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

<table>
<thead>
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<th>LTE</th>
<th>WiFi</th>
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**LTE**
- Scheduled access
- Continuous transmission

**WiFi**
- Random access
- Listen before talk (LBT)

Is the channel idle? received signal ≥ ED threshold

Channel busy, Defer access

*LTE-BS scheduler*

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LTE-BS scheduler

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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
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 (channel selection)
- Time (duty-cycling)
- Space (power adaptation)
Coexistence gaps put by LTE-U

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Coexistence gaps put by LTE-U

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

Our contribution in this paper:
coexistence gaps in multiple domains via interference nulling
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
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Motivation

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Interference-nulling for coexistence

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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 $T_{on}/(T_{on}+T_{off})$

LTE-U airtime for fair coexistence

- Ncs: number of WiFi nodes in carrier sensing range (CSR) of the LTE-U BS

\[
\text{airtime} = \frac{1}{1+N_{cs}}
\]
LTE-U airtime for fair coexistence

- Ncs: number of WiFi nodes in carrier sensing range (CSR) of the LTE-U BS

\[
\text{airtime} = \frac{1}{1 + N_{cs}}
\]

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

\[
\alpha_l(K_\varnothing) = \frac{1}{(N_{cs} - K_\varnothing) + 1}.
\]
Medium access under interference nulling

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

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

**Our proposal:**
2-D coexistence gaps

Transmission to **nulled WiFi** nodes
How does nulling affect WiFi’s medium access?

If receiver is nulled:
no signal, high SNIR

If transmitter is nulled:
channel idle, channel access (airtime=1)
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
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

**Best trade-off:** both LTE and WiFi does not decrease performance over no-nulling case
Which WiFi nodes (AP and STAs) to null?
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- **STA1**: hard to separate from UE, i.e. nulling STA1 will reduce gain of beamforming towards UE.

![Diagram showing WiFi nodes and UE](image)
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
- **STA2**: no need, outside range
- **STA3**: no need, outside range

**Motivation**

**Problem statement**

**Our proposal**

**Performance Analysis**

**Take-aways**
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

STA2, STA3, STA4: no need, outside range

STA4: null together

Motivation  Problem statement  Our proposal  Performance Analysis  Take-aways
Which WiFi nodes (AP and STAs) to null?

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- **null AP only**
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

- **STA2** and **STA3**: no need, outside range

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Motivation | Problem statement | Our proposal | Performance Analysis | Take-aways
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
- STA2, STA3: no need, outside range
- STA4: null together
- STA4: 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)

\[ R_{i,w}^0 = (1 - \alpha_i) B \log(1 + \frac{P_{w}d_{i,w}^{-\gamma}}{B \eta_0}) \]

- WiFi airtime remaining from LTE
- WiFi channel capacity

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

\[ \alpha_i B \log(1 + \frac{P_{w}d_{i,w}^{-\gamma}}{B \eta_0 + P_l d_{i,l}^{-\gamma} \Phi_i}) + (1 - \alpha_i) B \log(1 + \frac{P_{w}d_{i,w}^{-\gamma}}{B \eta_0}) \]

- LTE on-period
- LTE off-period
Throughput for LTE UE

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

\[ R_{j,l} = \alpha_l r_{j,l} \]

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

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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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
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10 antennas at the LTE-U BS

- Airtime increase of LTE

![Diagram showing airtime and SNIR changes](image-url)
How does airtime and SNIR change by nulling?

Slight decrease in LTE SNIR, but huge increase in its airtime

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
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Thank you,
Suzan Bayhan. suzanbayhan.github.io