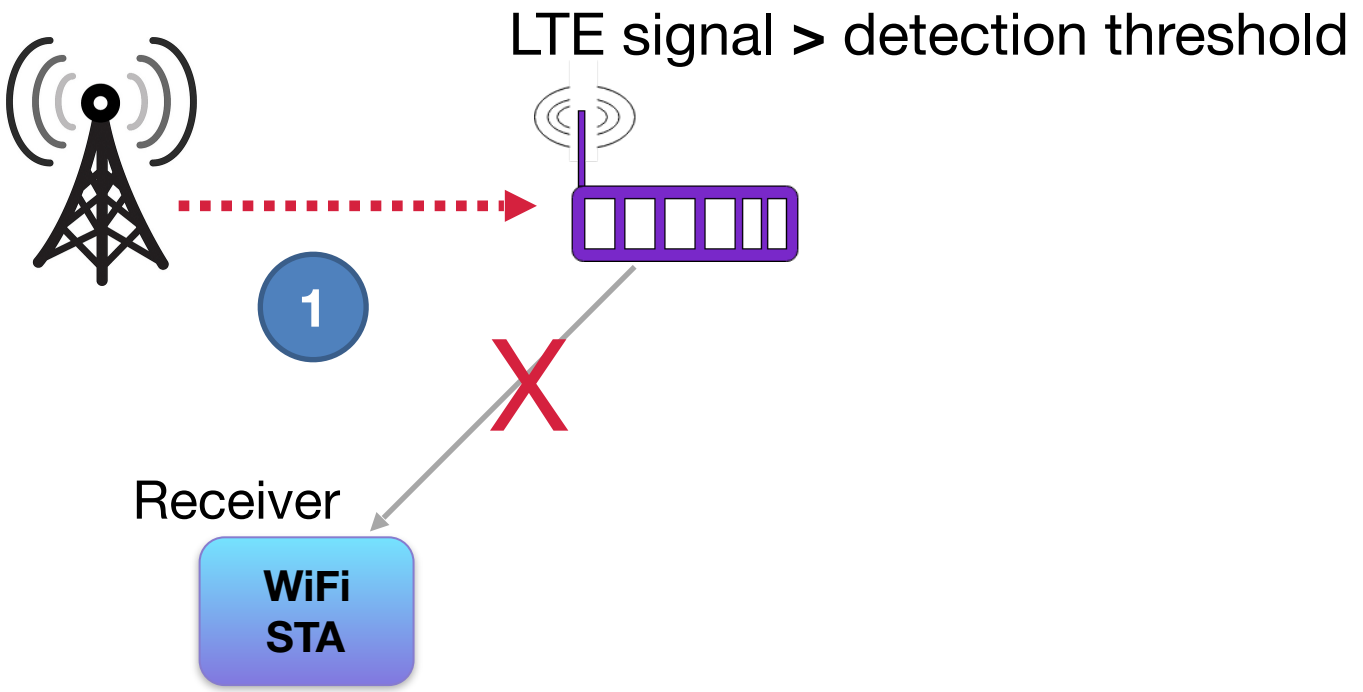

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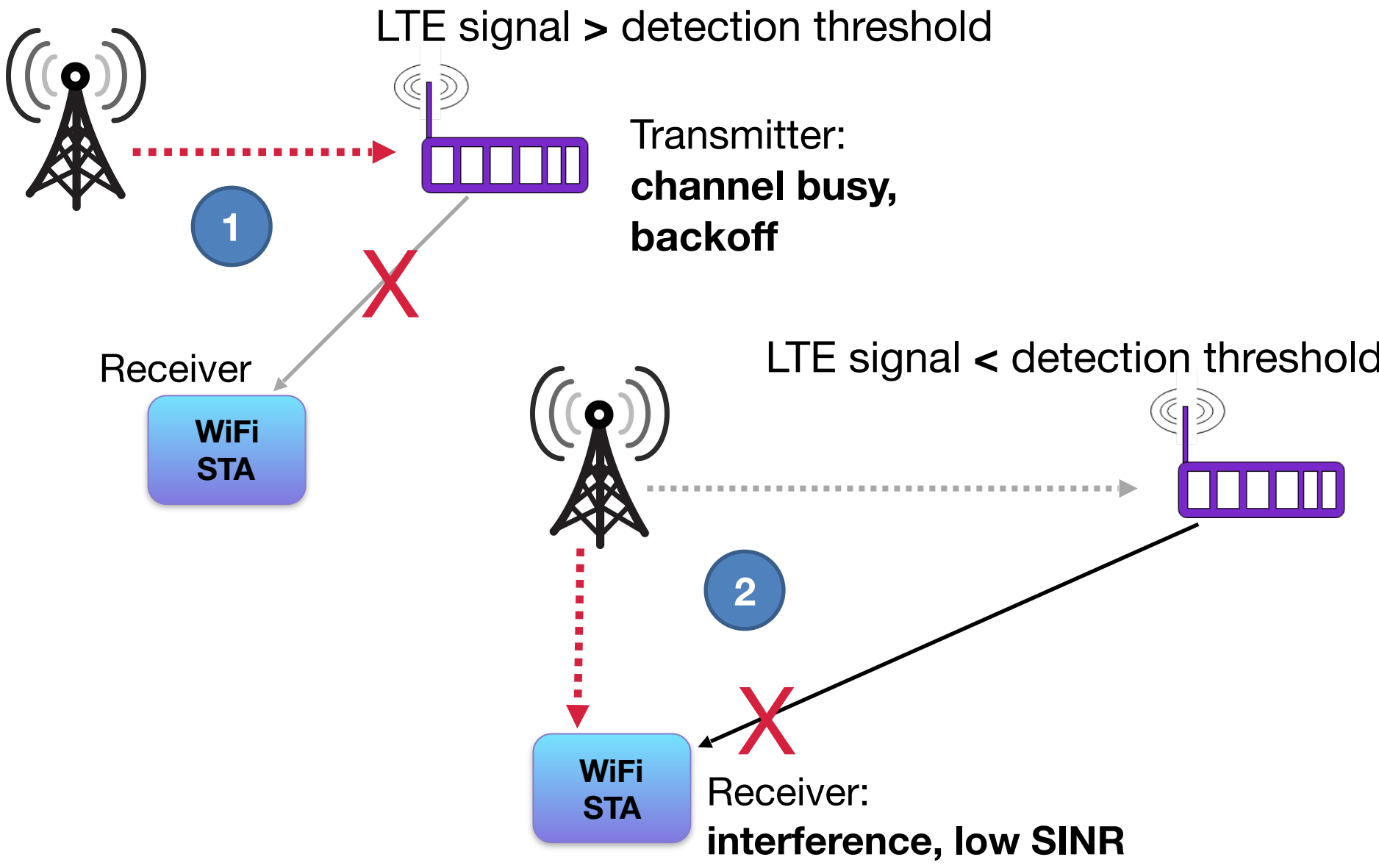
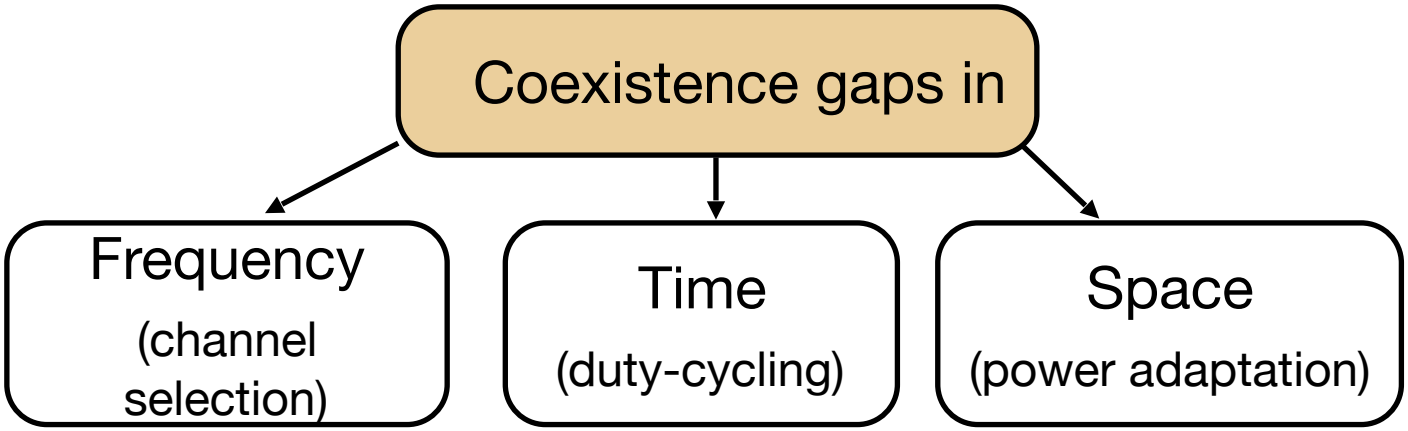


Coexistence gaps put by LTE-U

- Current solutions focus on simple but inefficient **uncoordinated coexistence**
  - LTE creates **coexistence gaps** in frequency/time/space domain,
  - E.g. LTE-U: channel access w/ adaptive duty cycling



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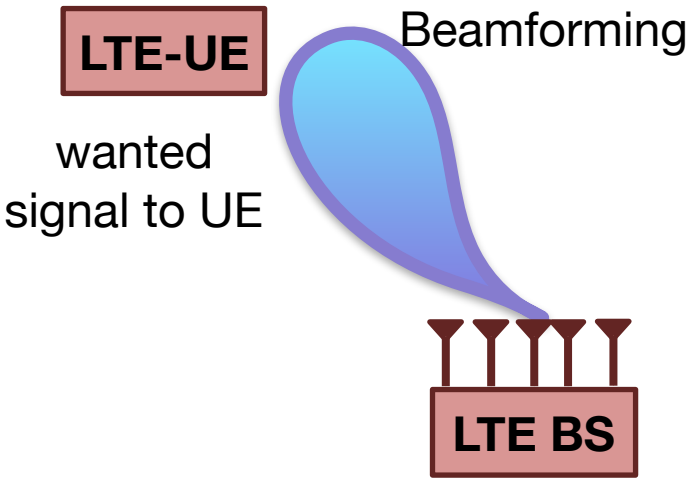

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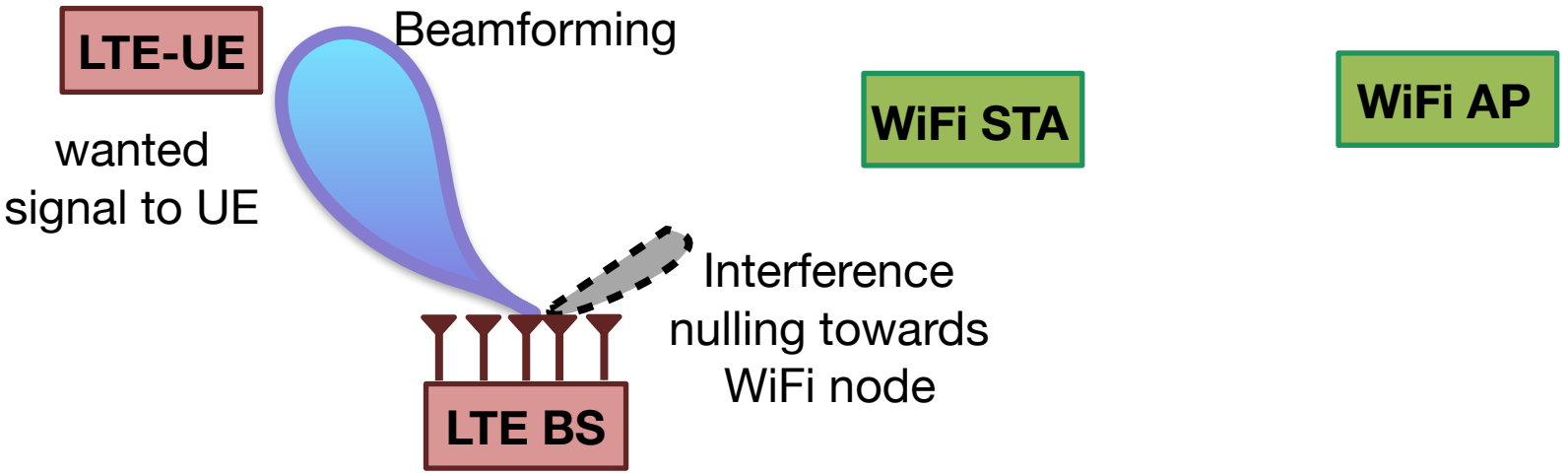

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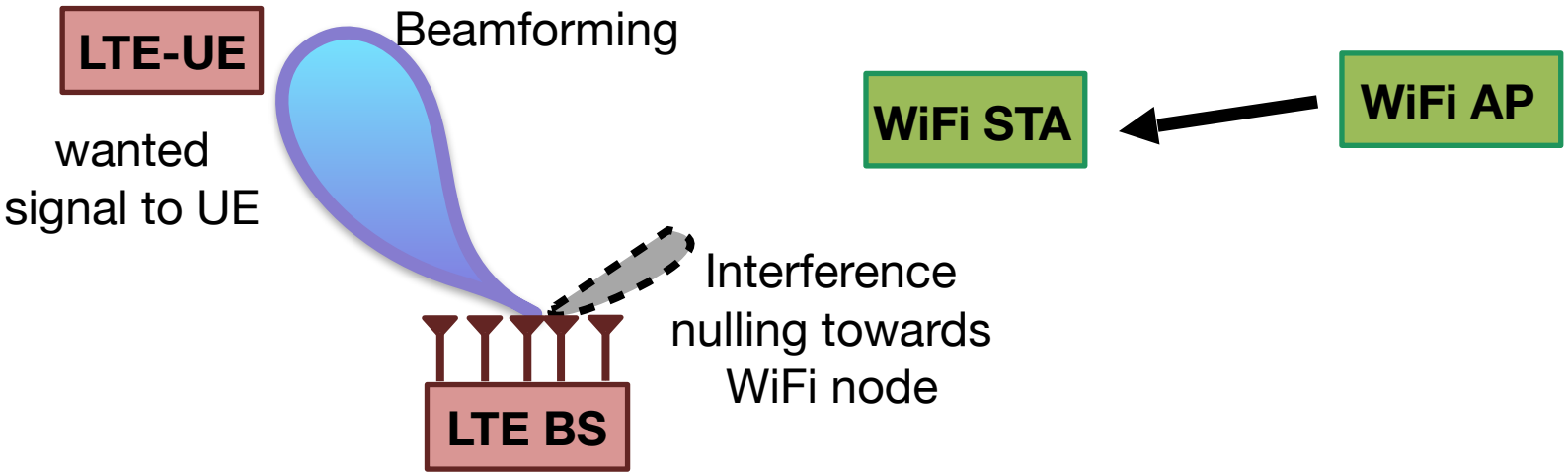

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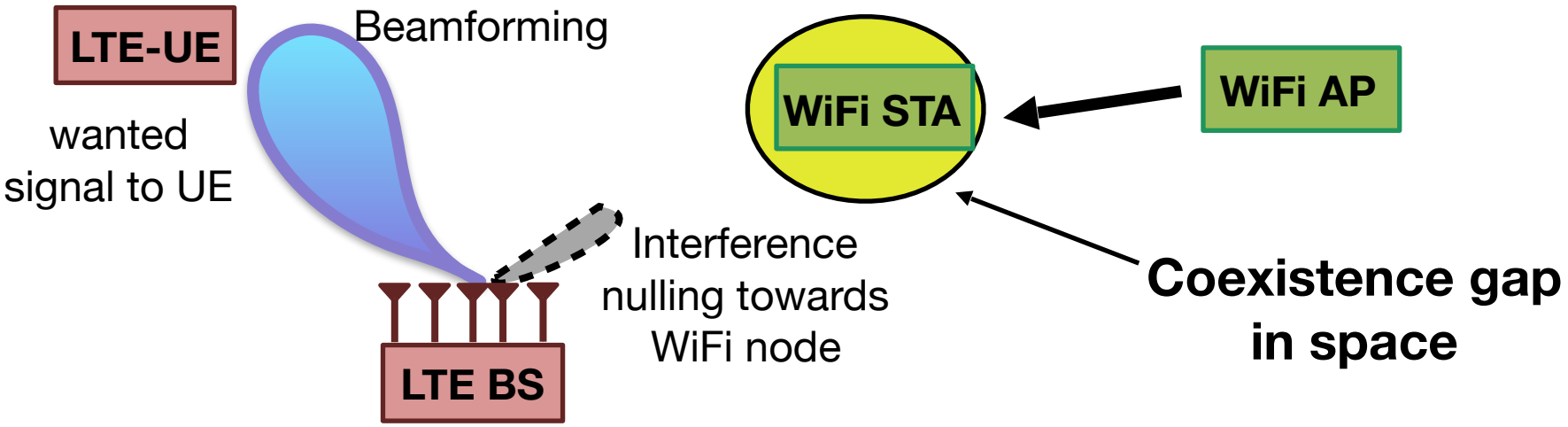

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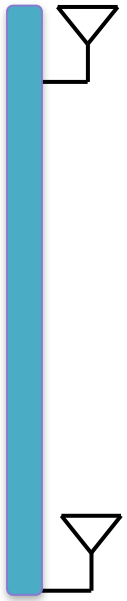

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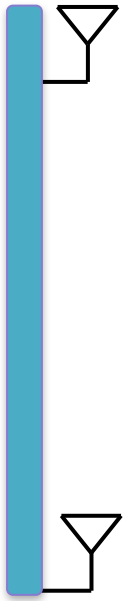

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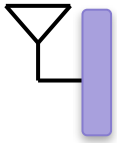

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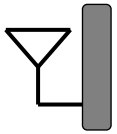

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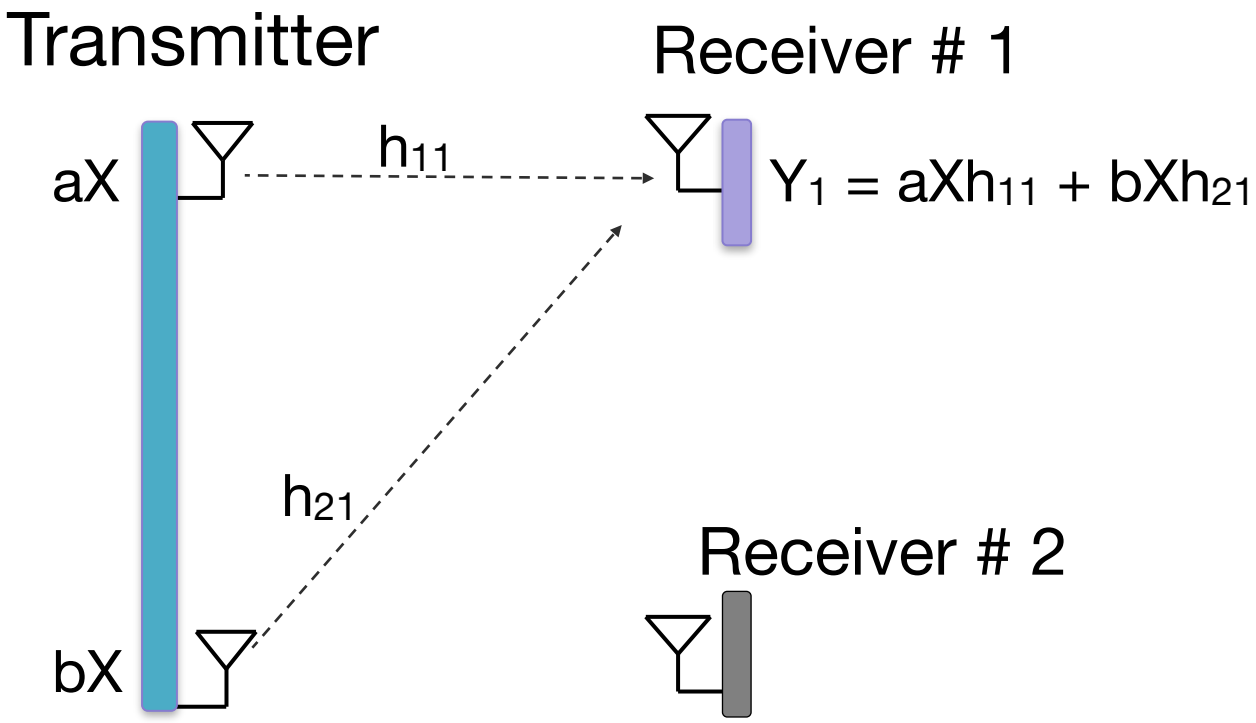

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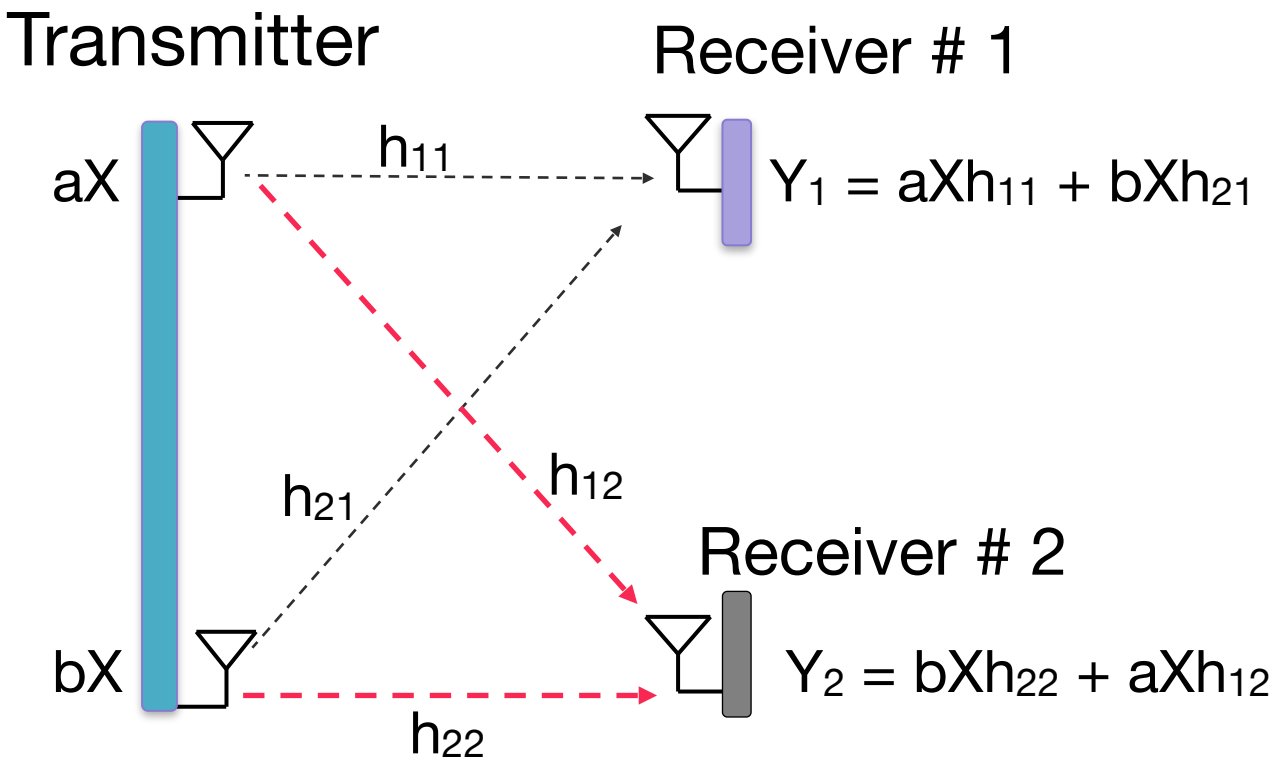

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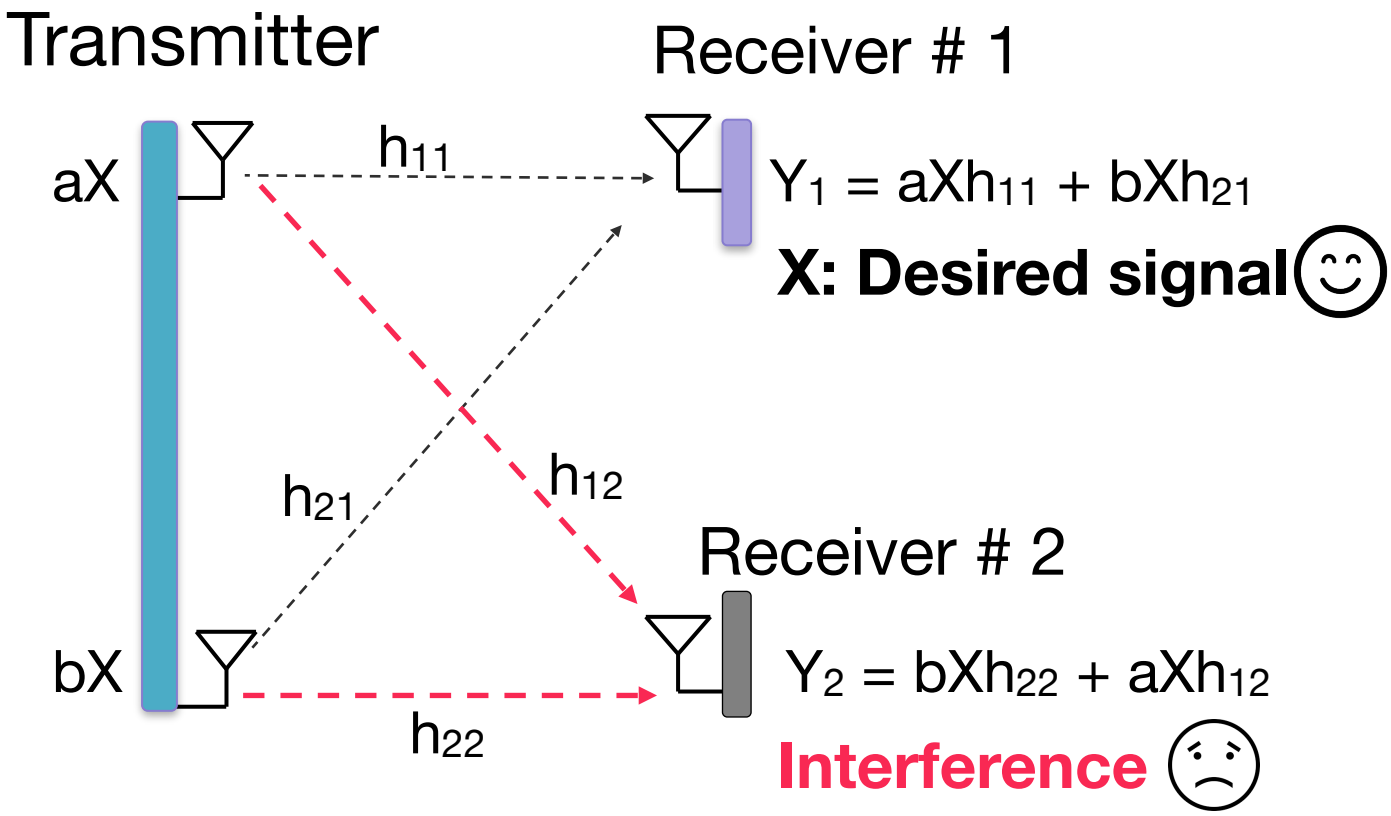

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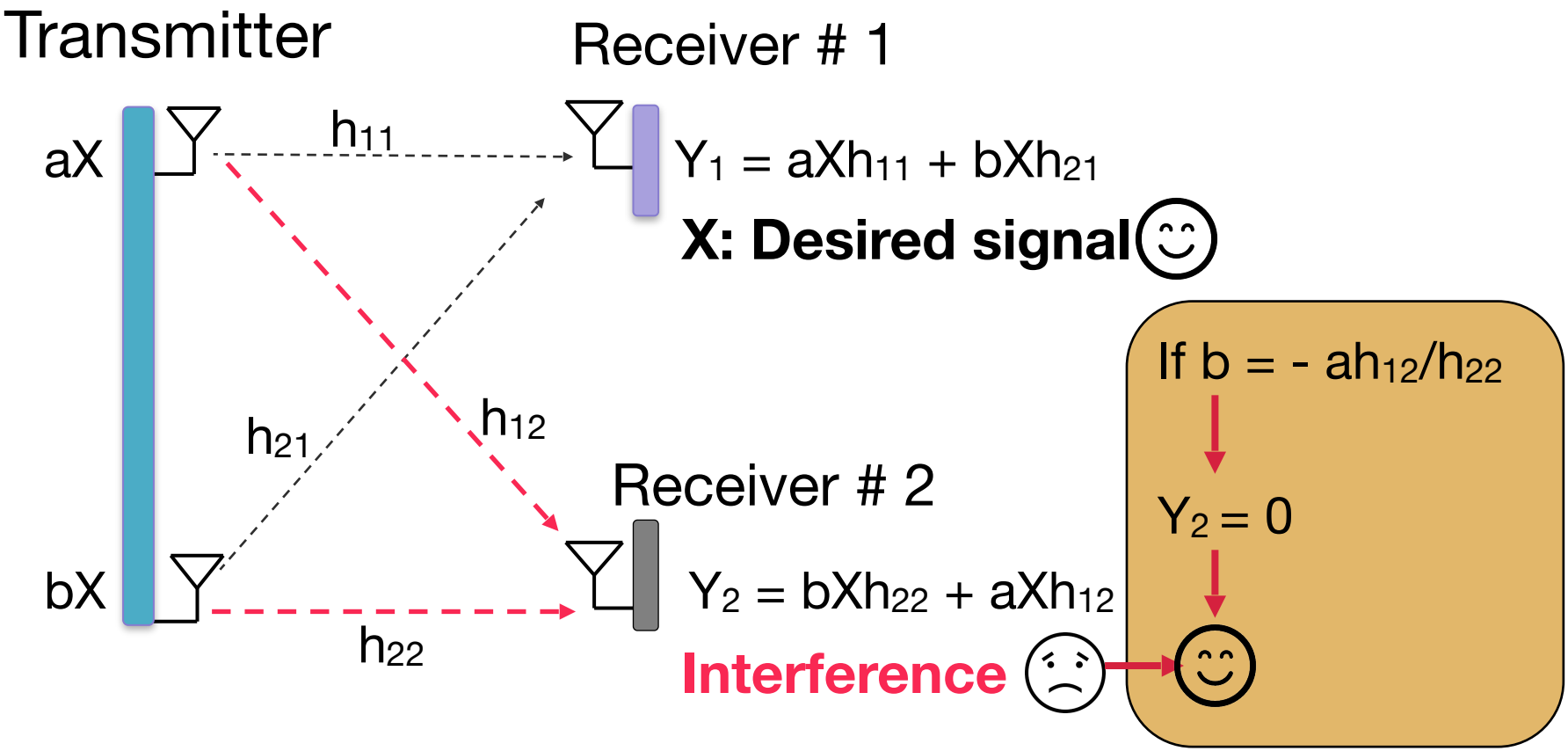

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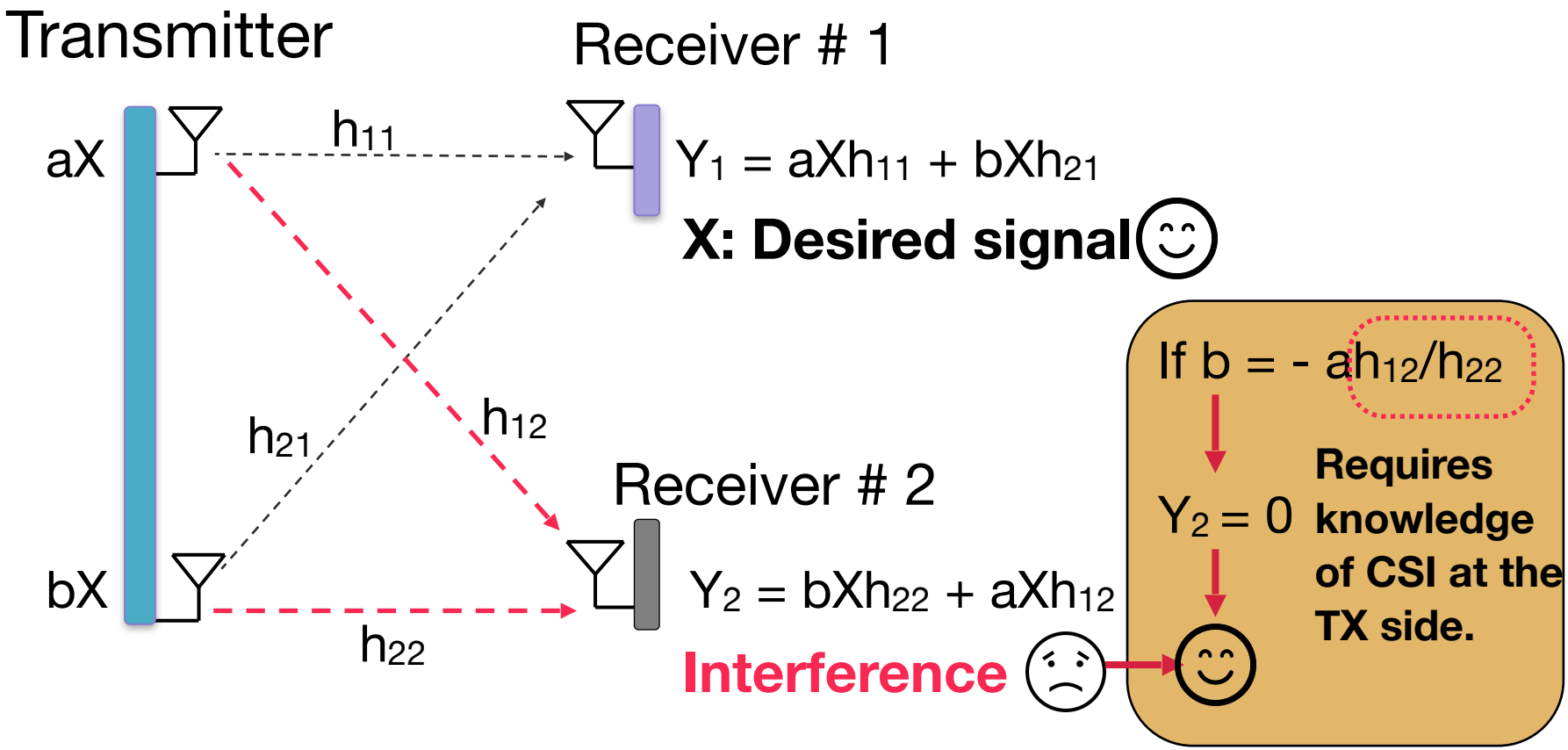
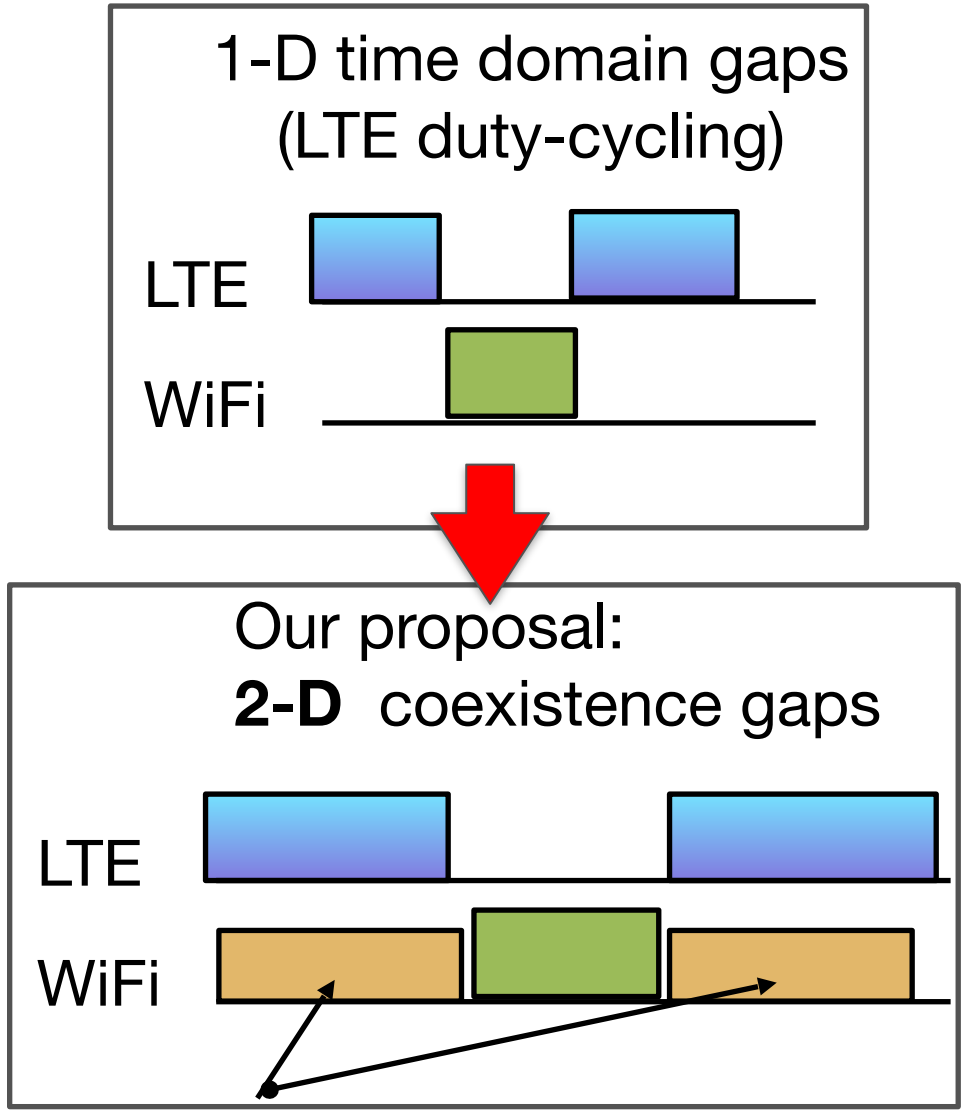


Coexistence Gaps in Space

- Favorable as competition for shared time/freq resources is reduced,
- Promises a **win-win** solution for both LTE & WiFi
  - Increased throughput,
  - Lower medium access delay
- Trend towards massive MIMO even for small cells



Why is Nulling beneficial for LTE-U?

- LTE-U must leave the medium for WiFi proportional to the number of WiFi nodes observed in its neighborhood.
- With nulling LTE-U can increase its airtime usage:

1/ No nulling:

$$\alpha_{no} = 1 / (N_{cs}+1)$$

2/ Nulling $K_{\emptyset}$ Wifi nodes:

$$\alpha(K_{\emptyset}) = 1 / (N_{cs} - K_{\emptyset} +1)$$

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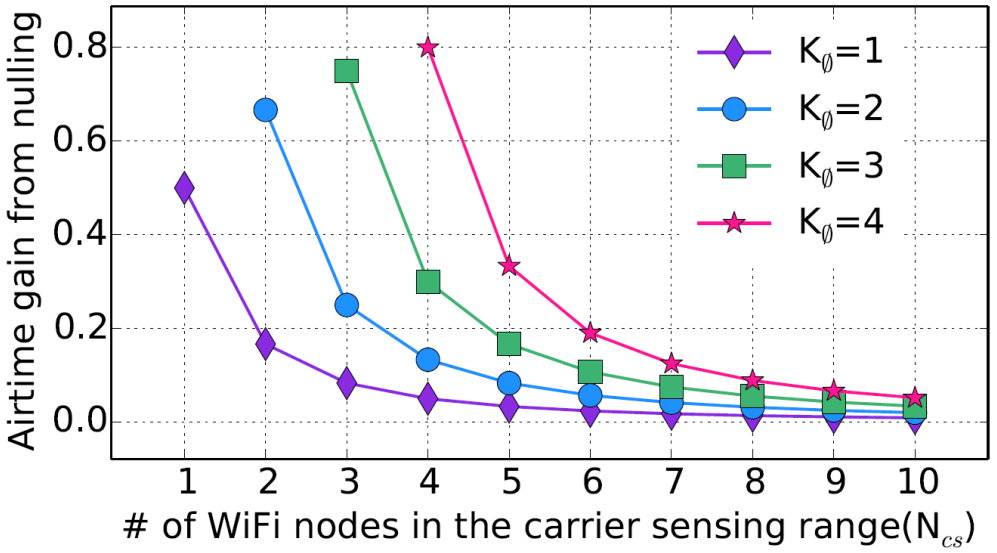

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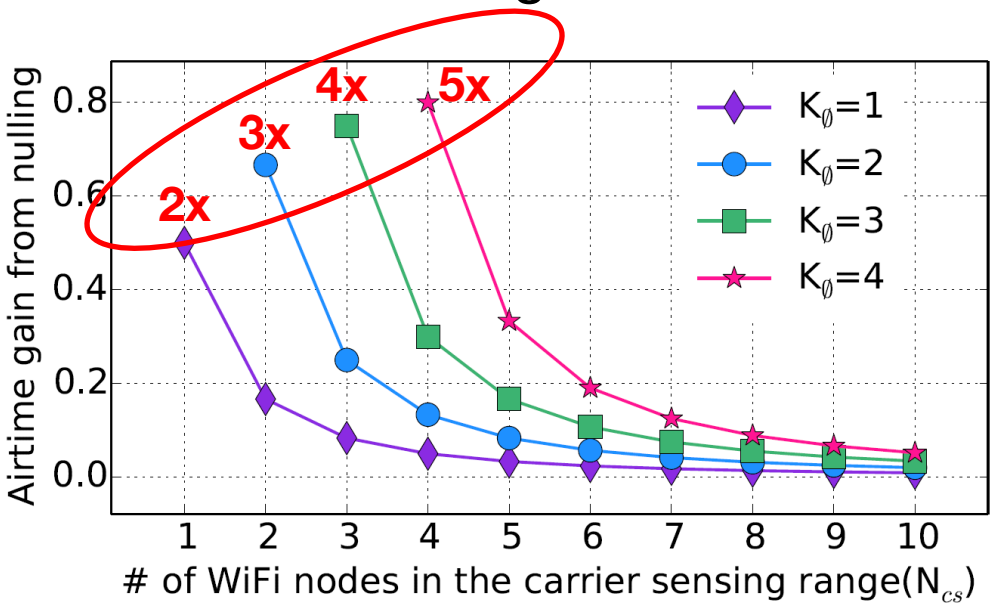

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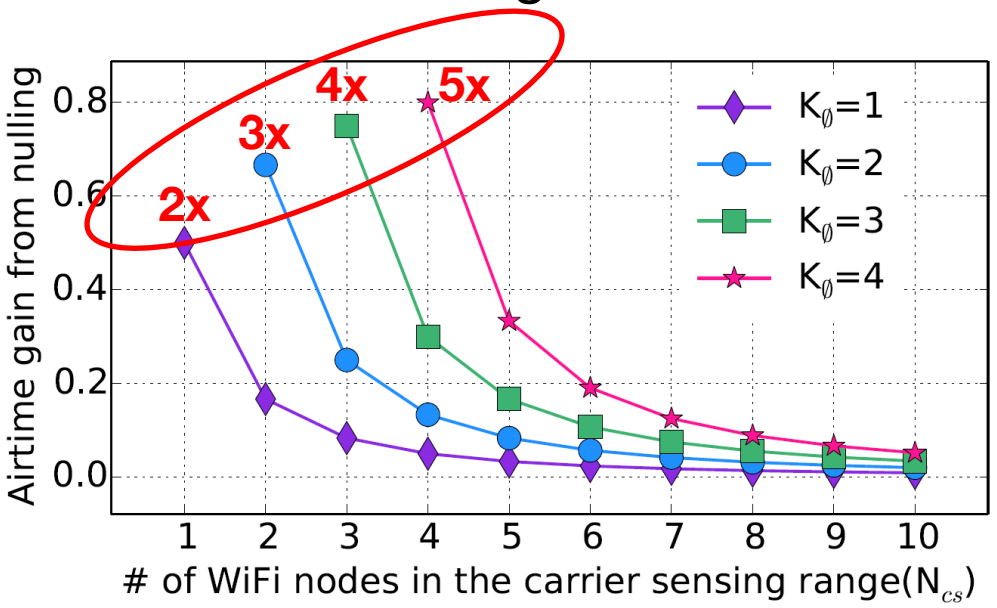

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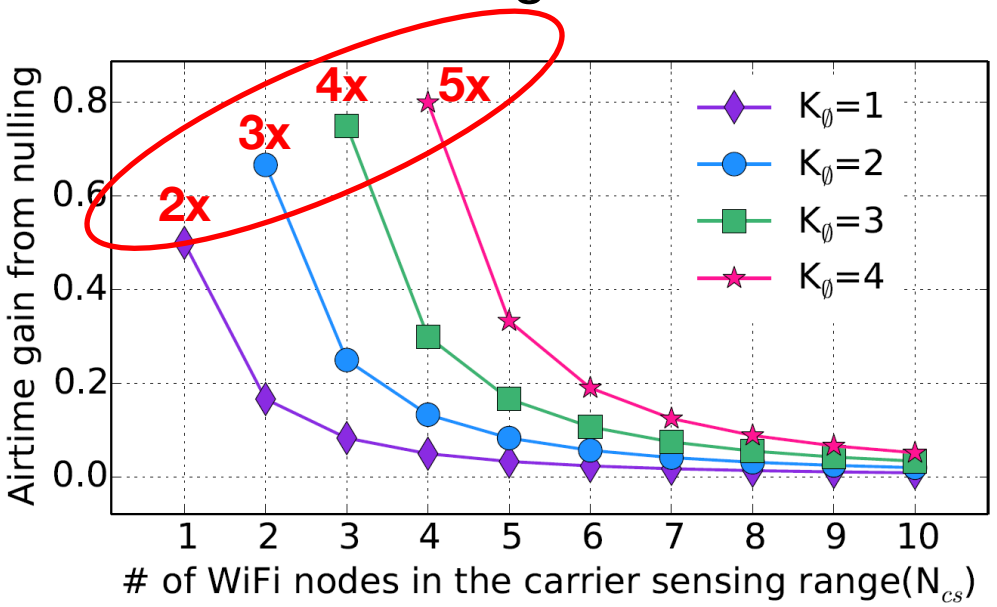

- … with some reduction in SNR on BS-UE link -> tradeoff,
- Interesting case when $K < N_{cs}$, where only a subset of WiFi nodes can be selected for nulling -> optimization problem [1]

[1] Bayhan, Zubow, Wolisz, “Coexistence Gaps in Space via Interference Nulling for LTE-U/WiFi Coexistence”, WoWMoM 2018

Is Cross-technology Interference-Nulling practically feasible?

- Such coordinated co-existence scheme requires:
  - **1.** Cross-Technology Communication (CTC) channel for the exchange of control messages
    - LtFi CTC by us ☺️
  - **2.** Interference nulling requires channel state information (CSI) at transmitter side, i.e. LTE-U BS
    - Cannot be obtained over LtFi-CTC
    - Cannot be obtained at all....

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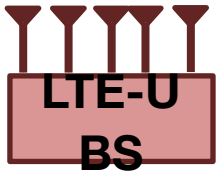

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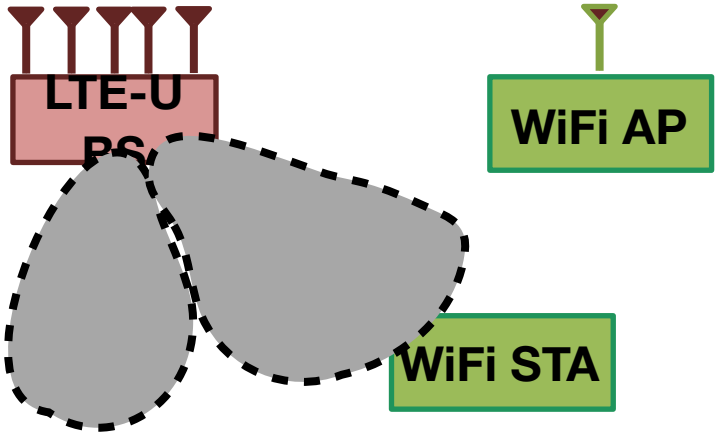

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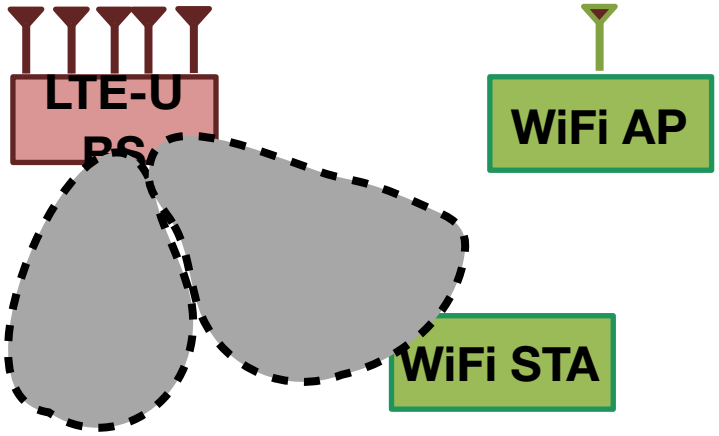

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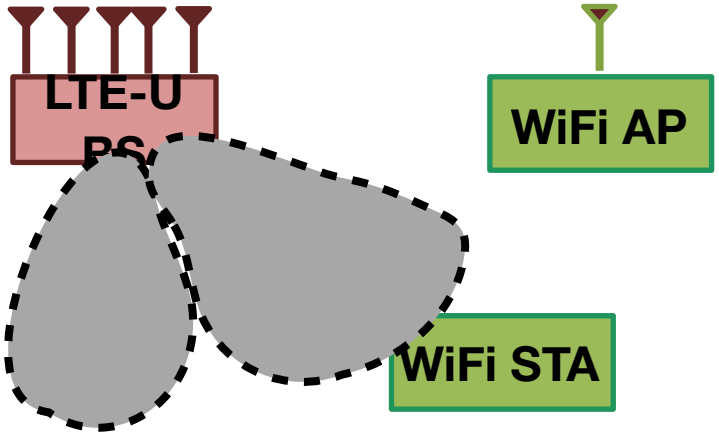

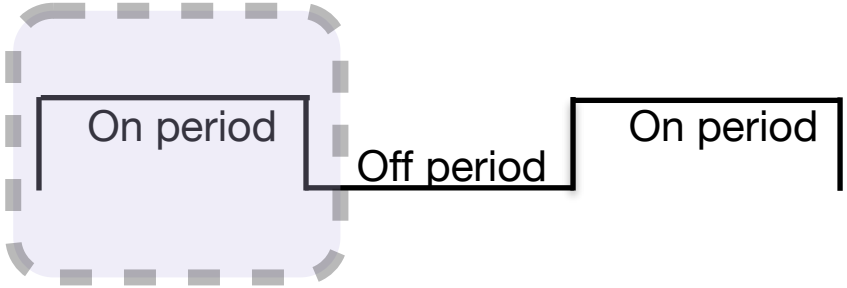

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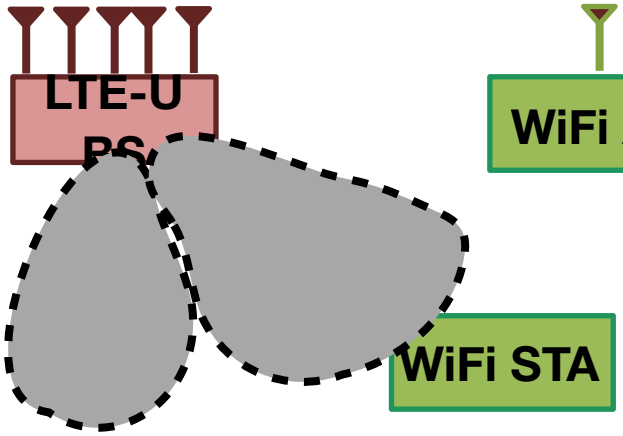

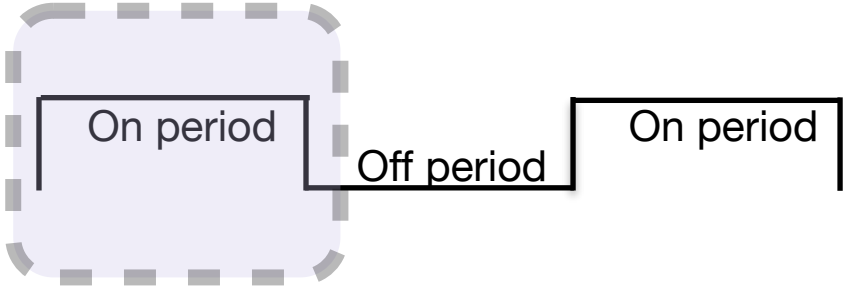

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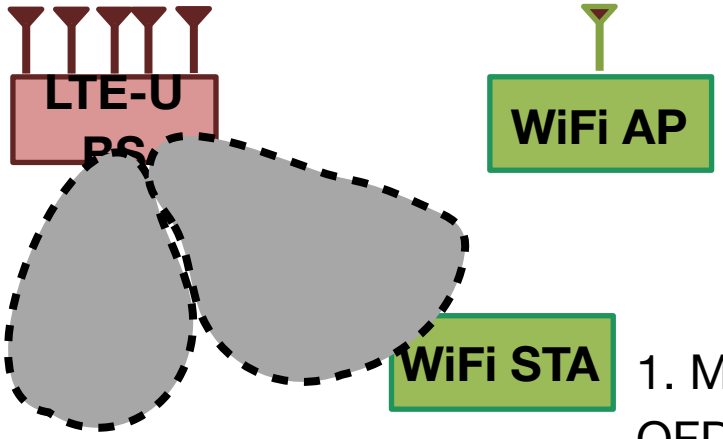

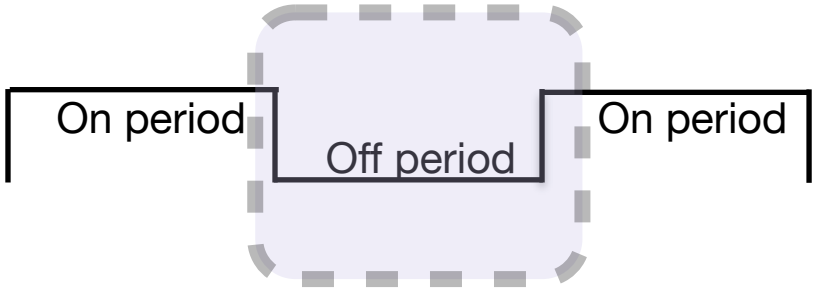

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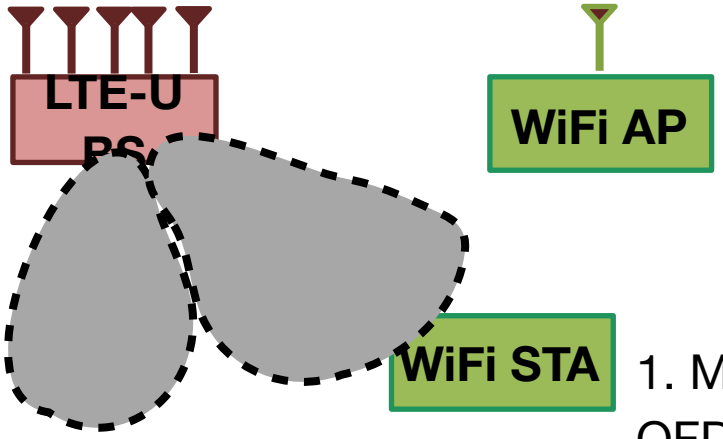

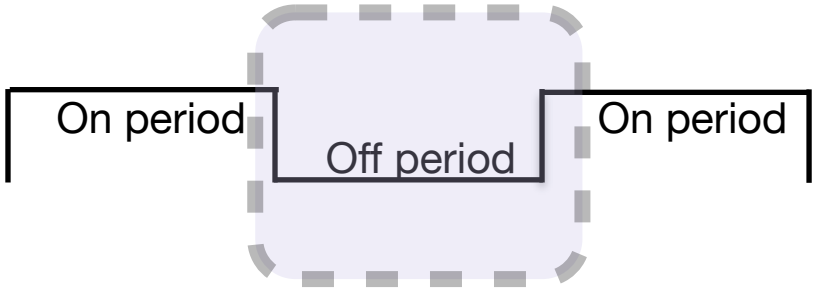

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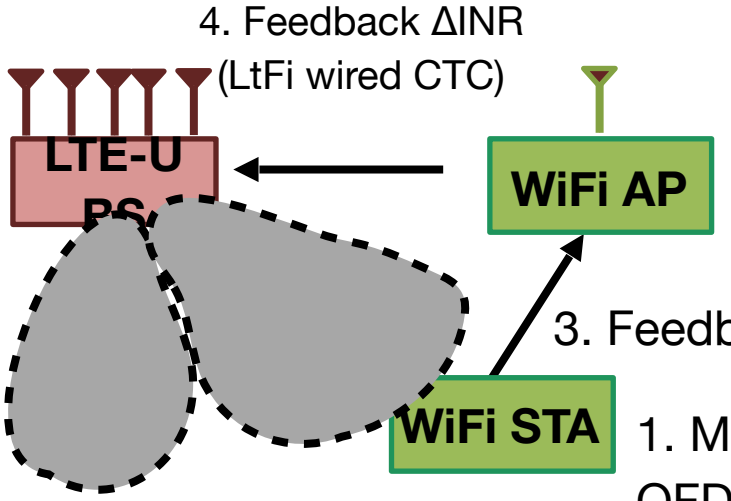

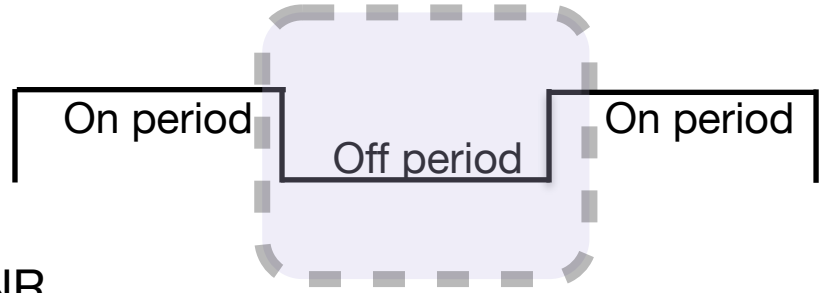

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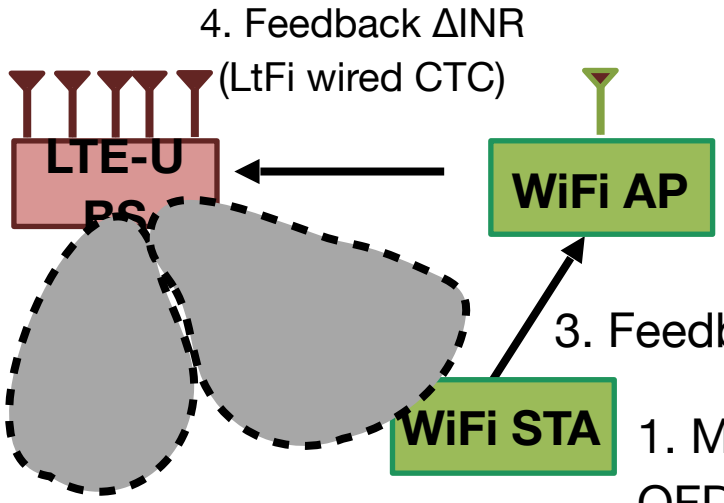

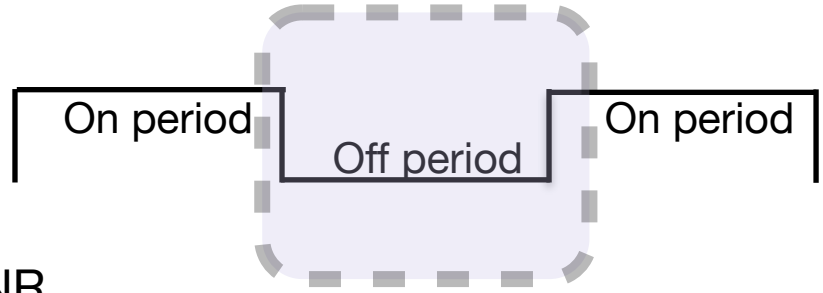

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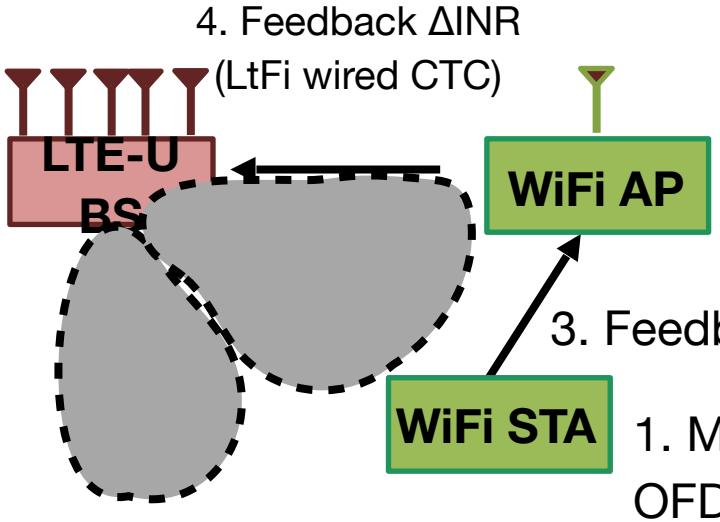

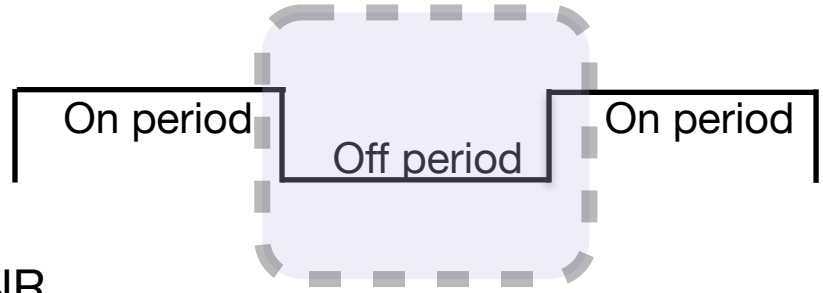

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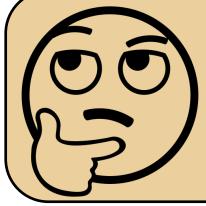
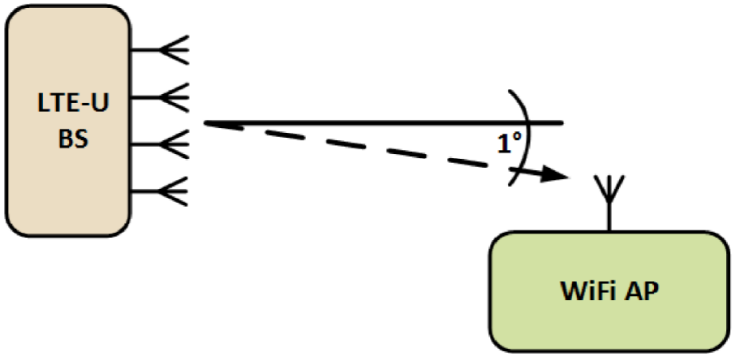
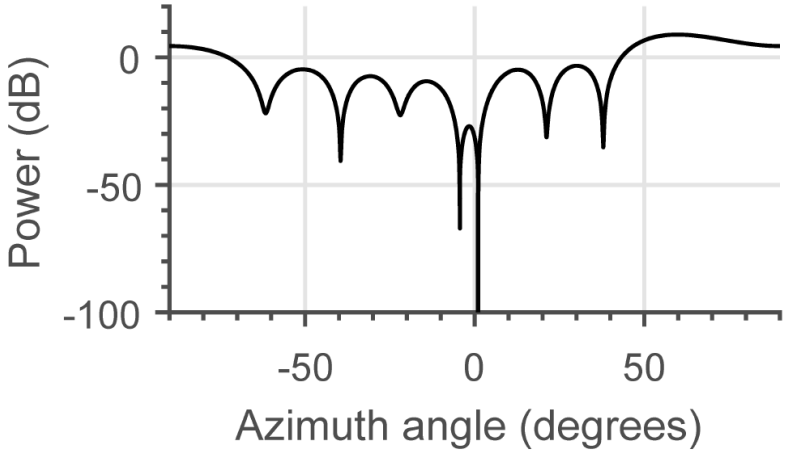
Tree-based Null Search



Problem: Linear (exhaustive) search is very slow
Our idea: Tree-based search testing null regions

- Ground truth nulling direction: 1°





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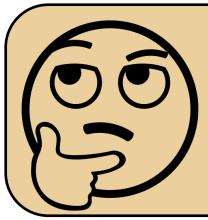

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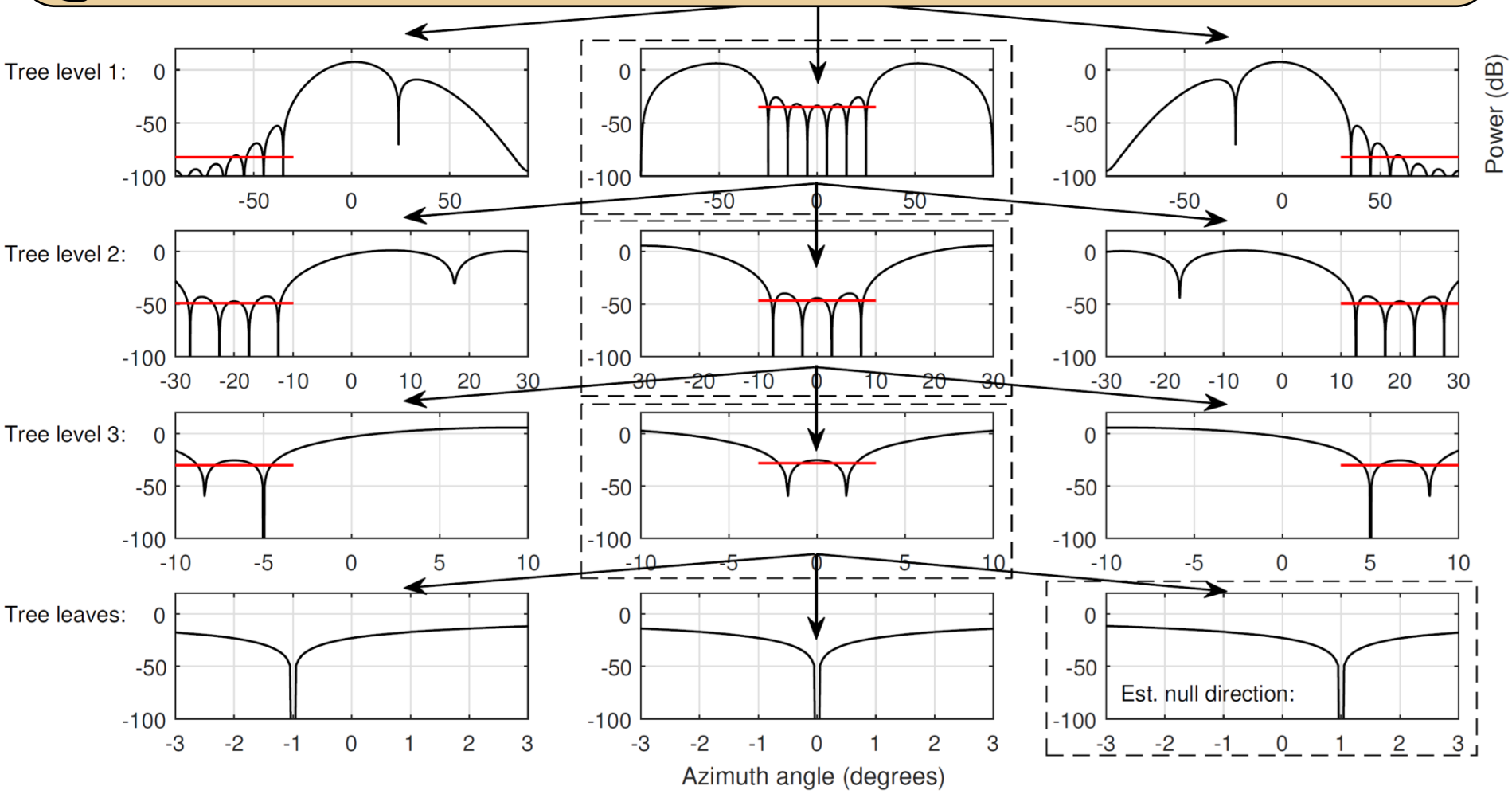

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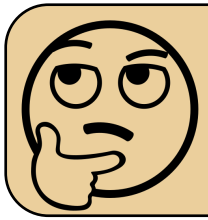

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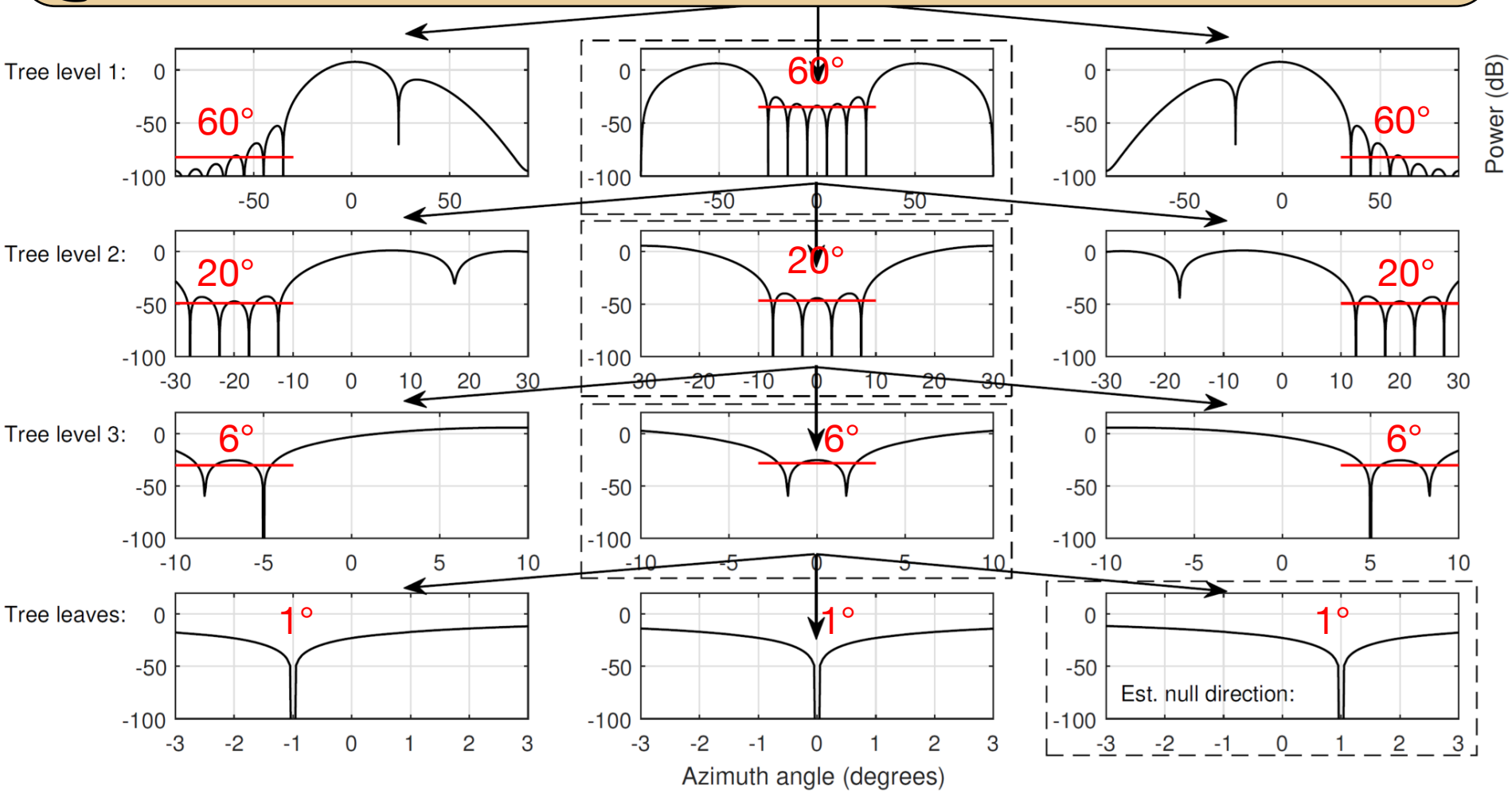

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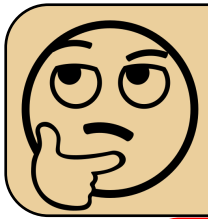

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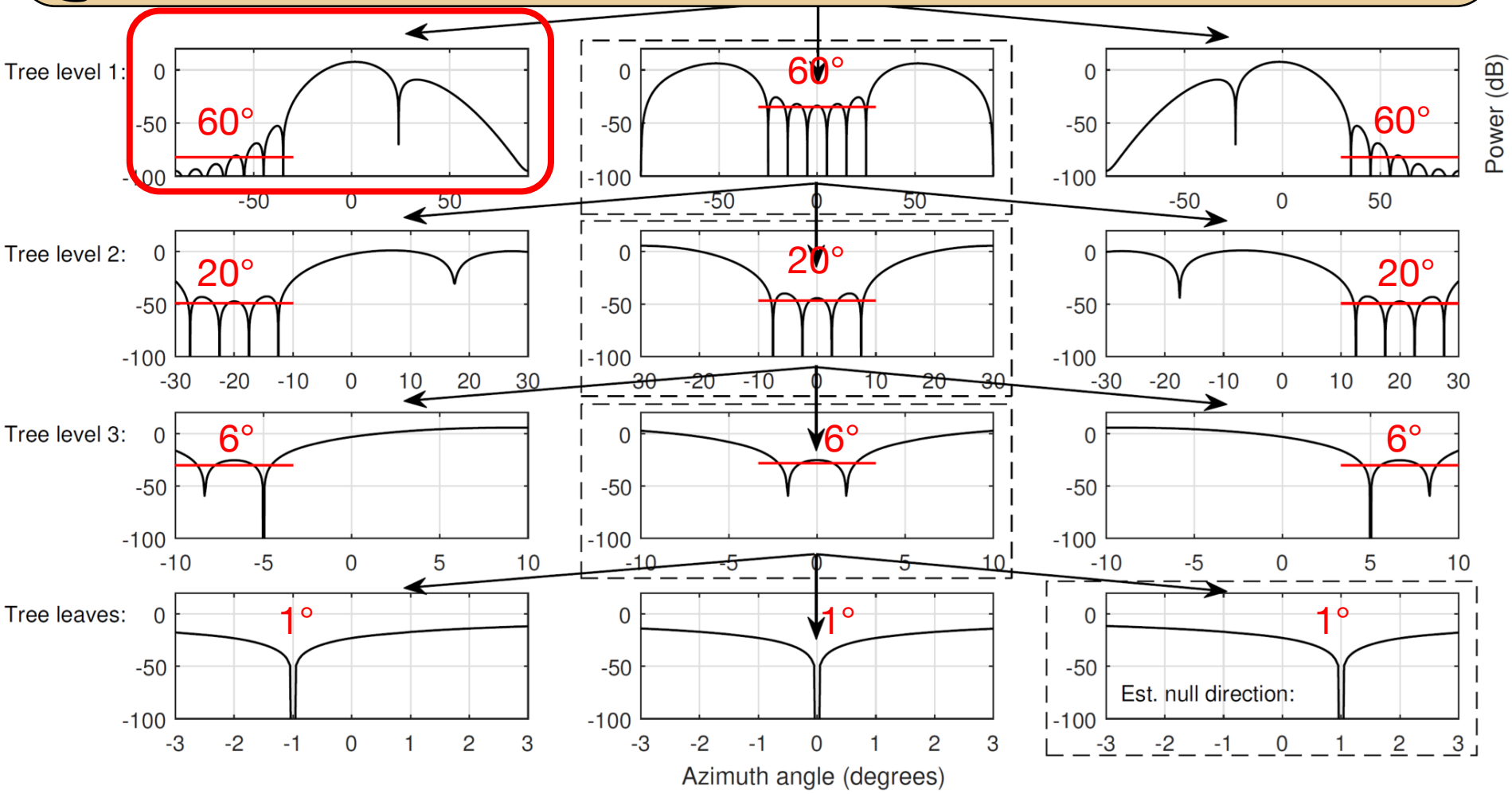

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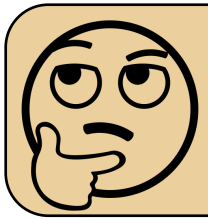

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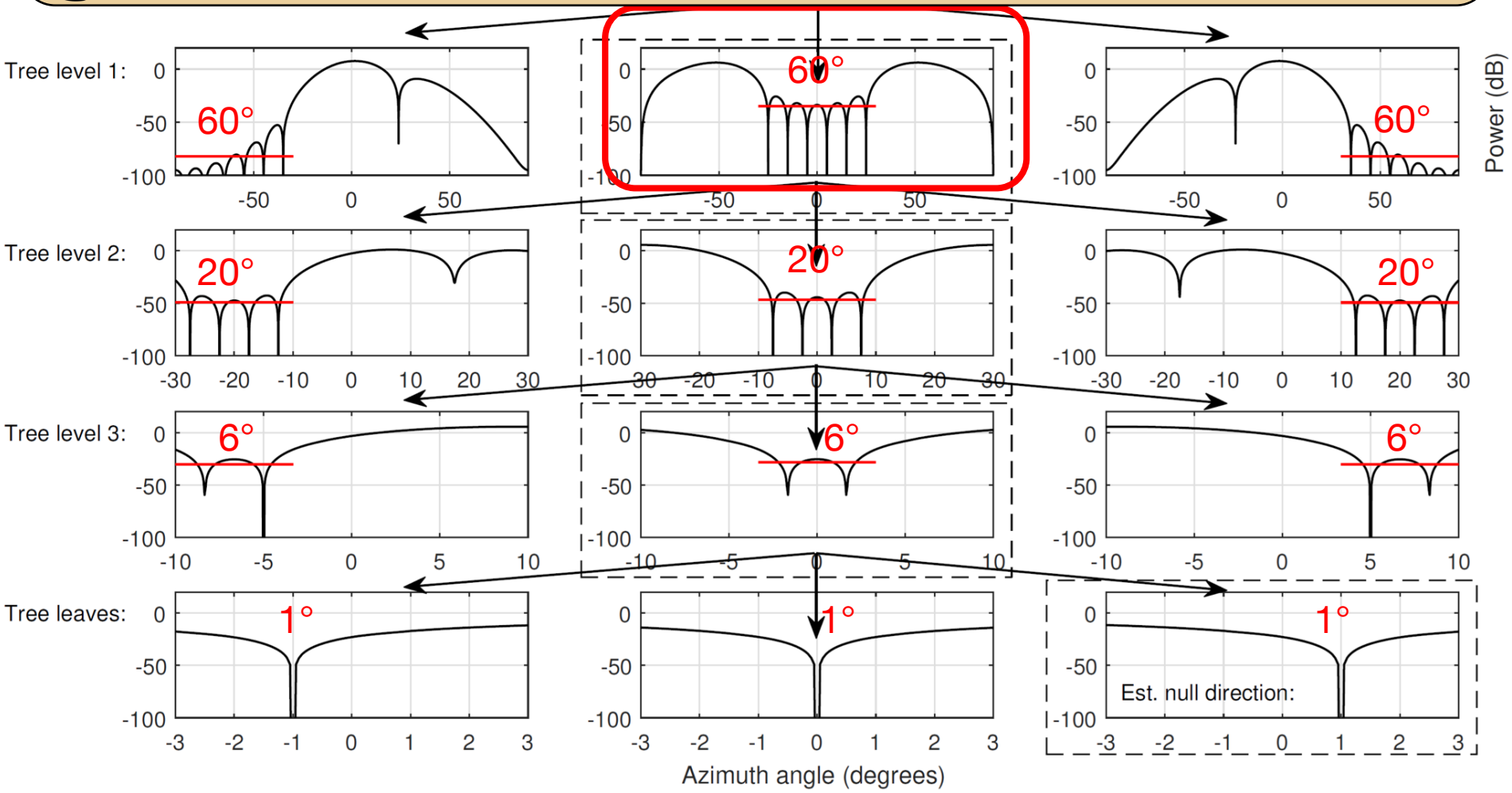

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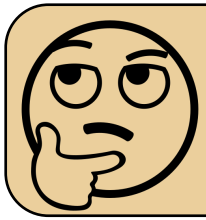

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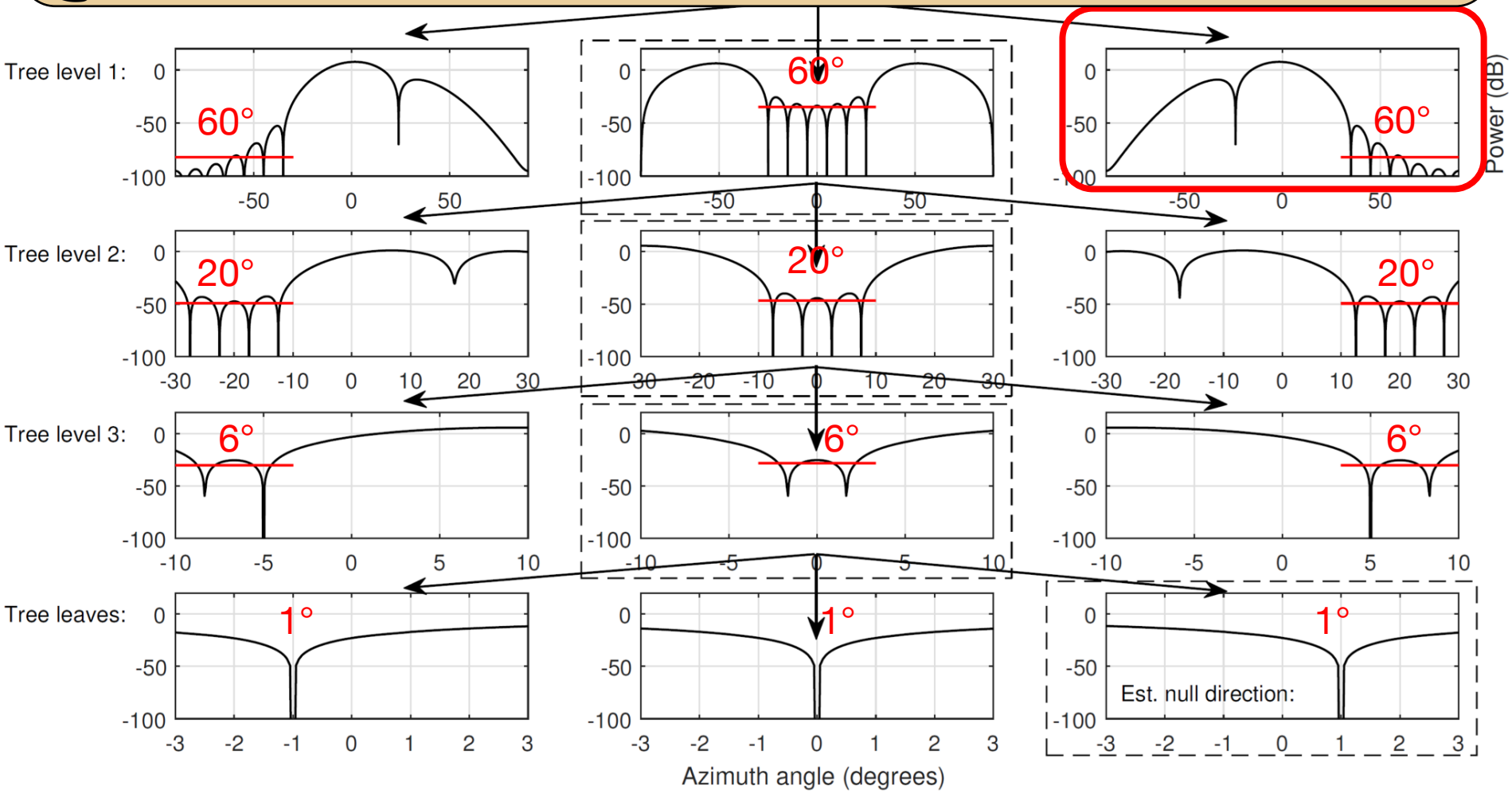

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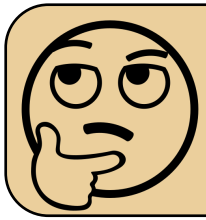

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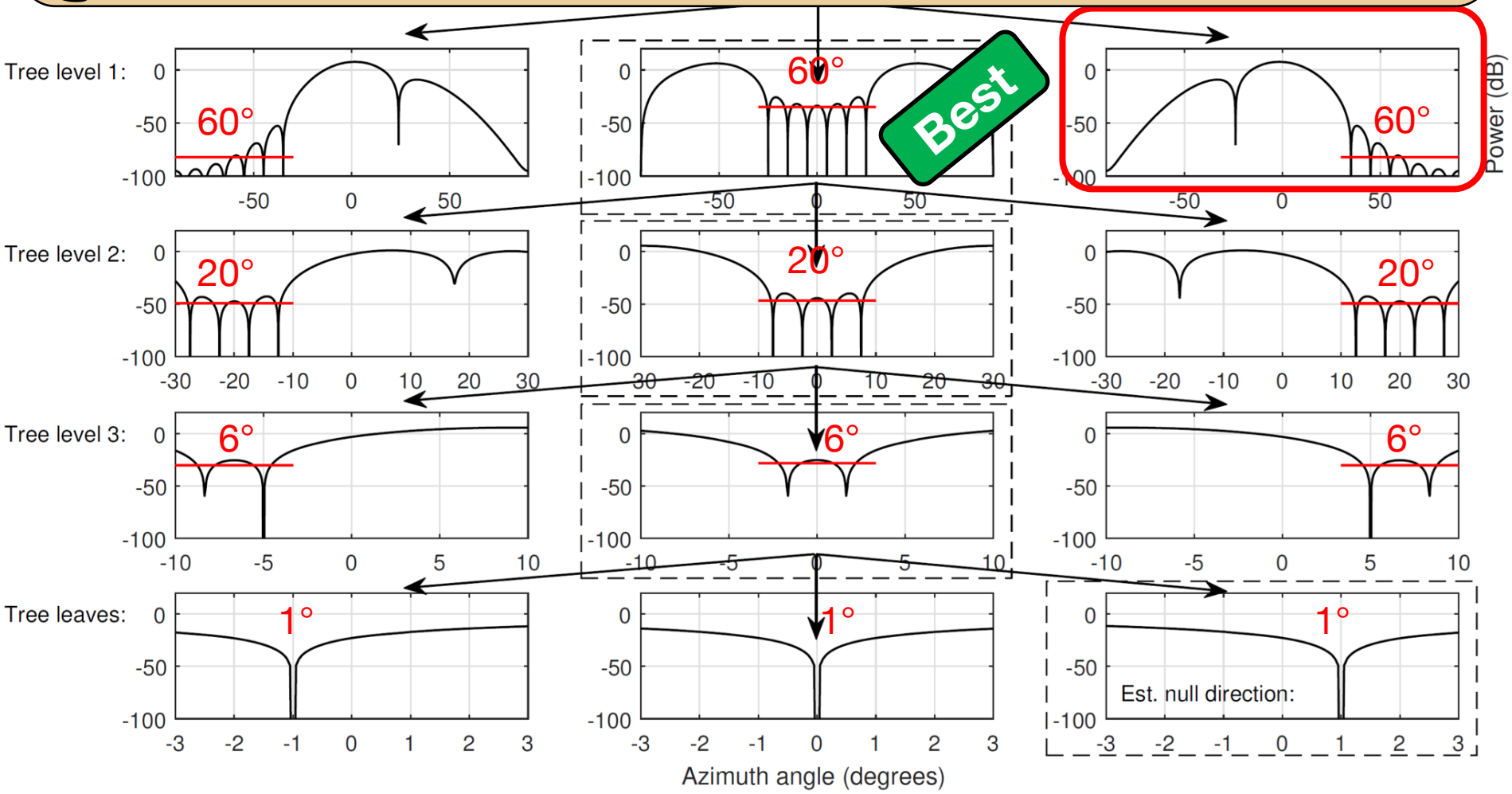

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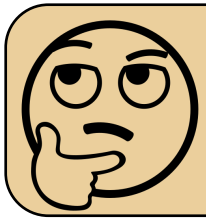

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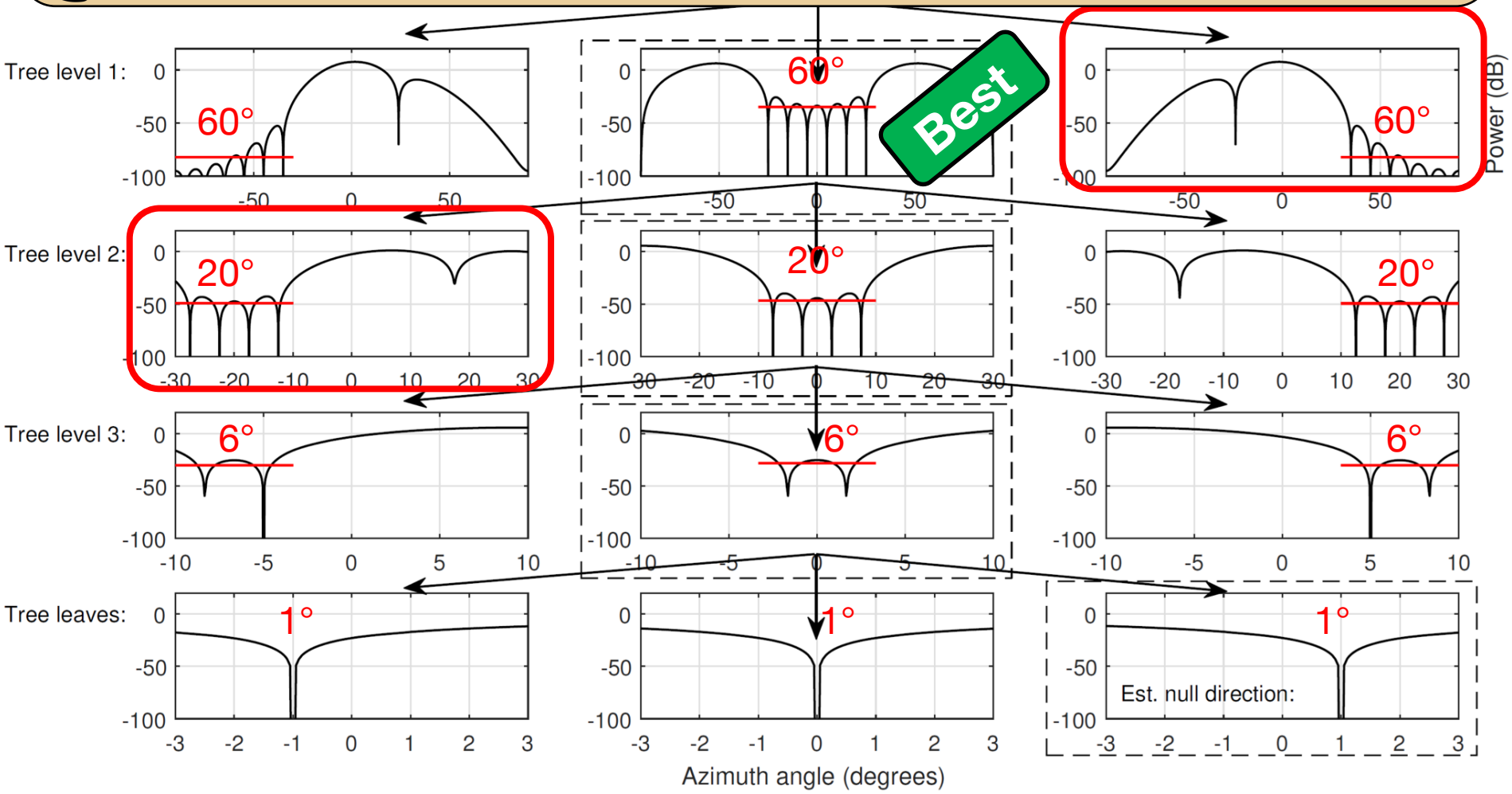

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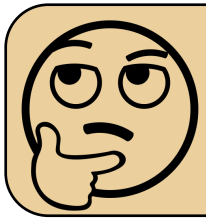

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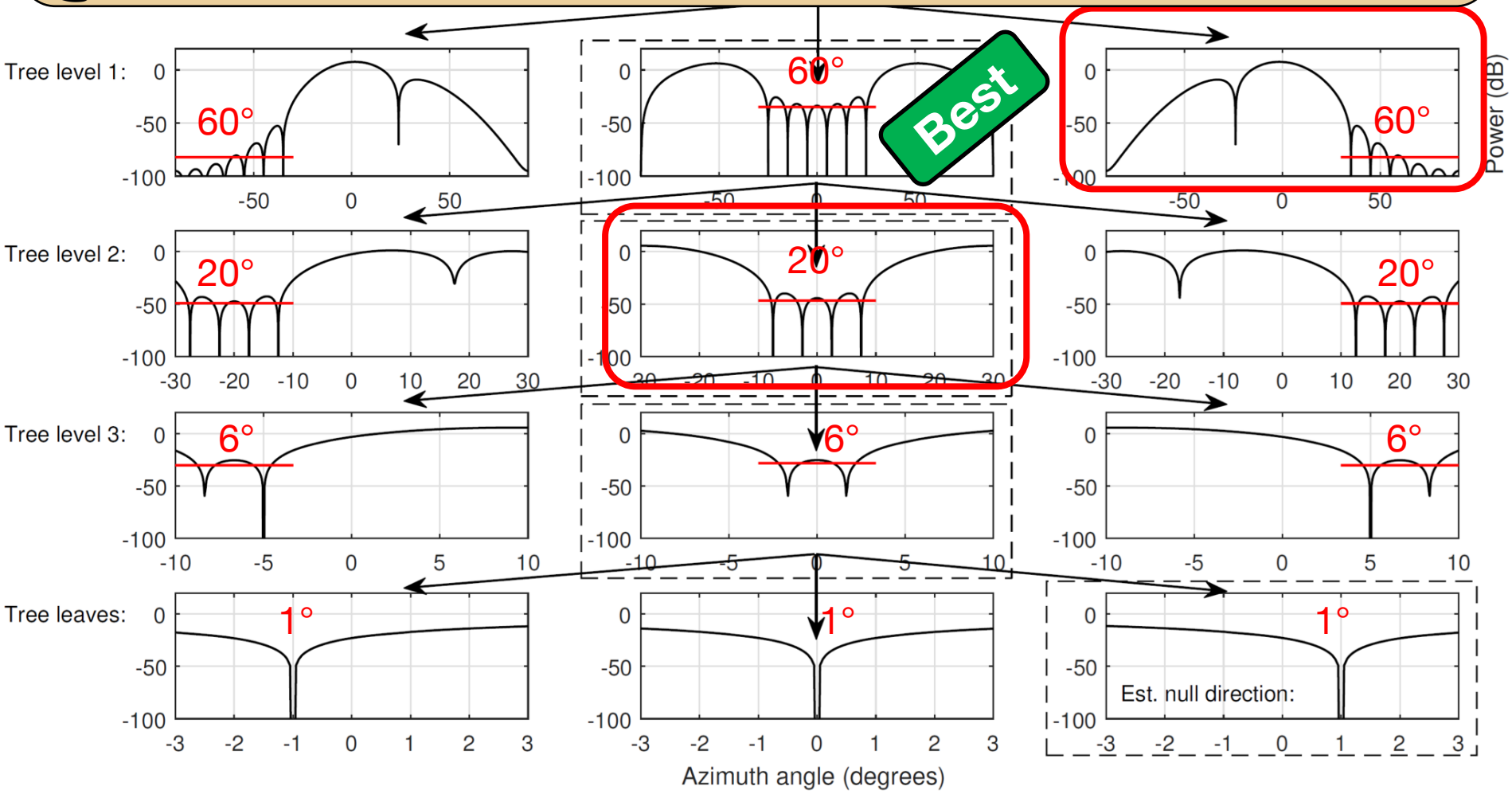

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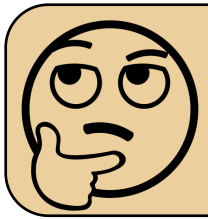

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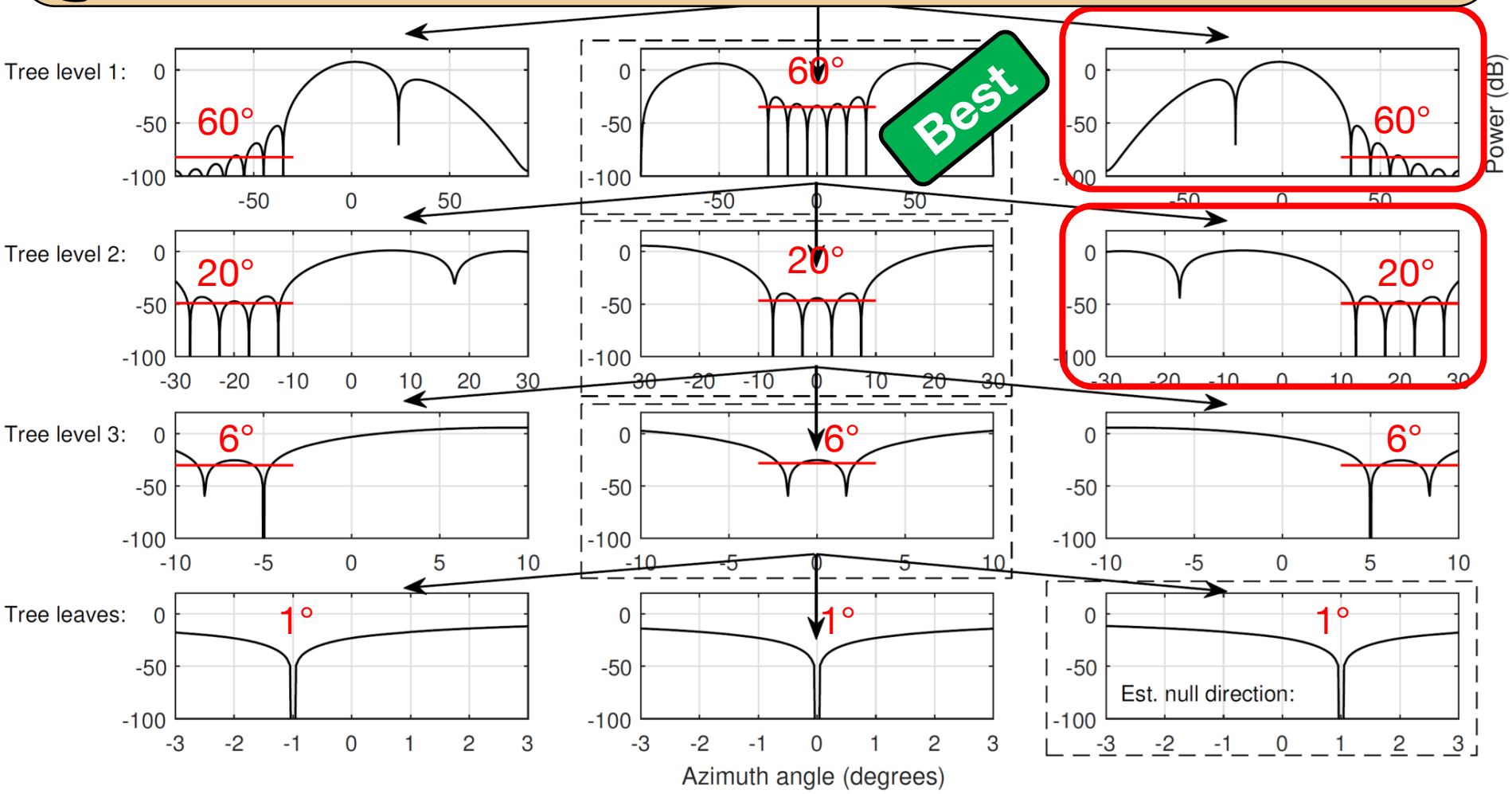

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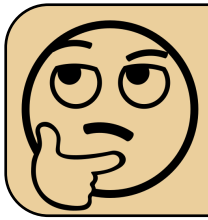

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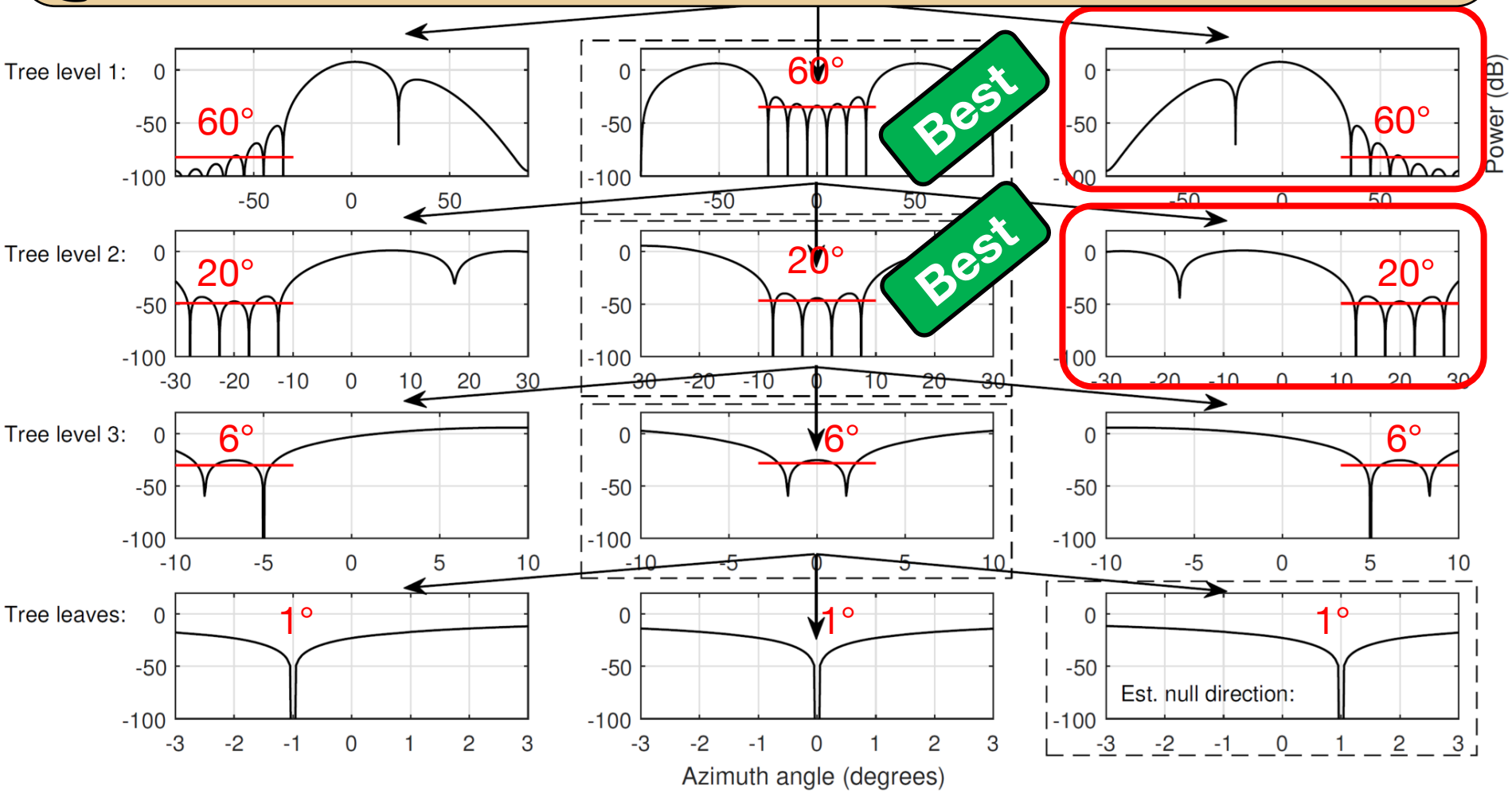

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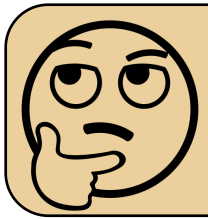

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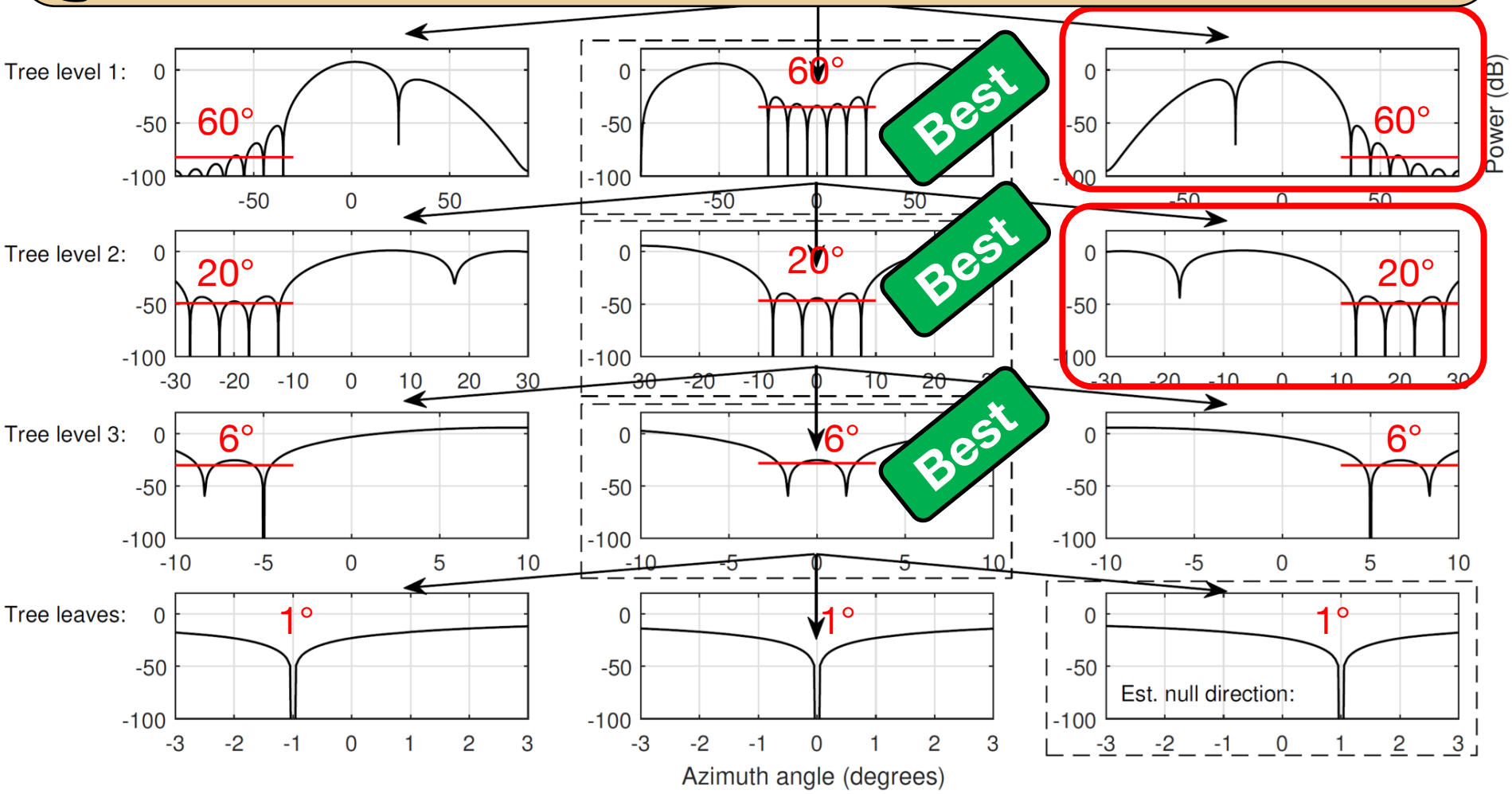

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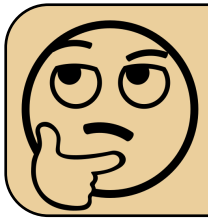

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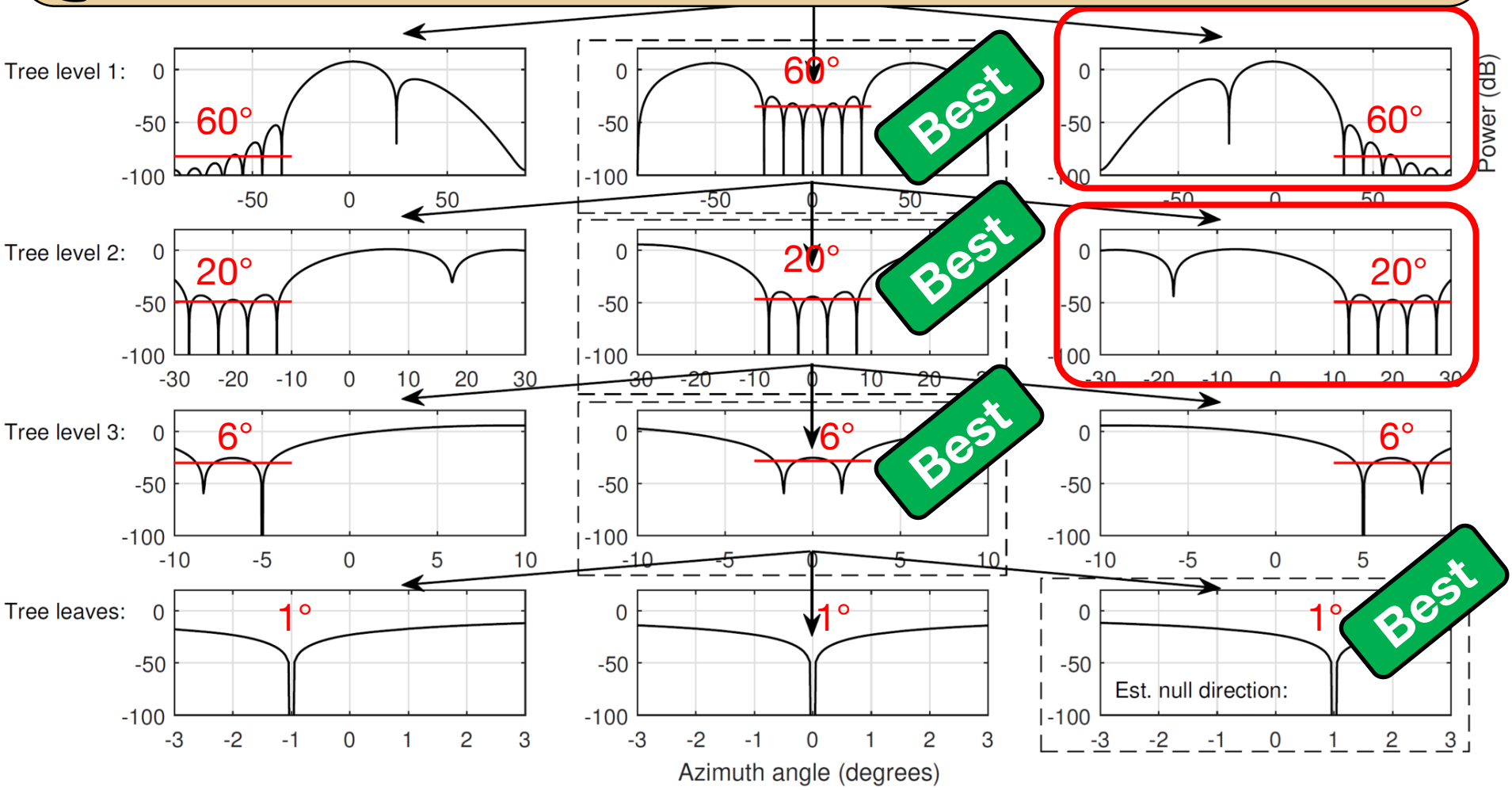
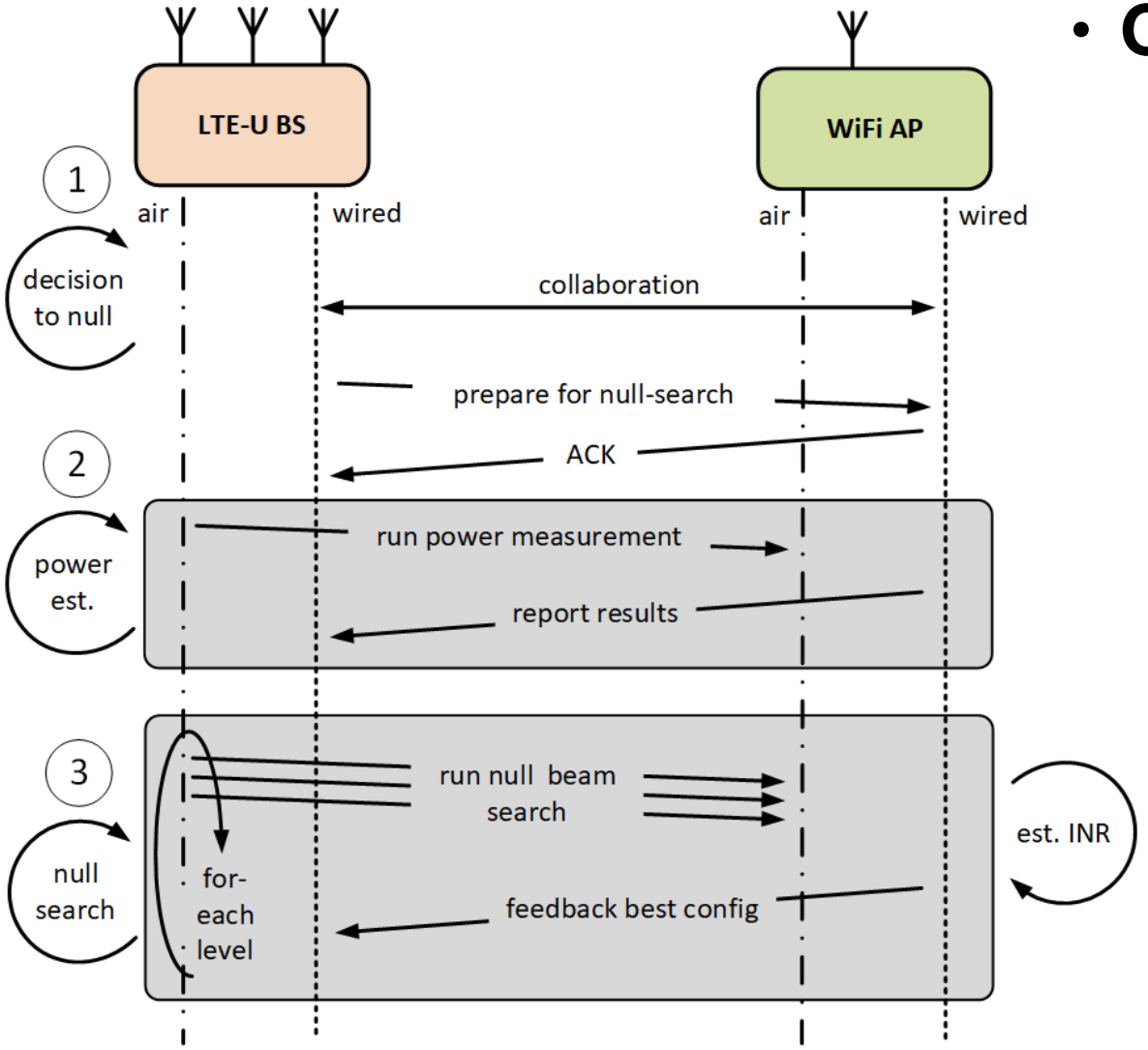


Main Steps in XZero



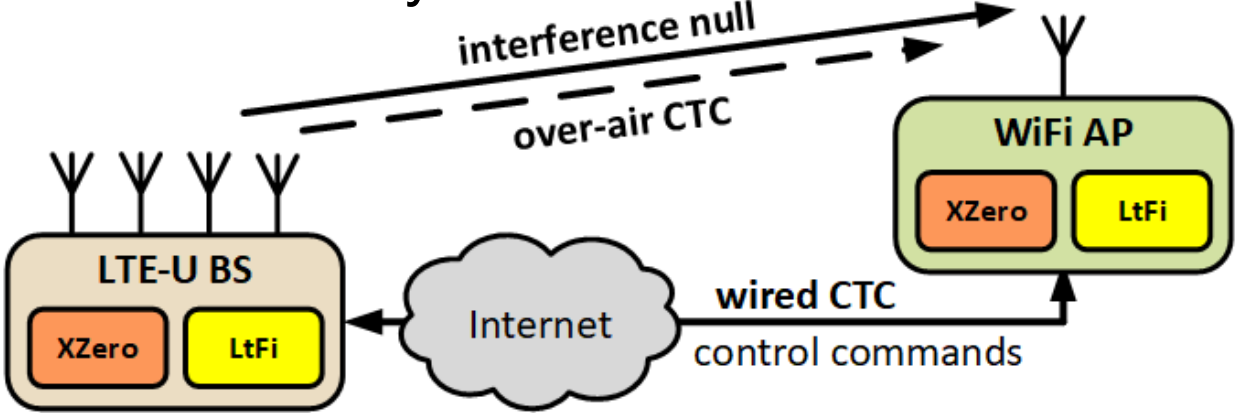
- **Challenges:**
  - Power correction for precoding vector needed to tackle multi path propagation,
  - Backhaul latency for feedback from WiFi to LTE,
  - Precoding weight: for each LTE OFDMA RRB,
  - WiFi-side measurement: OFDM subcarrier,
  - A mapping needed between WiFi side and LTE side

XZero Prototype

- Is custom hardware needed?
  - No, prototype based on SDR-USRP (LTE) and COTS (WiFi)
- Is special software needed?
  - No, usage of open-source software-based LTE stack (srsLTE) & WiFi driver (ATH9k),
  - Most functionality of XZero implemented in Python

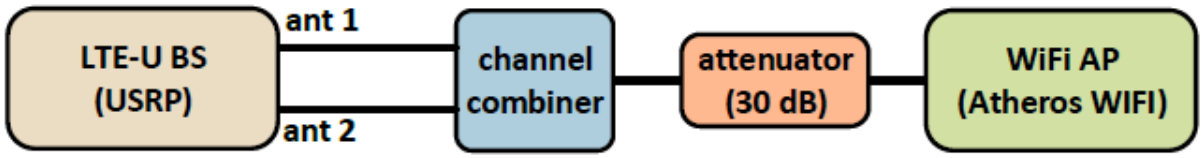
LTE-U BS+UE

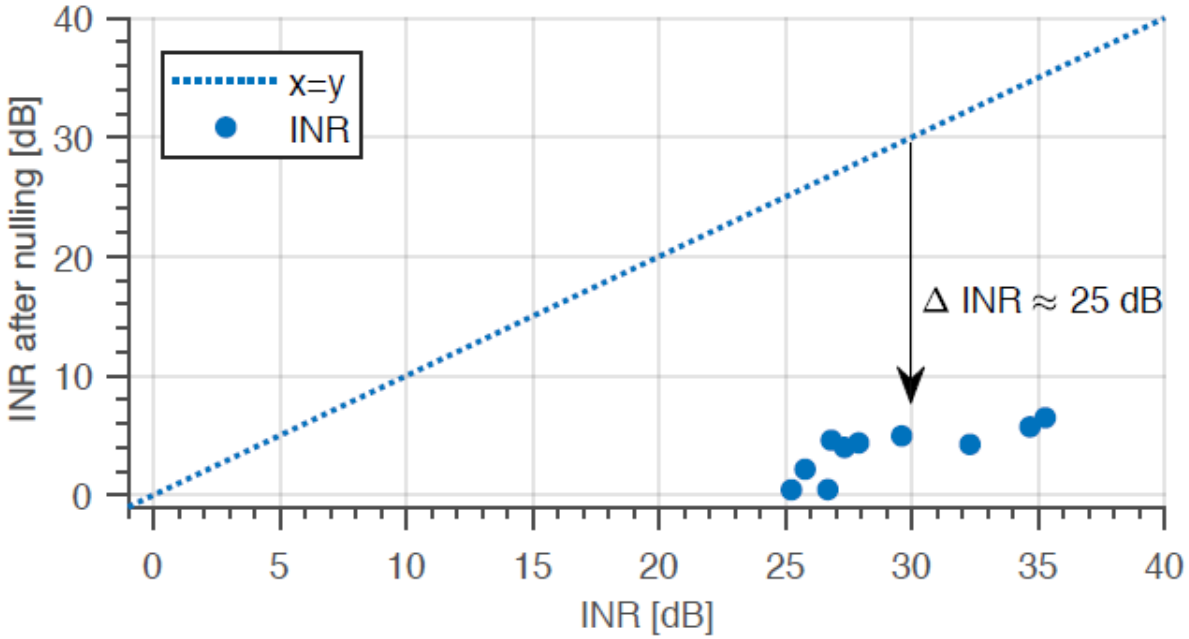
WiFi nodes (Atheros AR95xx



Small-scale Evaluation at TKN

- Interference-to-noise ratio (INR) reduction under optimal conditions - frequency-flat wired channel



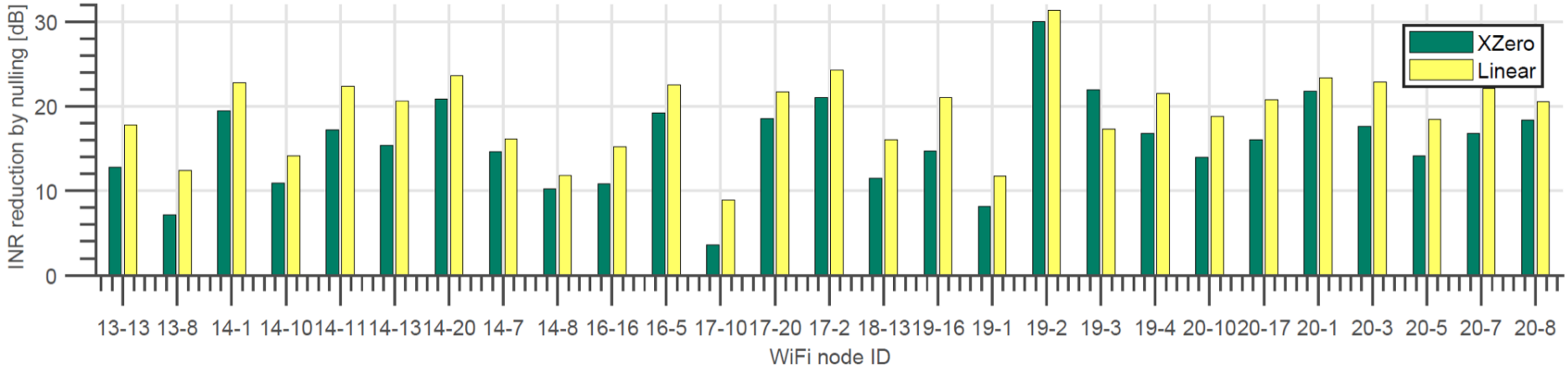


Large-scale Evaluation in ORBIT Grid

- Real wireless (frequency-selective) channel, 2.4 GHz

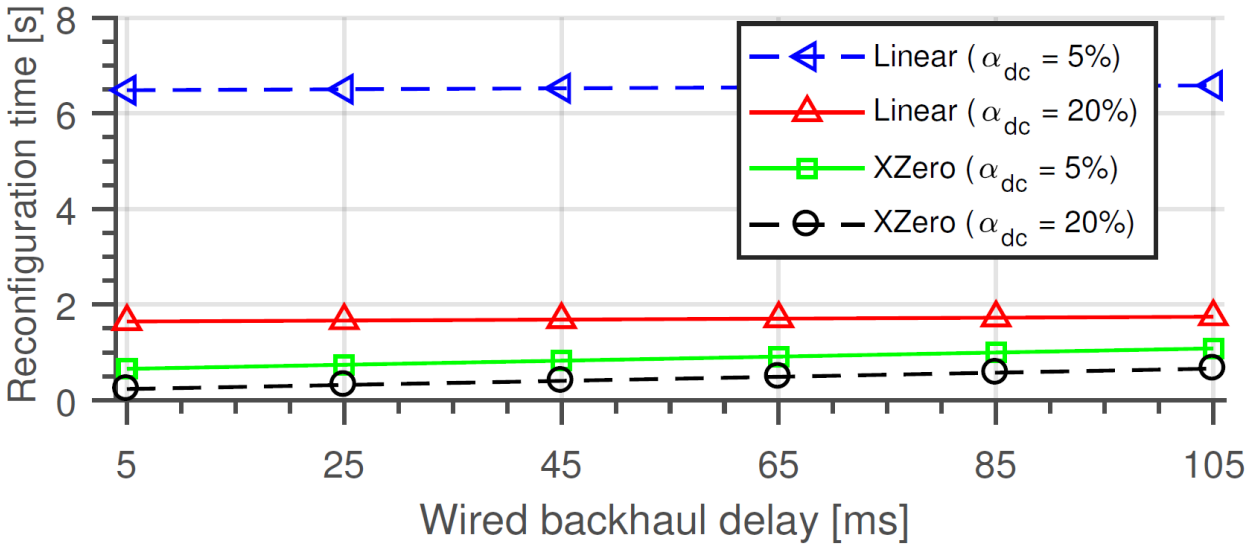
ULA w/ K=4 antennas selected

- 27 randomly selected WiFi nodes
- Main results:
  - 15.7 dB decrease in INR at nulled WiFi nodes
  - Linear-search slightly better: higher INR
  - Tree-search: 10× faster than linear search



Reconfiguration Delay

- Null search has to be performed upon change in network topology,
- Parameters affecting configuration delay:
  - Selected angular resolution, length of LTE-U on-period, WiFi sampling frequency, LTE-WiFi backhaul latency, tree-search fan-out
- For single WiFi node: < 1 sec & speed-up of 10x compared to linear search



Take-aways

- Need for **efficient coexistence** schemes for operation in unlicensed 5 GHz spectrum,
- We propose **explicit cooperation** between co-located LTE-U and WiFi networks,
- We suggest to create coexistence gaps in space by means of **cross-technology interference nulling (CTIN)**,
- XZero is practical CTIN on SDR/COTS hardware

Thank you!

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