Coexistence Gaps in Space
via Interference Nulling for LTE-U/WiFi Coexistence

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LTE operators' interest in unlicensed operation

- Mobile network operators (MNO) can expand their capacity with unlicensed spectrum via **carrier aggregation**
- Bundling licensed+unlicensed spectrum: less over-provisioning needed
- No spectrum fees!
- Lots of capacity at 5 GHz
- LTE-unlicensed (LTE-U)

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A big challenge: Coexistence with the WiFi
LTE-Unlicensed (LTE-U)

Why is coexistence a challenge?

LTE incompatible for unlicensed spectrum sharing

LTE
- Scheduled access
- Continuous transmission

WiFi
- Random access
- Listen before talk (LBT)
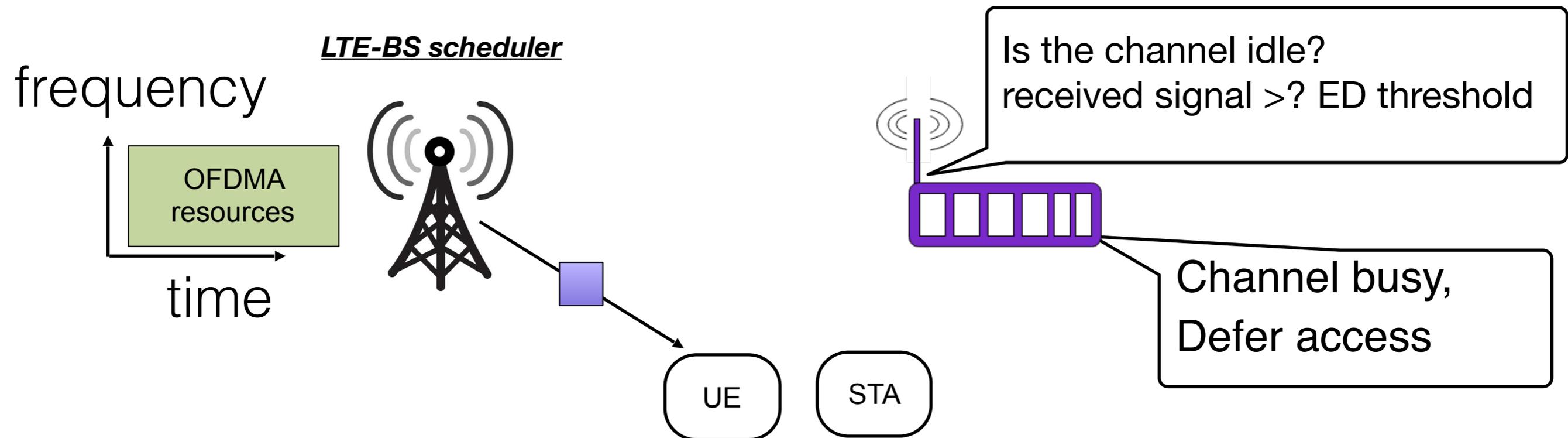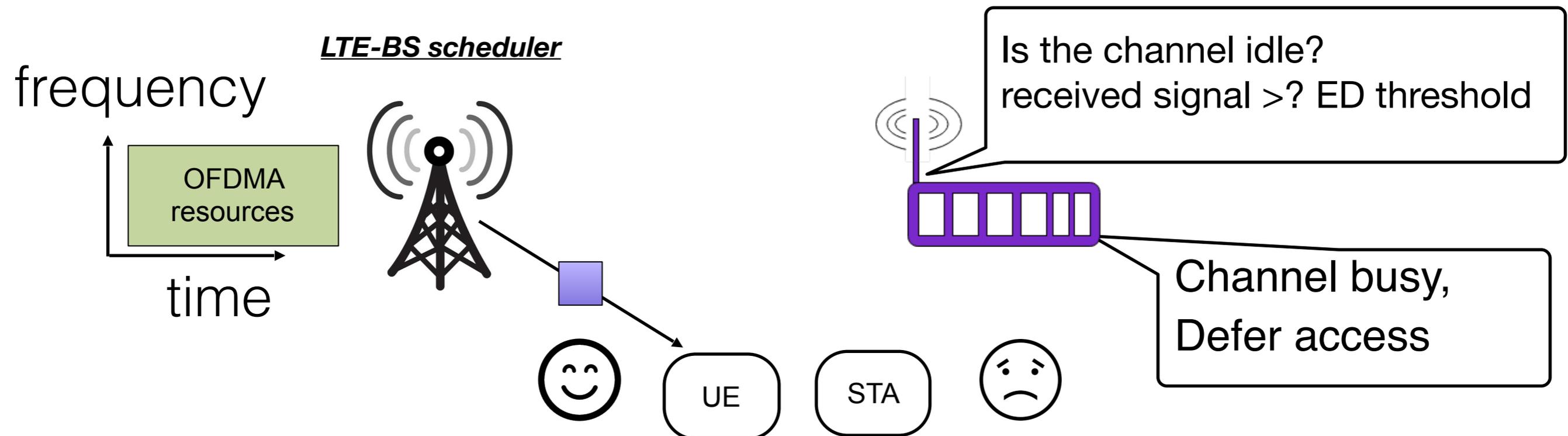
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LTE-BS scheduler

frequency

OFDMA resources

time

Is the channel idle?
received signal >? ED threshold

Channel busy,
Defer access

UE   STA

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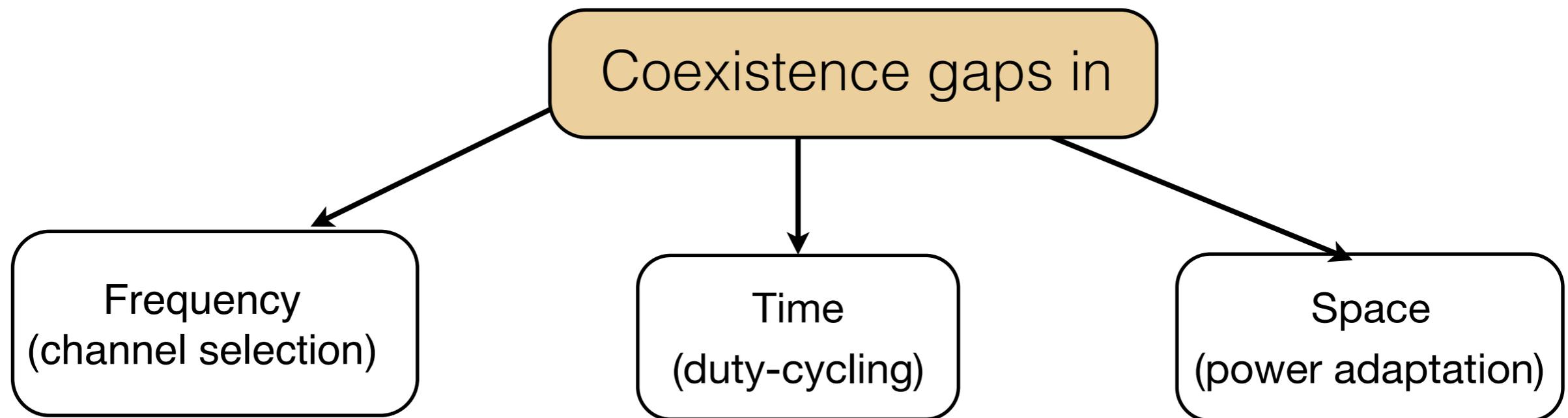
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**WiFi might suffer from LTE
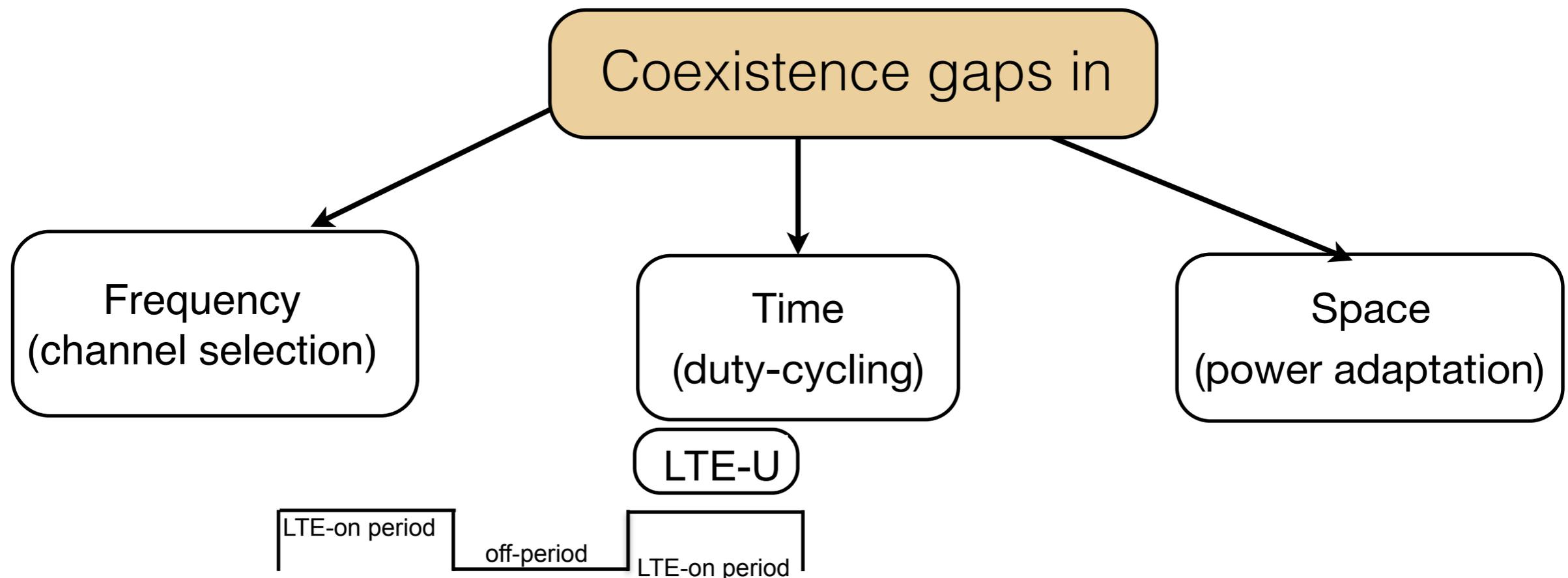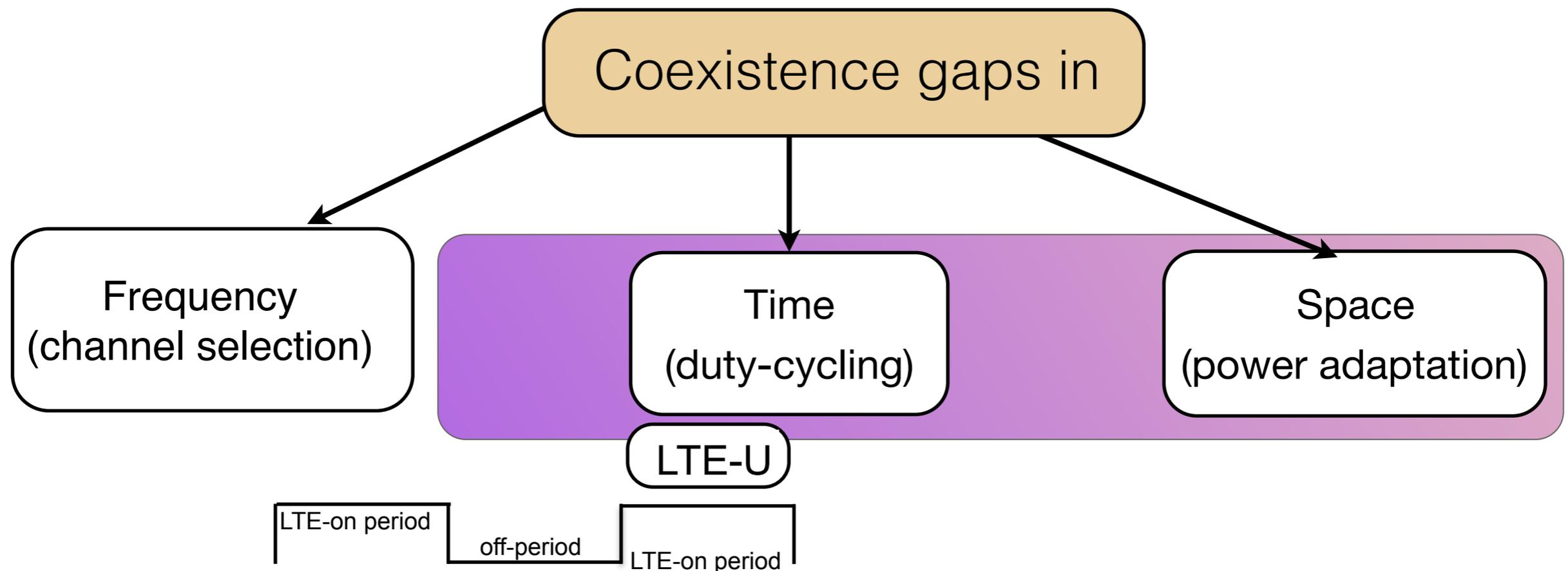if coexistence schemes are not implemented!**

Coexistence gaps put by LTE-U

- Coexistence gap: Resource blocks left for the other technology's use for fair coexistence

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              ┌─────────────────────────┐
              │   Coexistence gaps in   │
              └─────────────────────────┘
                /          │          \
               ↙           ↓           ↘
    ┌──────────────┐ ┌──────────────┐ ┌──────────────────┐
    │  Frequency   │ │     Time     │ │      Space       │
    │ (channel     │ │ (duty-       │ │ (power           │
    │  selection)  │ │  cycling)    │ │  adaptation)     │
    └──────────────┘ └──────────────┘ └──────────────────┘
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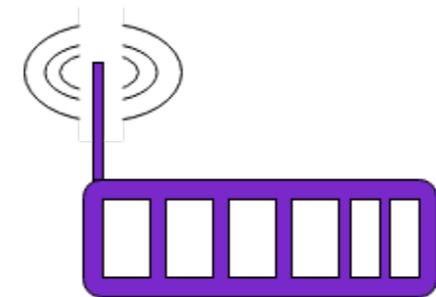
Interference-nulling for coexistence

- Our idea: use precoding at LTE-U BS to achieve interference nulling towards WiFi node(s) while beamforming towards LTE-UE
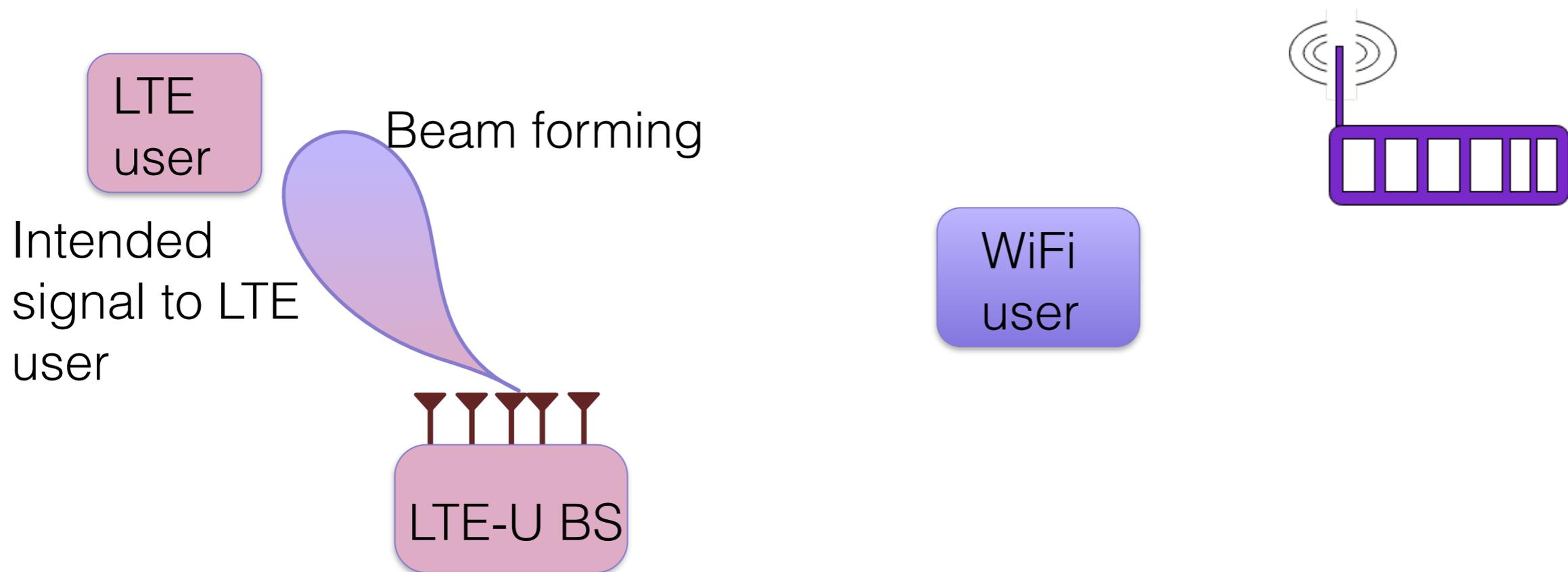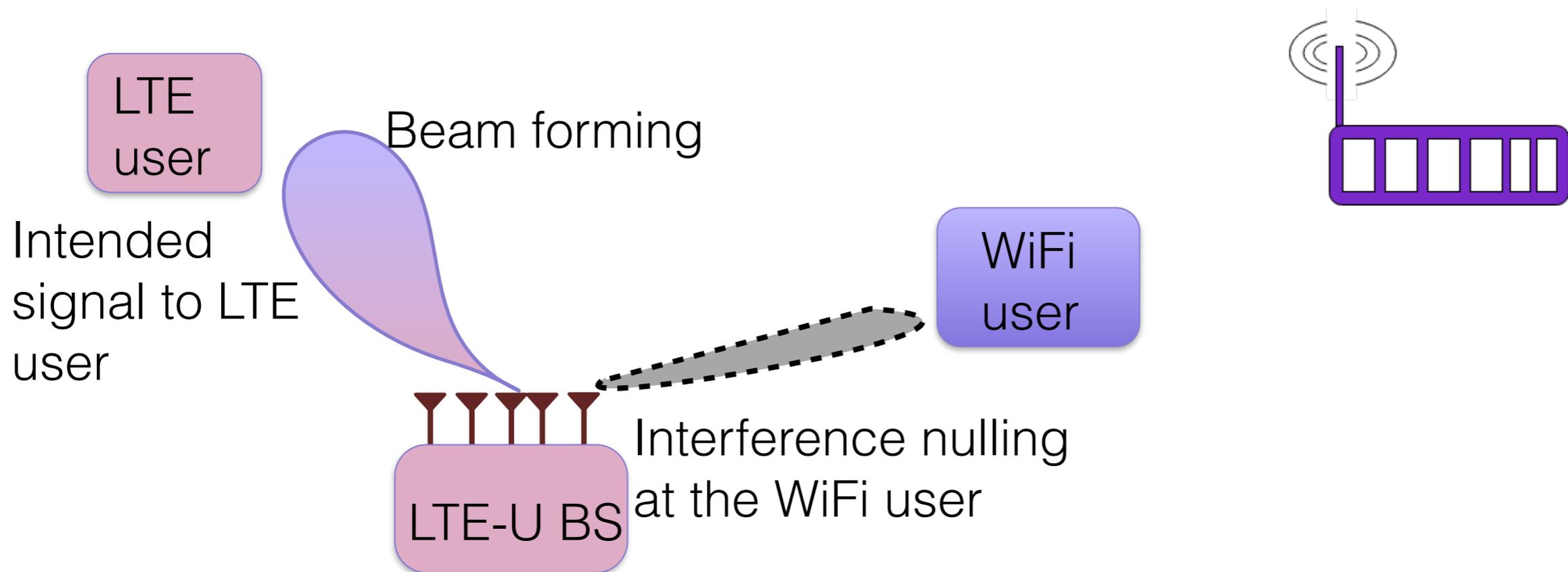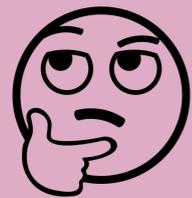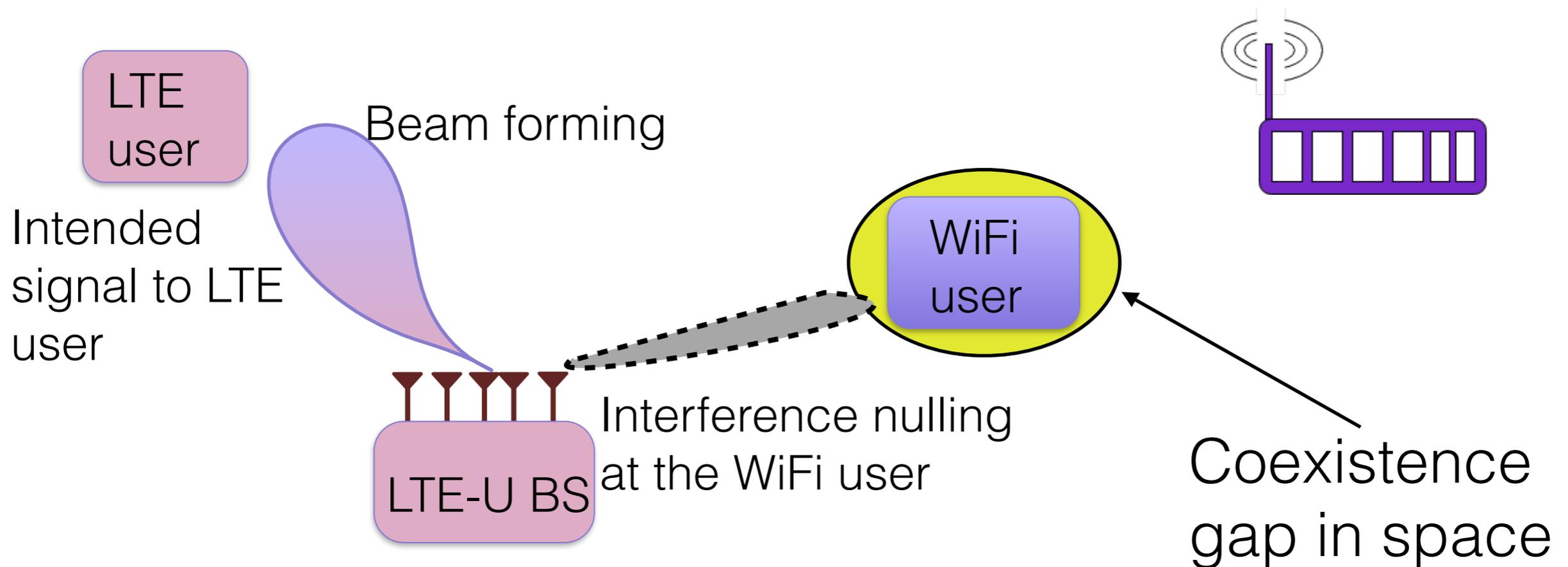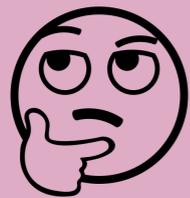
LTE user

WiFi user

LTE-U BS

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LTE user

Beam forming

Intended signal to LTE user
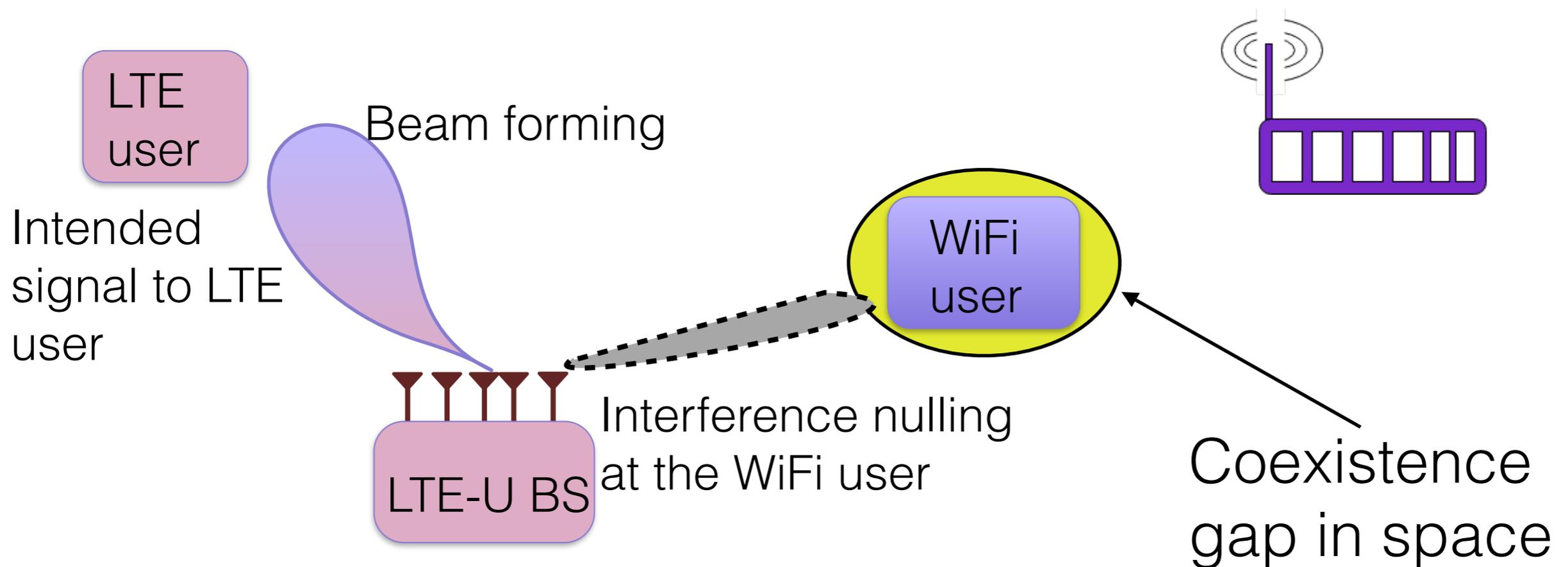
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Interference nulling at the WiFi user

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Coexistence gap in space

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Coexistence gap in space

Interference nulling can enable concurrent LTE-U and WiFi transmissions: improved coexistence compared to separation of transmissions
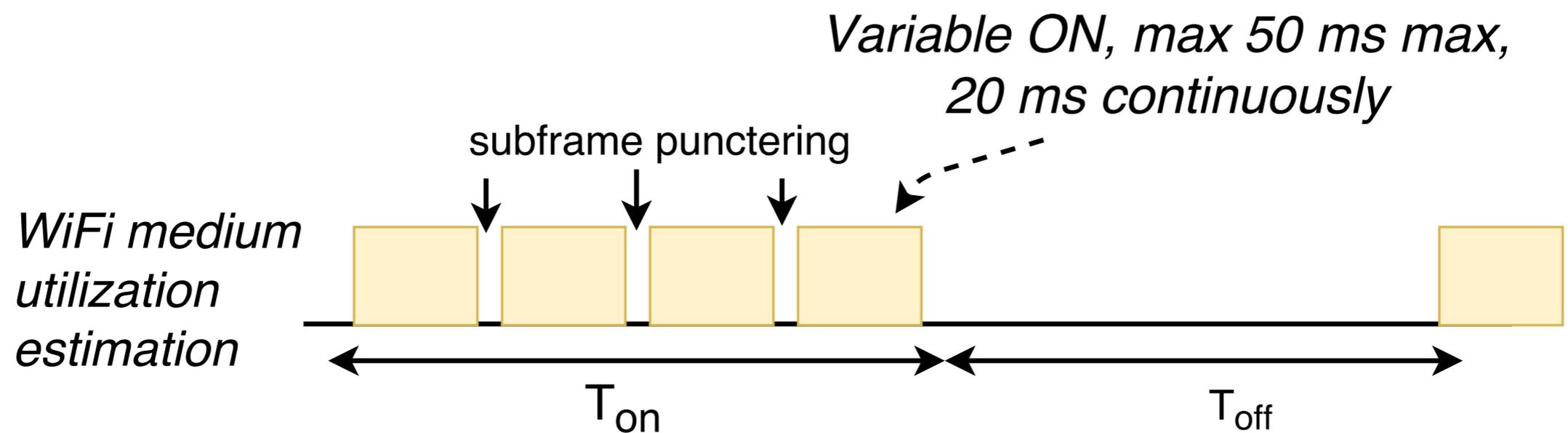
Cross-technology interference nulling based coexistence

- Challenge:
  - LTE-U BS needs to know:
    - locations of WiFi stations
    - its complex Channel State Information (CSI) towards WiFi station

    - No communication channel bw. LTE-U BS and WiFi
- In this paper, we assume all information is available at the LTE-U BS
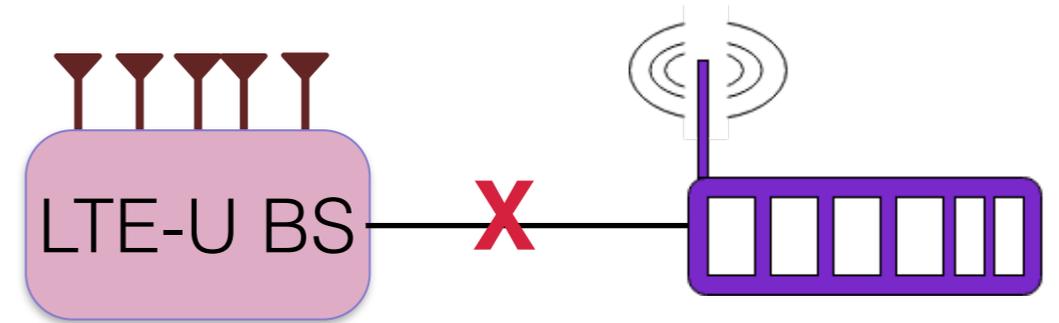
A brief overview of LTE-U

- LTE-U implements duty-cycling (no listen-before-talk before medium access)

- **CSAT**: Carrier-sense Adaptive Transmission by Qualcomm

  - LTE-U BS senses the medium

  - LTE-U must leave the medium for WiFi proportional to the number of WiFi nodes observed in the neighborhood (N_{cs}).

  - Airtime = LTE Ton/(Ton+Toff)

*Variable ON, max 50 ms max,
20 ms continuously*

subframe punctering

*WiFi medium
utilization
estimation*

T_{on} T_{off}

Motivation   Problem statement   Our proposal   Performance Analysis   Take-aways   7

LTE-U airtime for fair coexistence

- Ncs: number of WiFi nodes in carrier sensing range (CSR) of the LTE-U BS
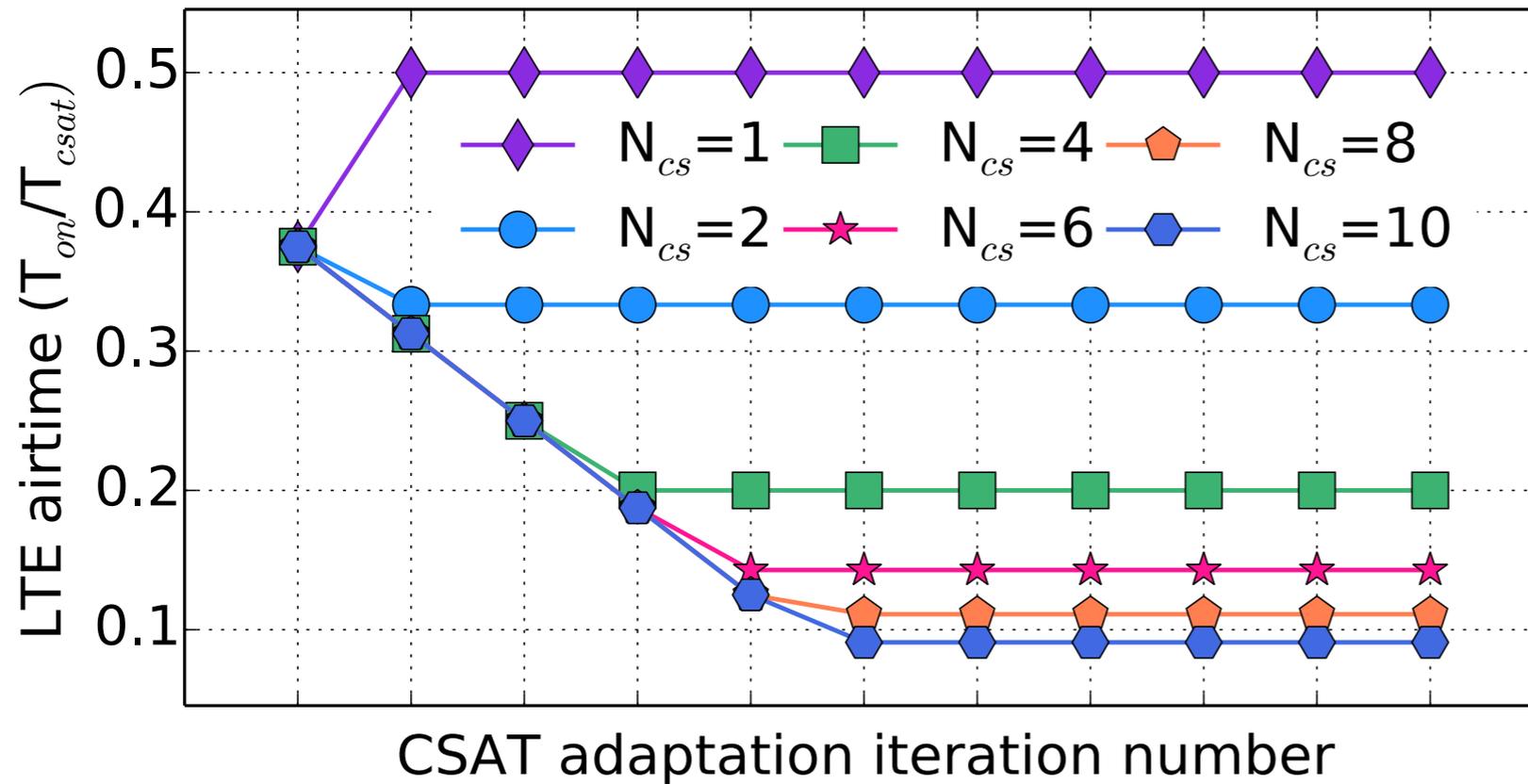
$$\text{airtime} = \frac{1}{1+\text{N}_{cs}}$$

LTE-U airtime for fair coexistence

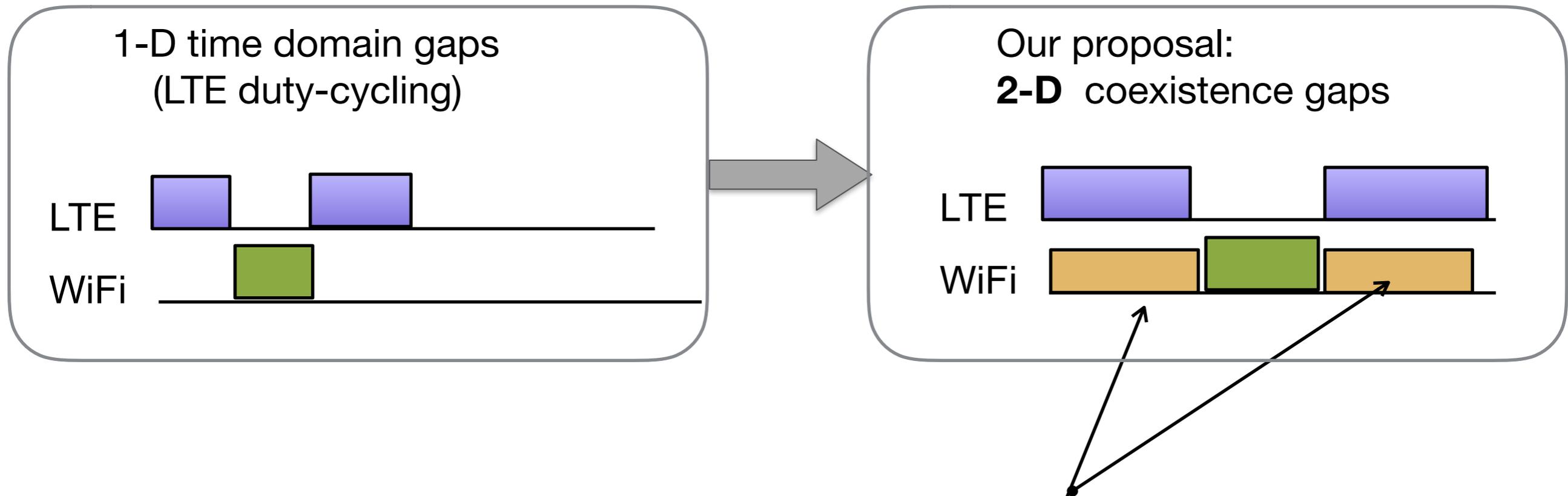- Ncs: number of WiFi nodes in carrier sensing range (CSR) of the LTE-U BS
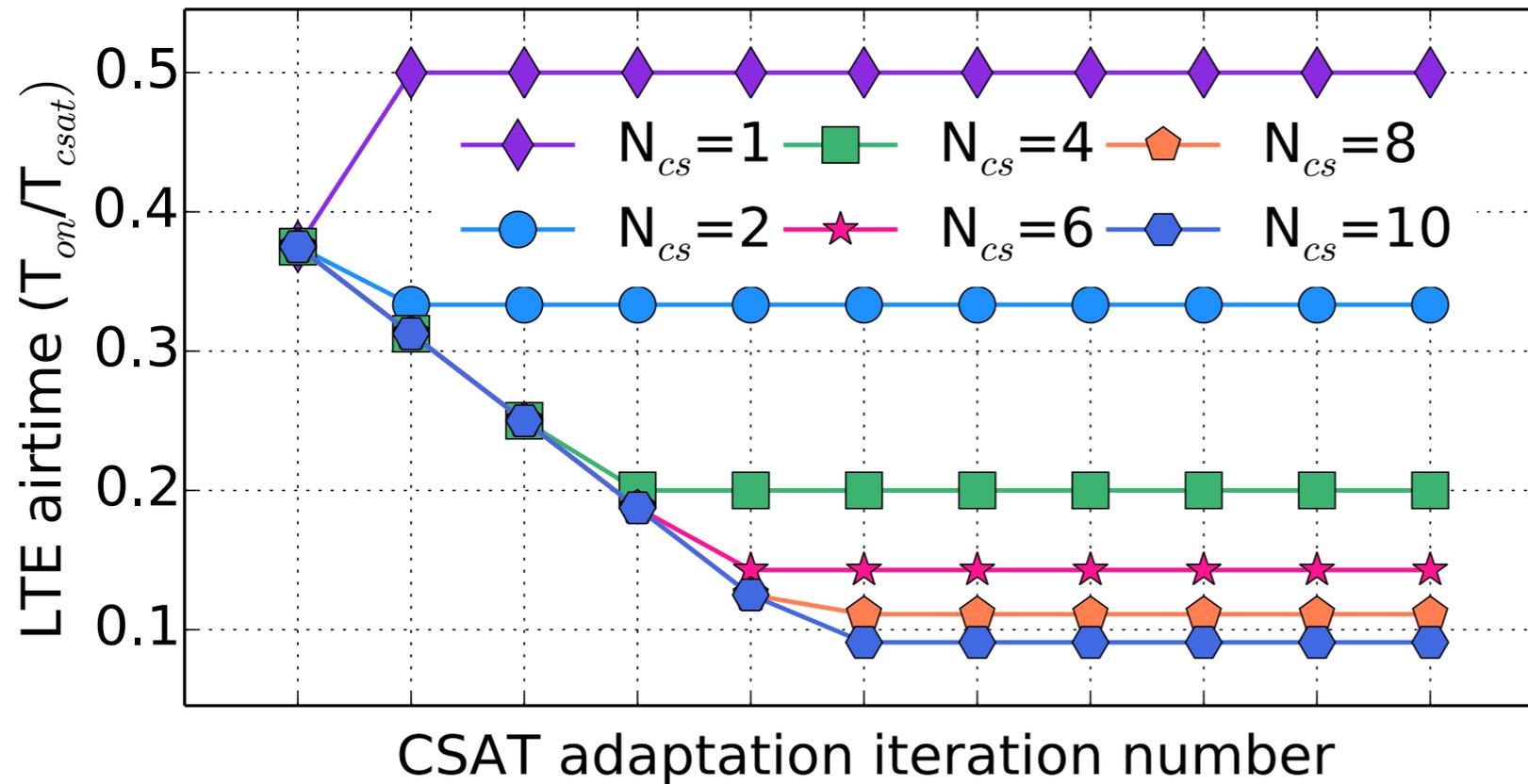
$$\text{airtime} = \frac{1}{1+N_{cs}}$$

Decrease N_{cs}

$$\alpha_l(K_\varnothing) = \frac{1}{(N_{cs} - K_\varnothing) + 1}.$$

Interference nulling moves the airtime figure above without violating the fairness notion

Medium access under interference nulling

1-D time domain gaps
(LTE duty-cycling)

LTE

WiFi

Our proposal:
2-D coexistence gaps

LTE

WiFi

Transmission to ***nulled WiFi*** nodes

Promises a **win-win** solution for both LTE and WiFi
- Increased throughput for both
- Lower medium access delay for both

How does nulling affect WiFi's medium access?
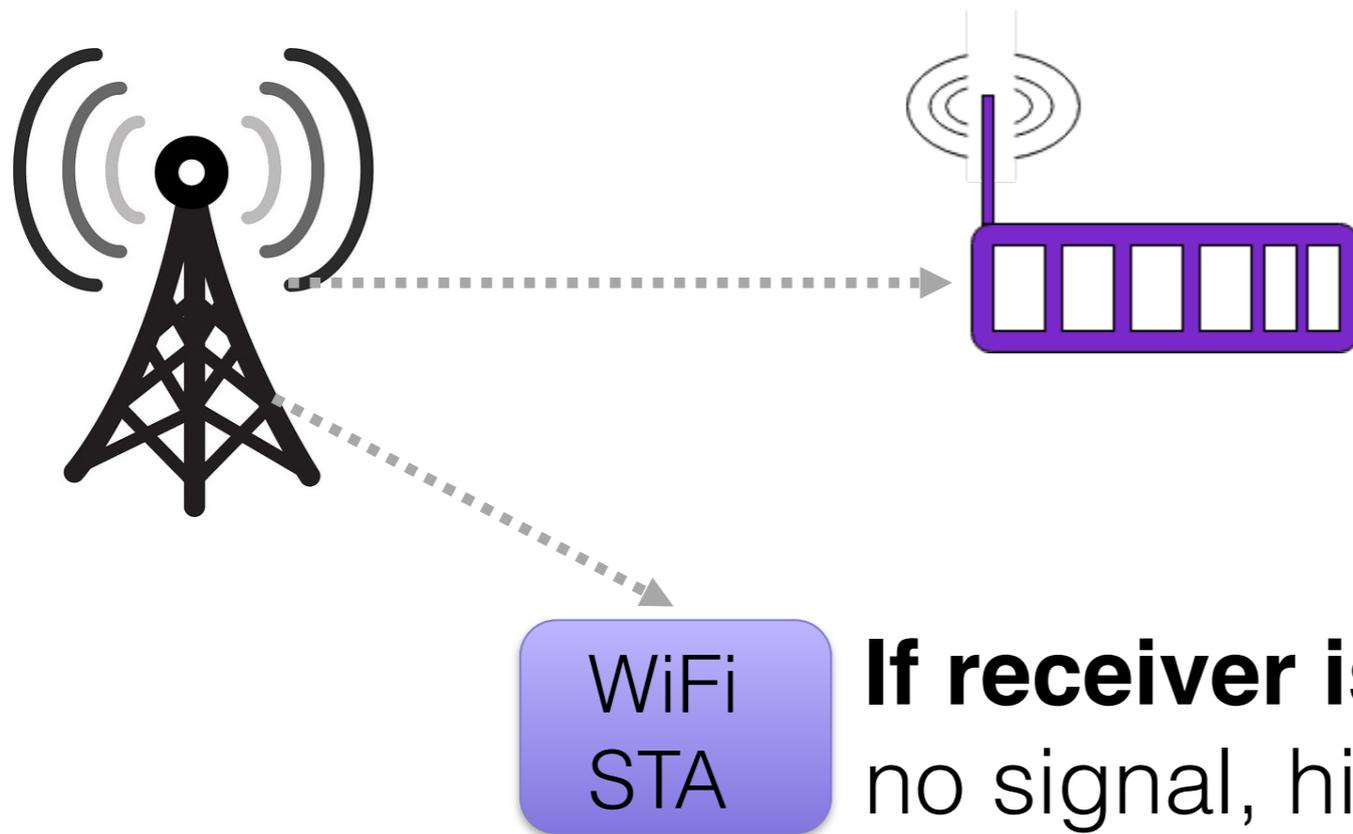
If transmitter is nulled: channel idle, channel access (airtime=1)

WiFi STA

If receiver is nulled: no signal, high SNIR

Caveats!

LTE-U uses some of its antenna resources (degrees of freedom) for nulling

- Nulling towards particular direction might lower the gain from beamforming towards its own UE (WiFi in a similar angular direction to UE)

- Increase in airtime vs. decrease in LTE-U DL SNR due to lower gain from beam forming

- Nulling may not always improve WiFi throughput

- Longer airtime for LTE during which WiFi has some DL traffic

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Best trade-off: both LTE and WiFi does not decrease performance over no-nulling case

Which WiFi nodes (AP and STAs) to null?
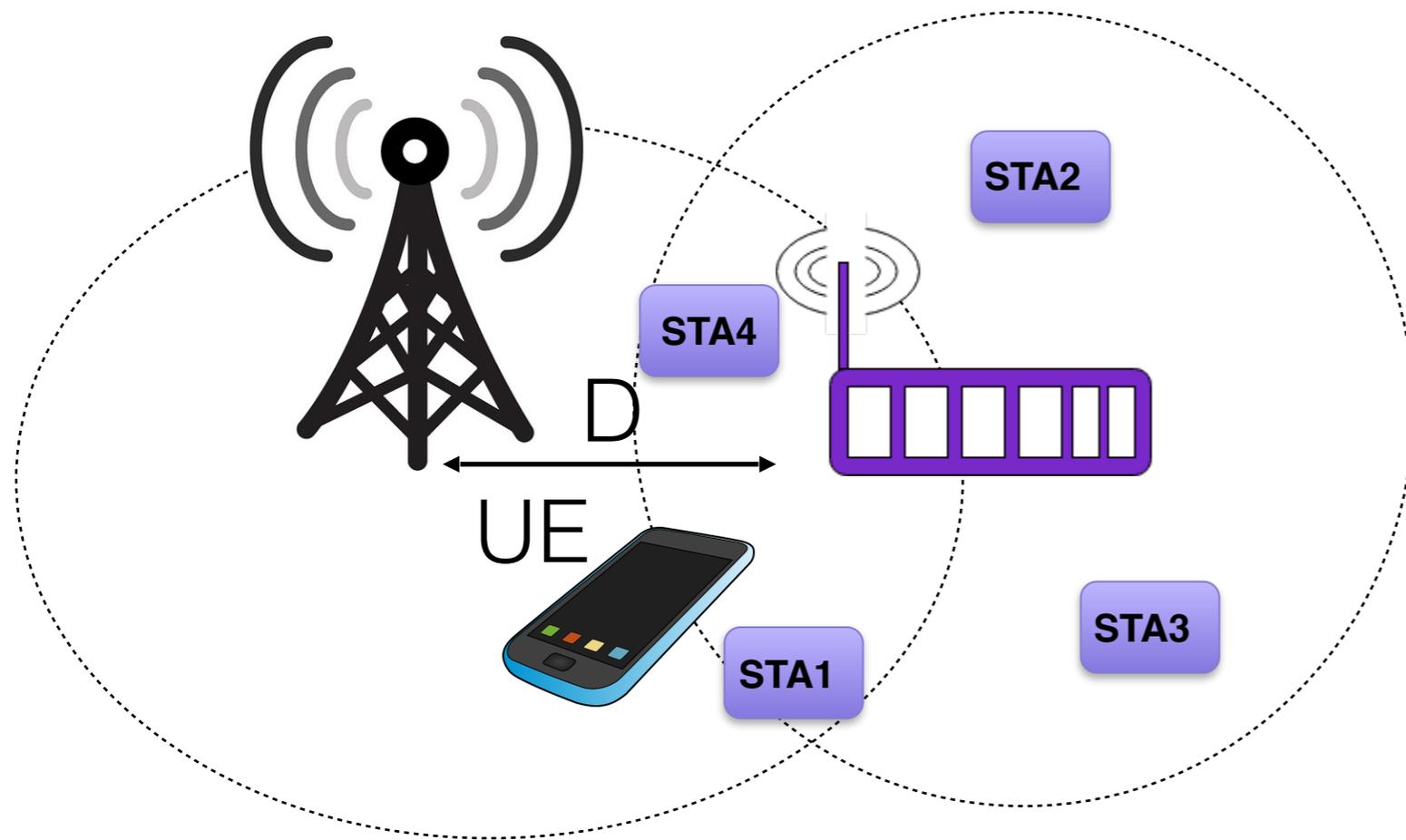
STA2

STA4

D

UE

STA1

STA3

Which WiFi nodes (AP and STAs) to null?

STA1 — hard to separate from UE, i.e. nulling STA1 will reduce gain of beamforming towards UE
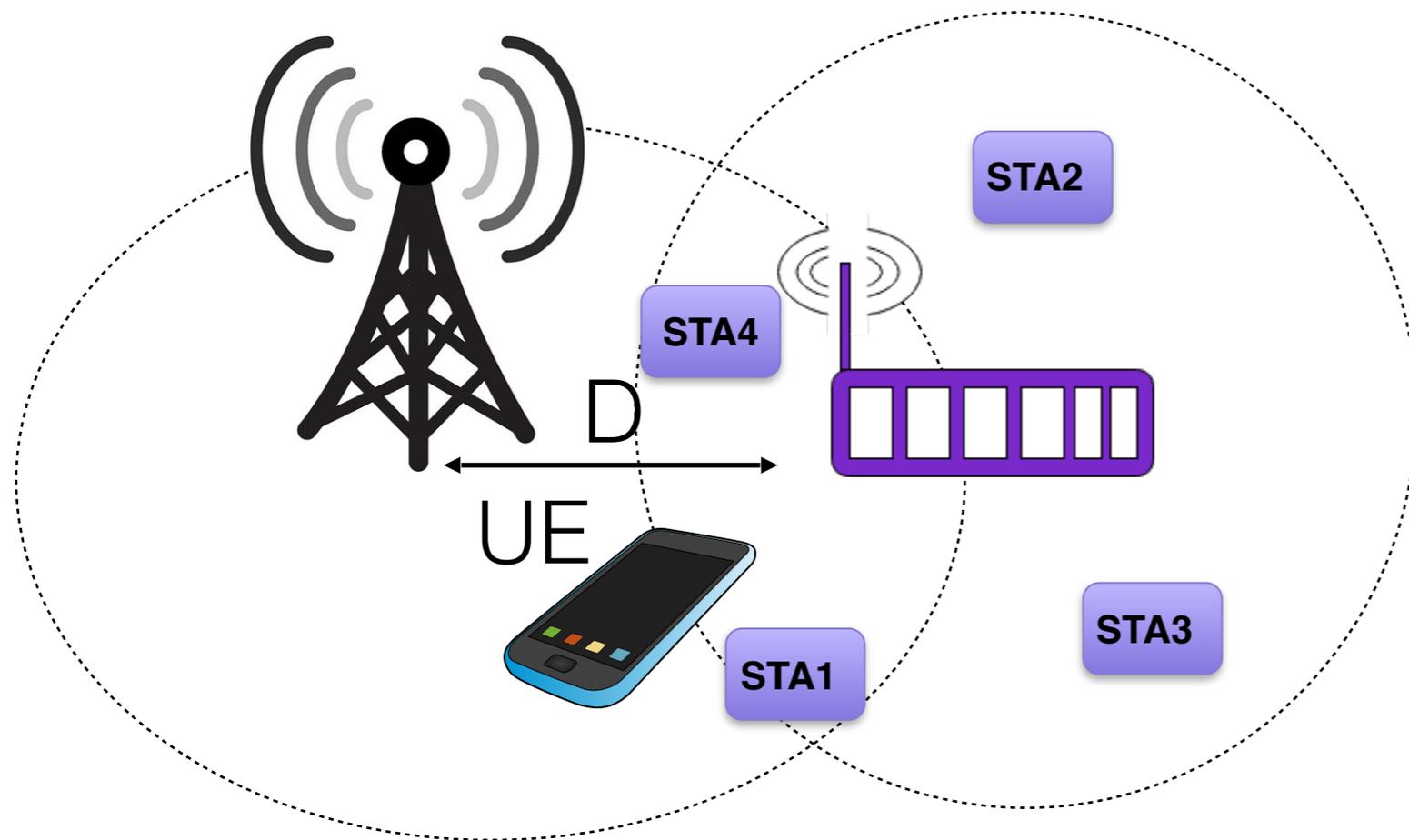
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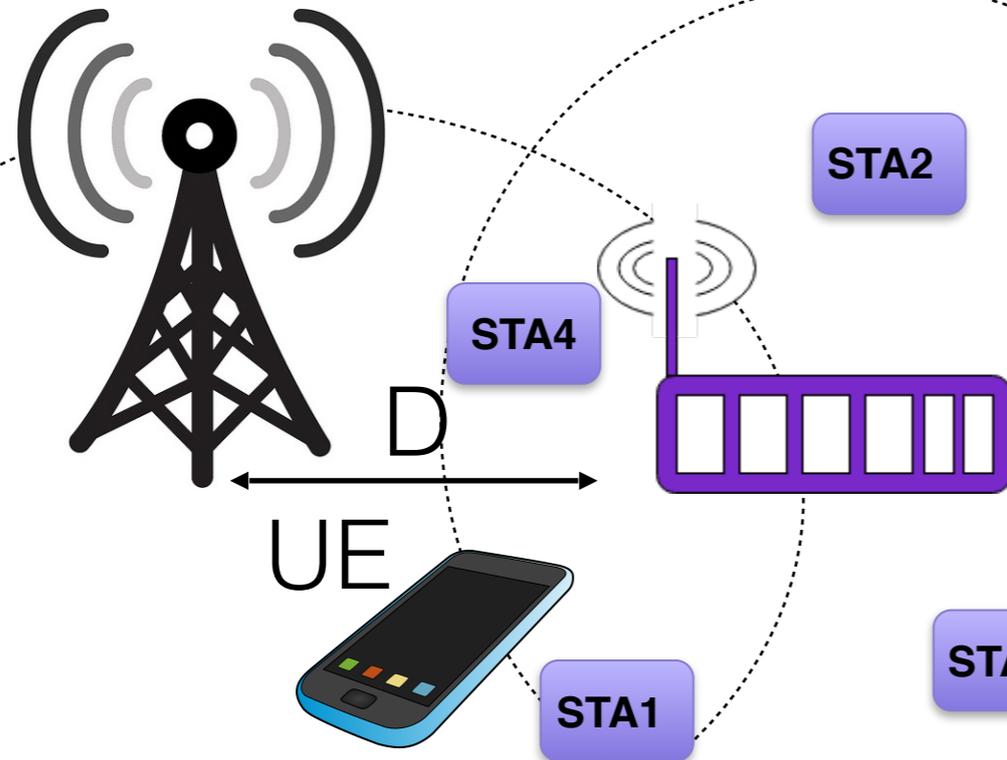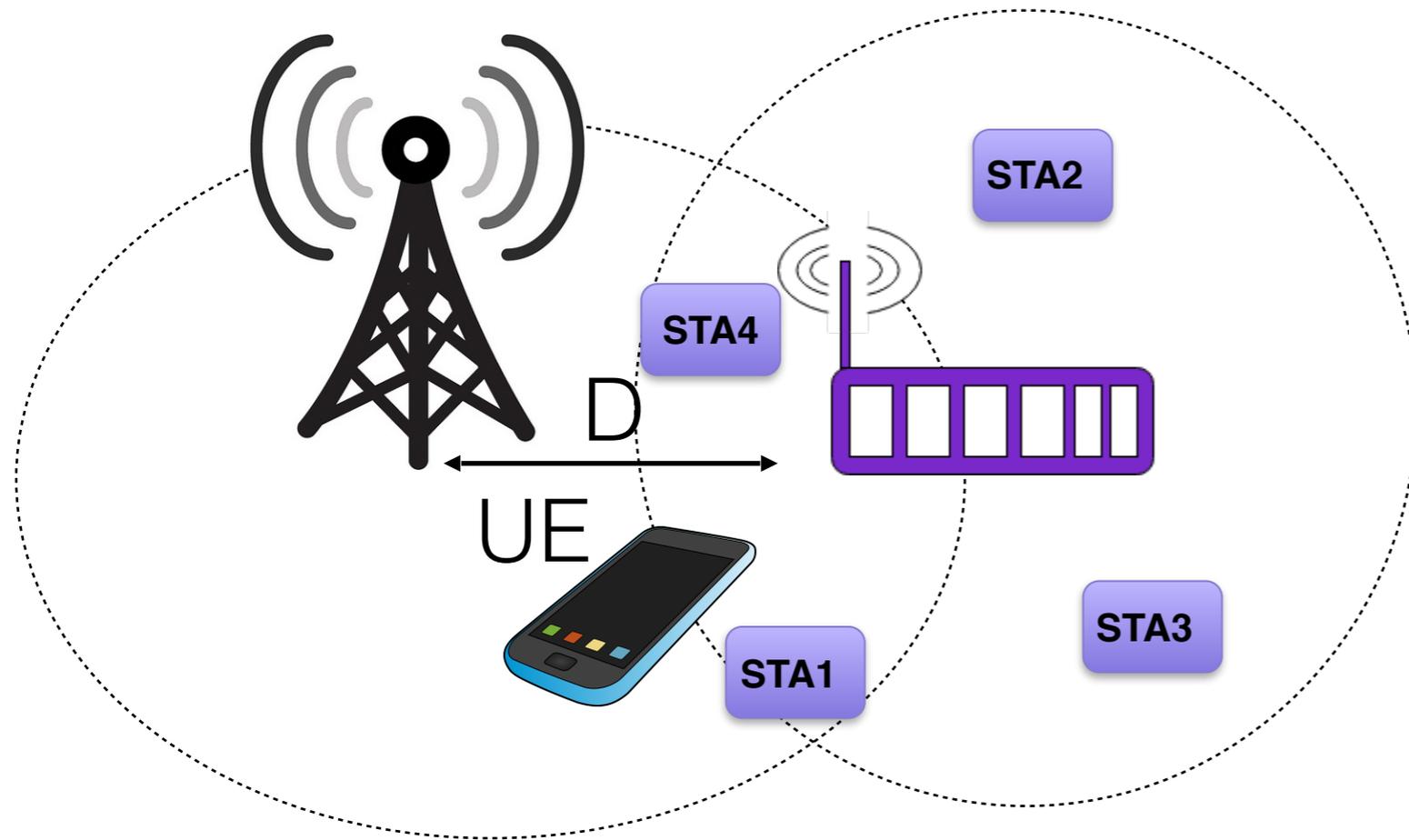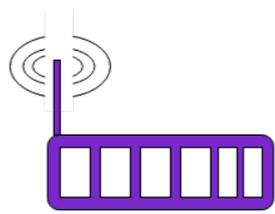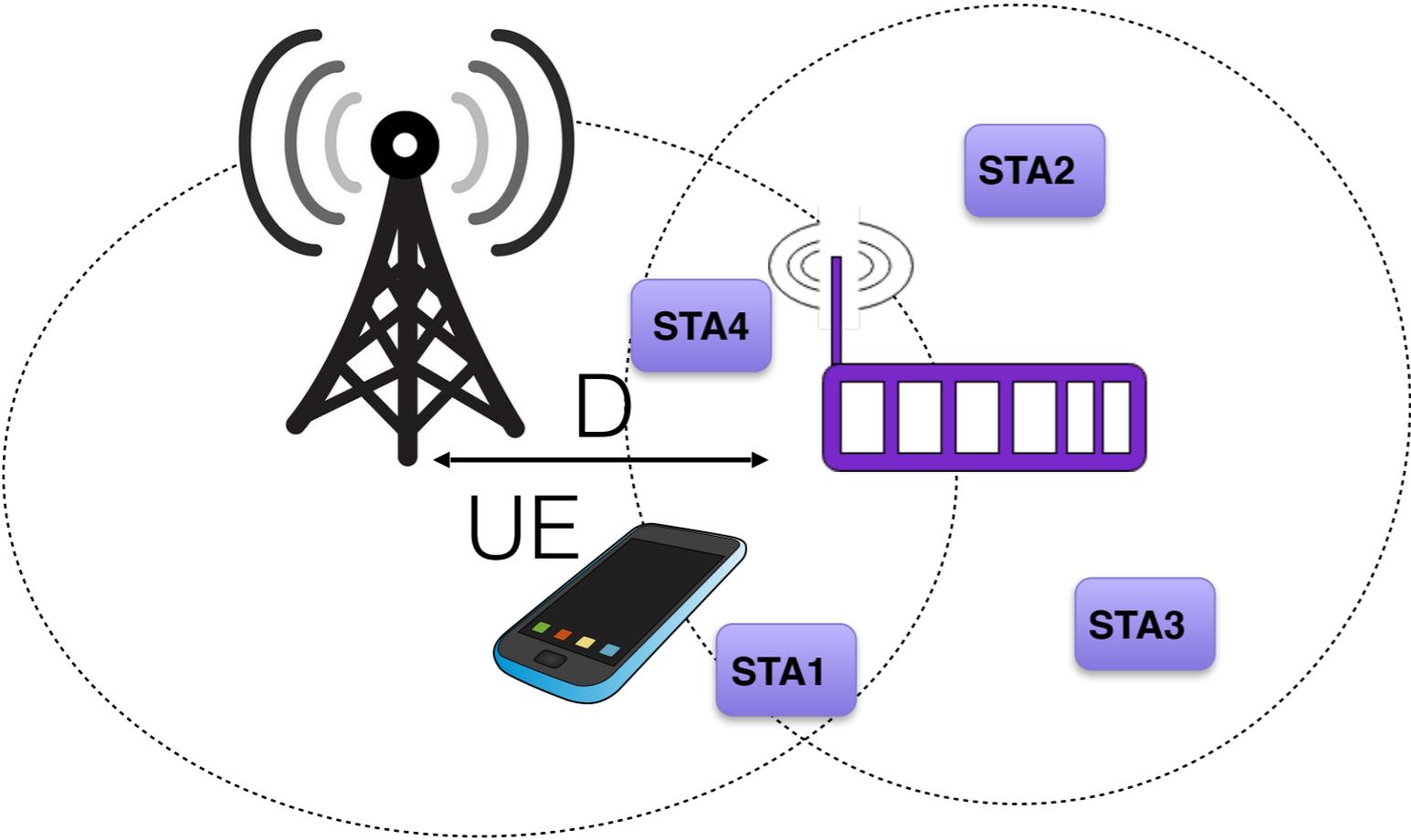
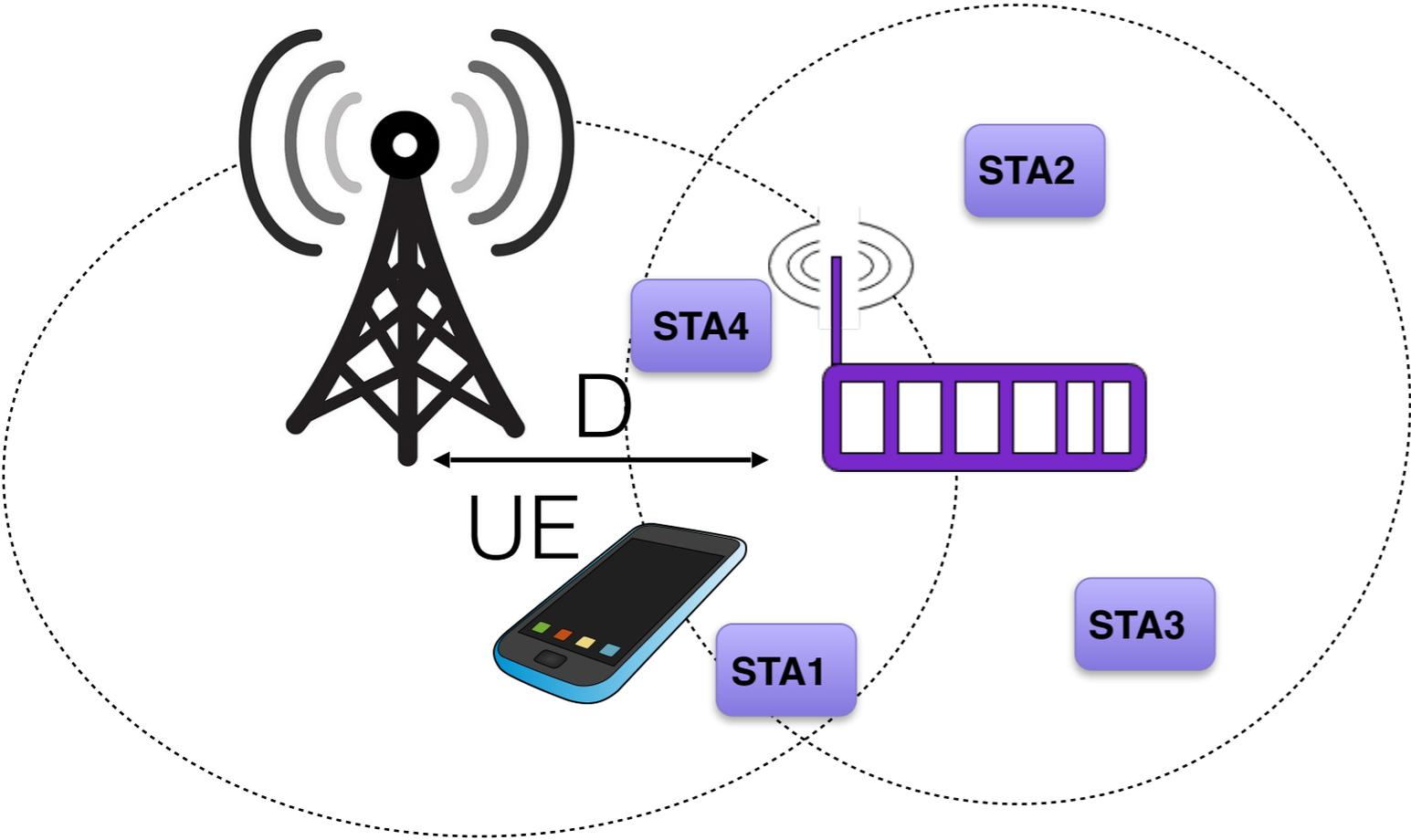STA2
STA3
} no need, outside range

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STA3 — } no need, outside range

STA4 — null together

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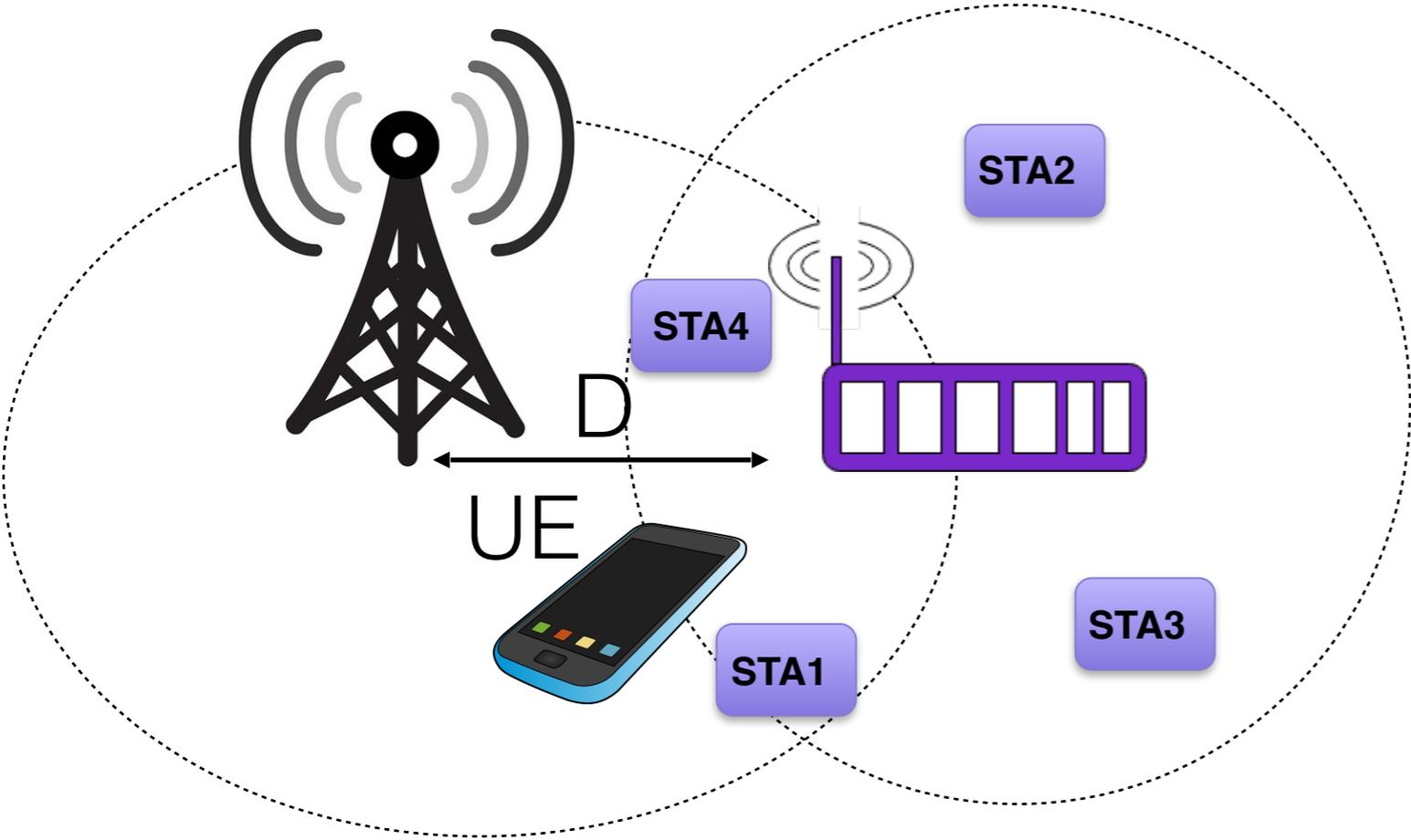STA3 } no need, outside range

STA4 — null together
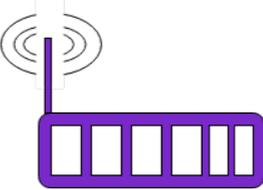null AP only

Which WiFi nodes (AP and STAs) to null?

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Which WiFi nodes (AP and STAs) to null?

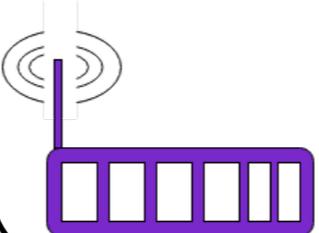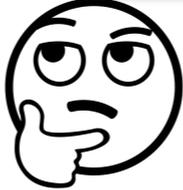STA1 — hard to separate from UE, i.e. nulling STA1 will reduce gain of beamforming towards UE

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STA4 — null together / null AP only

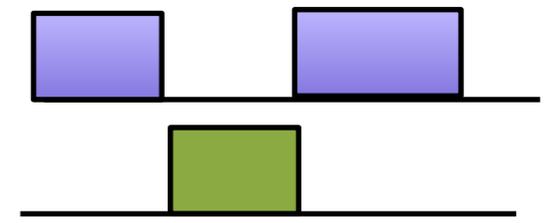Which option is better?
We model airtime and average rate

Throughput for WiFi nodes

Case 1: Only time-domain gaps (No LTE interference)

$$R^0_{i,w} = (1 - \alpha_l) B \log(1 + \frac{P_w d_{i,w}^{-\gamma}}{B \eta_0})$$
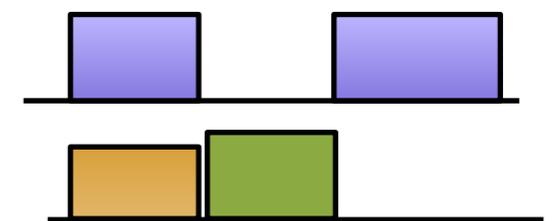
WiFi airtime
remaining from LTE

WiFi channel capacity

Case 2: Time and space-domain gaps: (LTE interference during LTE-on period)

$$\underbrace{\alpha_l B \log(1 + \frac{P_w d_{i,w}^{-\gamma}}{B \eta_0 + P_l d_{i,l}^{-\gamma} \Phi_i})}_{\text{LTE on-period}} + \underbrace{(1 - \alpha_l) B \log(1 + \frac{P_w d_{i,w}^{-\gamma}}{B \eta_0})}_{\text{LTE off-period}}$$

Throughput for LTE UE

- We assume that LTE scheduler first decides which UE to serve in the DL

LTE airtime

$$R_{j,l} = \alpha_l r_{j,l}$$

LTE antenna gain at the UE

$$r_{j,l} = \begin{cases} r_{j,l}^0 = B \log\left(1 + \frac{P_l d_{j,l}^{-\gamma} \Phi_j}{B \eta_0}\right), & \text{blocked WiFi AP} \\ r_{j,l}^1 = B \log\left(1 + \frac{P_l d_{j,l}^{-\gamma} \Phi_j}{B \eta_0 + P_w d_{j,w}^{-\gamma}}\right), & \text{unblocked WiFi AP} \end{cases}$$

WiFi interference when AP is unblocked (nulled or LTE-BS is outside AP's sensing range)

Optimisation problem: please see the details in the paper

# Greedy WiFi node selection for nulling

- Under a given # of antennas (K):
  - select the WiFi node which gives highest gain in the metric (LTE, WiFi, sum capacity)
  - add nodes till max.nulls (#antennas-1) are reached or no increase in gain

Complexity of the selection algorithm: $O((N + 1)^2)$,
N is number of WiFi stations in CSR of LTE-U BS

Performance analysis

- Python simulations, Matlab's Phased Array system toolbox

- LCMV beamformer

- Baseline: no nulling, duty-cycling, i.e., LTE-U CSAT

- Parameters to investigate:
  - distance between LTE and WiFi cells
  - number of antennas at LTE-U BS
  - number of WiFi users

- Performance metrics:
  - Throughput gain in LTE, gain in WiFi
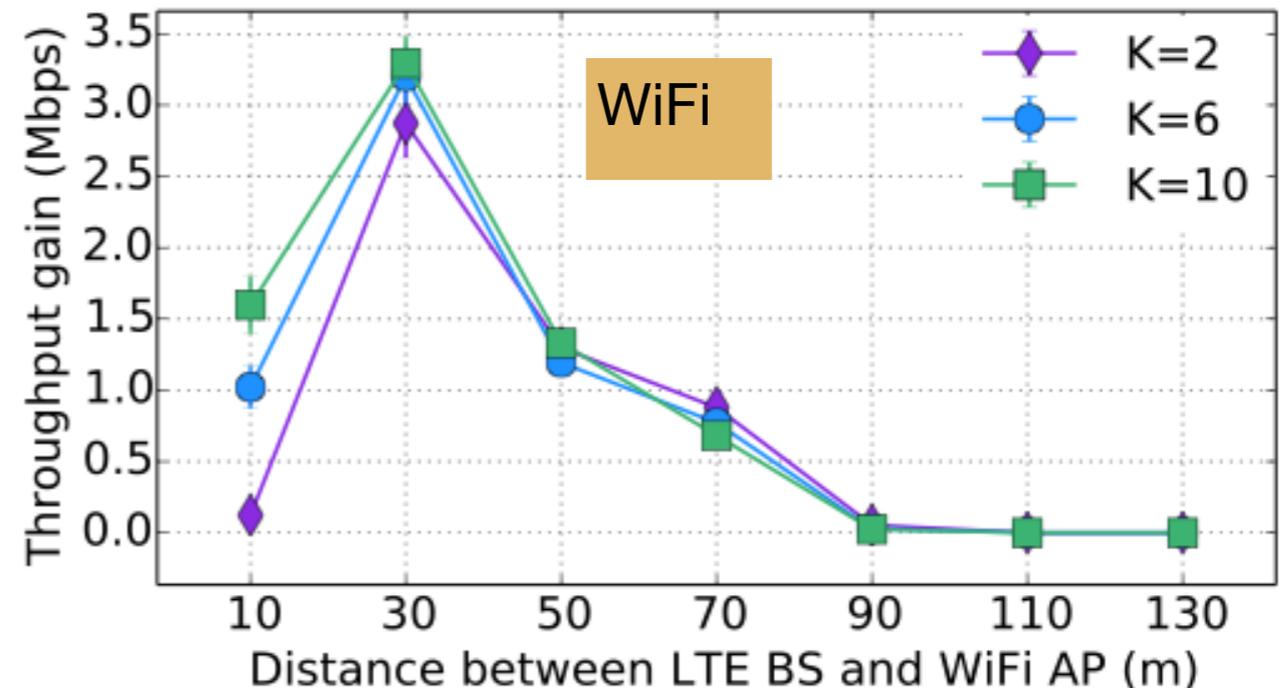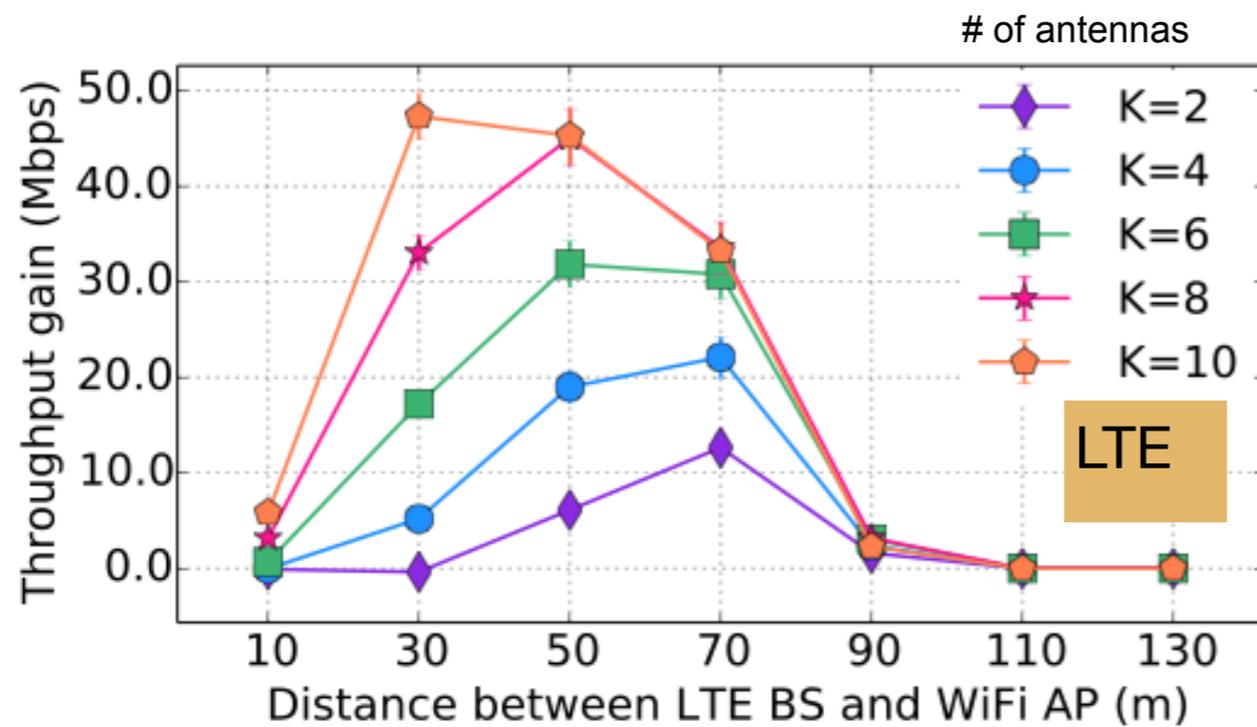 - Medium access delay for LTE and WiFi
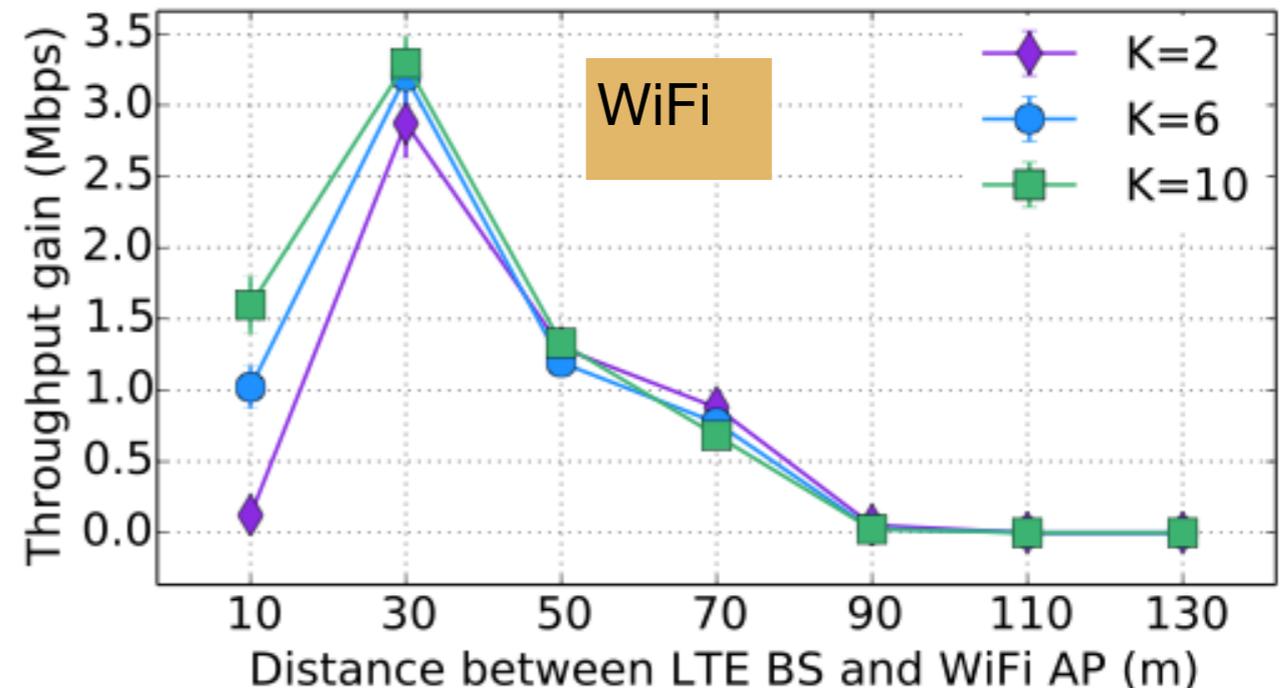
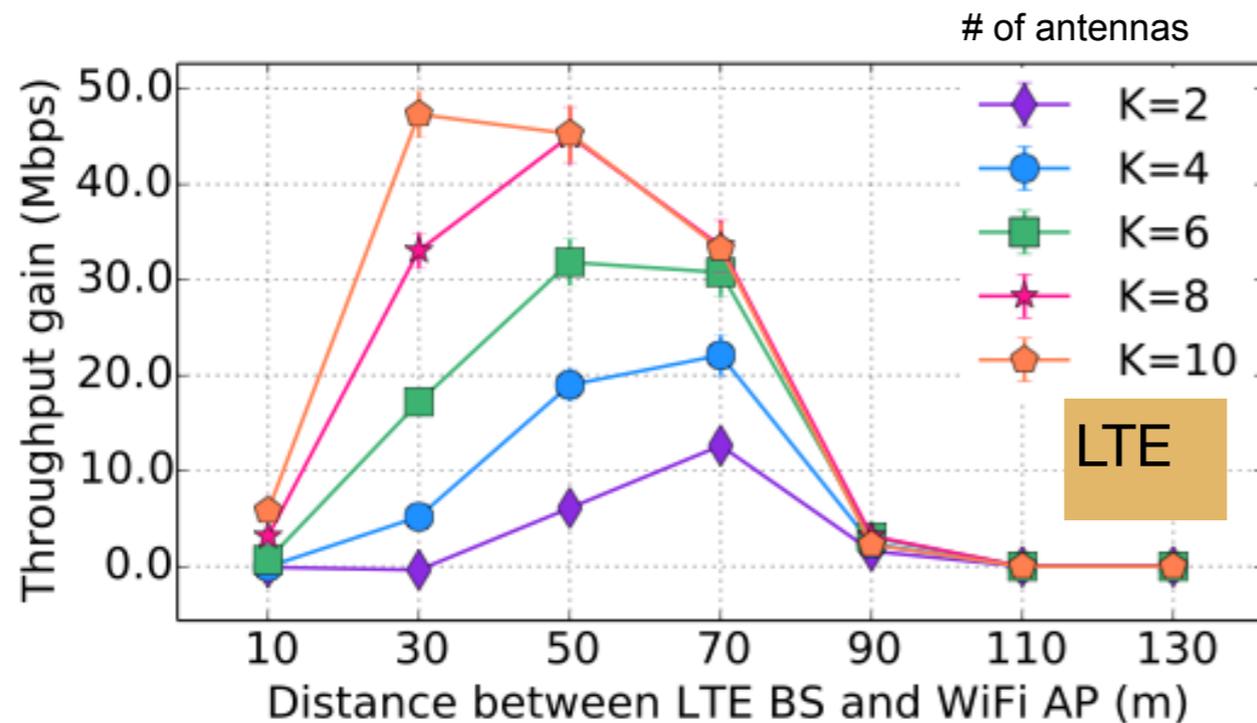# Throughput gain (8 WiFi stations)

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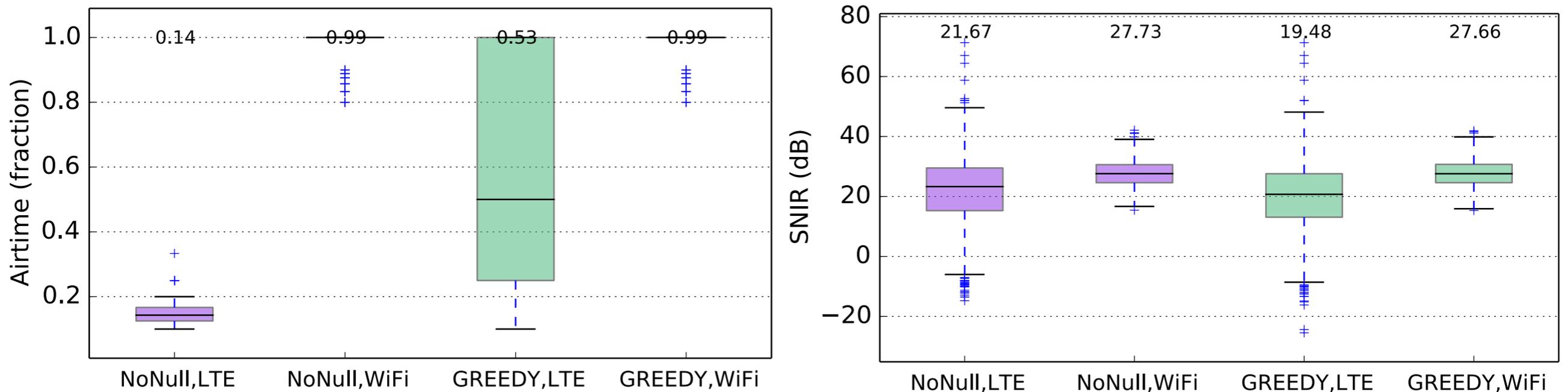

D

# of antennas

LTE
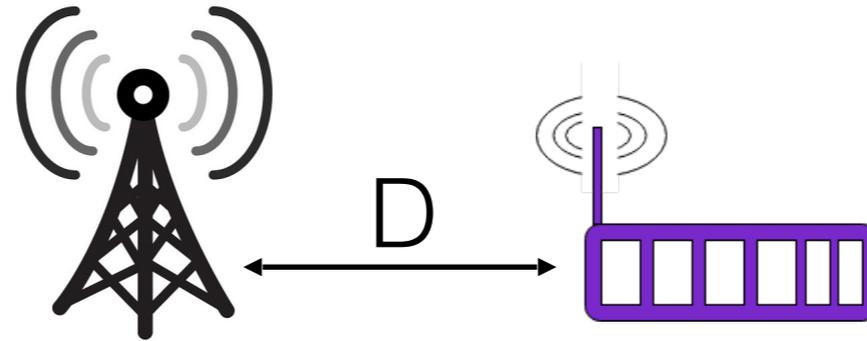
WiFi

Throughput gain (8 WiFi stations)

- Throughput increase for LTE/WiFi: up to 221%, 44%
- Significant improvement: inter-technology hidden node distances

How does airtime and SNIR change by nulling?

10 antennas at the LTE-U BS

- Slight decrease in LTE SNIR, but huge increase in its airtime
- WiFi only slightly affected

How does airtime and SNIR change by nulling?

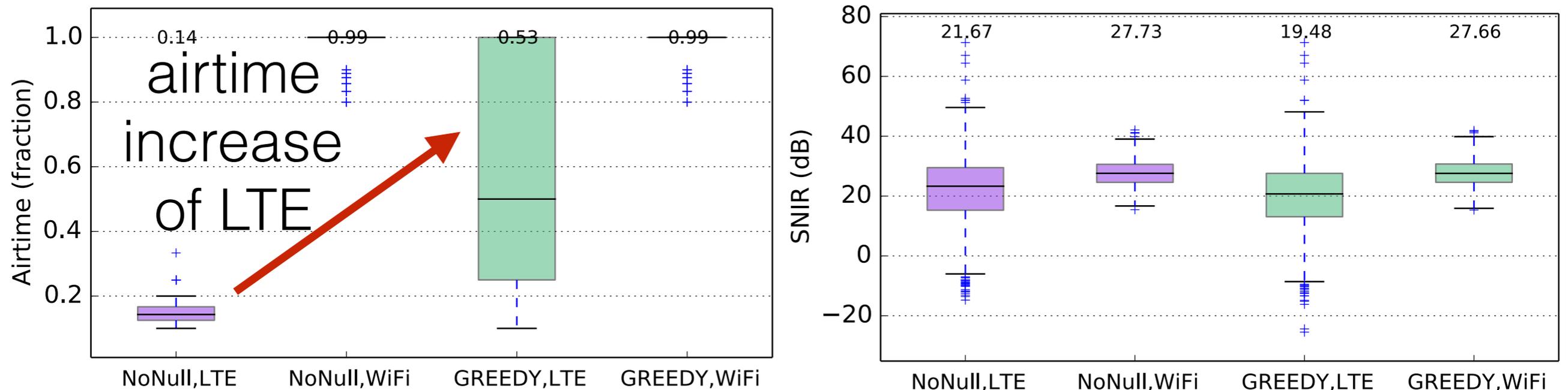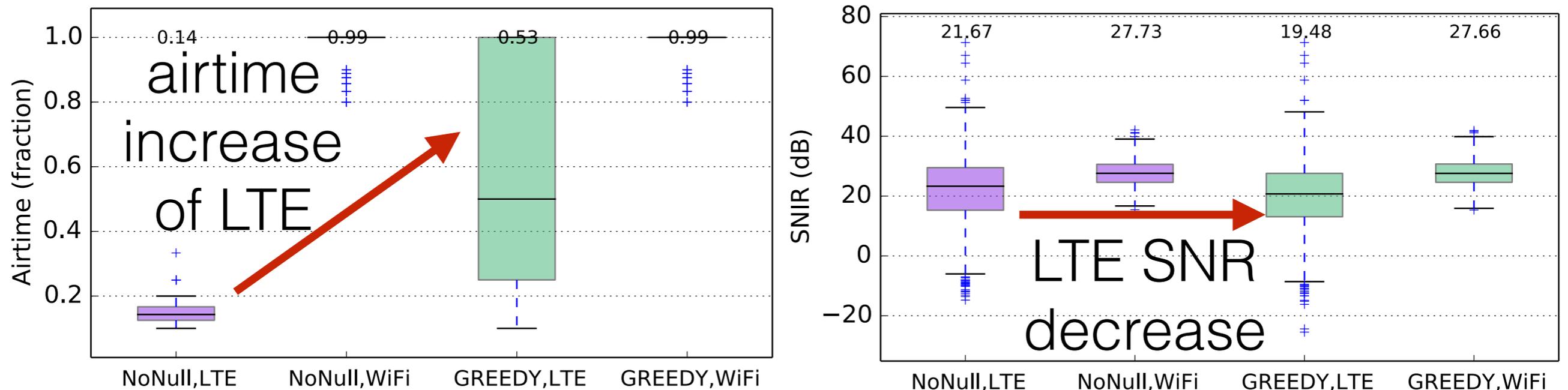## 10 antennas at the LTE-U BS

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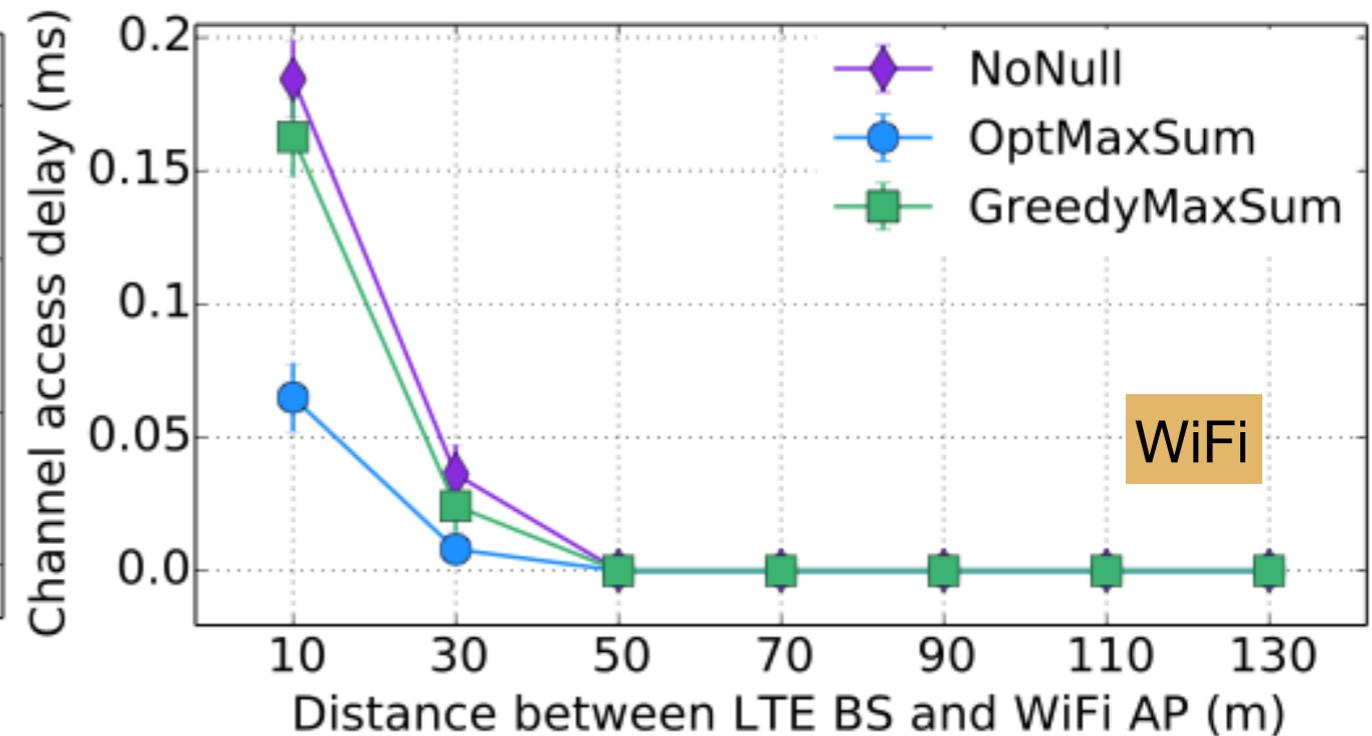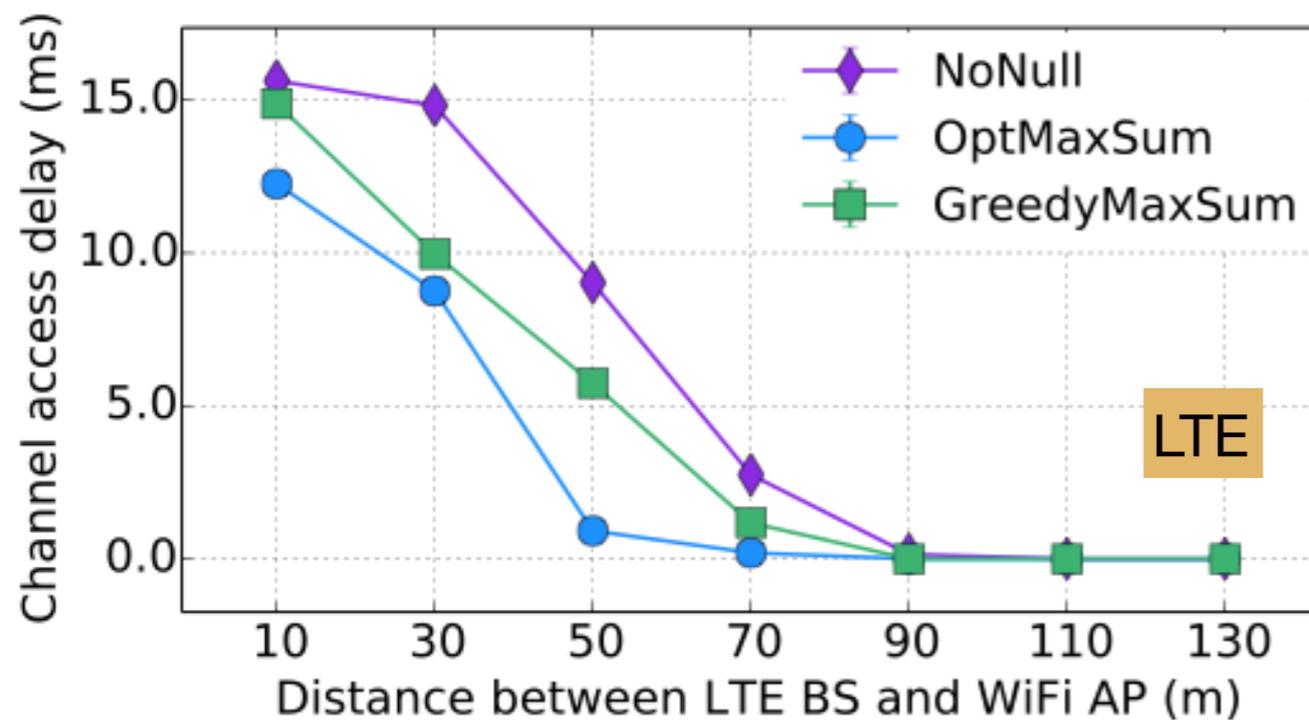- WiFi only slightly affected

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- WiFi only slightly affected

Medium access delay decreases

- Interference nulling decreases medium access delay

Key take-aways

- Interference nulling for improving coexistence: coexistence gaps in space and time

- Promising gains in throughput, medium access delay

- LTE benefits more from nulling than WiFi:

  - future research on how to change our formula to make it fair

- We assumed existence of perfect CSI at LTE-U BS towards each WiFi node

  - practically hard to obtain because of incompatible PHYs

  - our recent paper addresses this problem

  - Anatolij Zubow, Piotr Gawłowicz, Suzan Bayhan, On Practical Coexistence Gaps in Space for LTE-U/WiFi Coexistence, European Wireless 2018.

  - Piotr Gawłowicz, Anatolij Zubow, Suzan Bayhan, Demo: Cross-Technology Interference Nulling for Improved LTE-U/WiFi Coexistence, ACM Mobisys *Demo* 2018.

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Thank you,
Suzan Bayhan. <u>suzanbayhan.github.io</u>