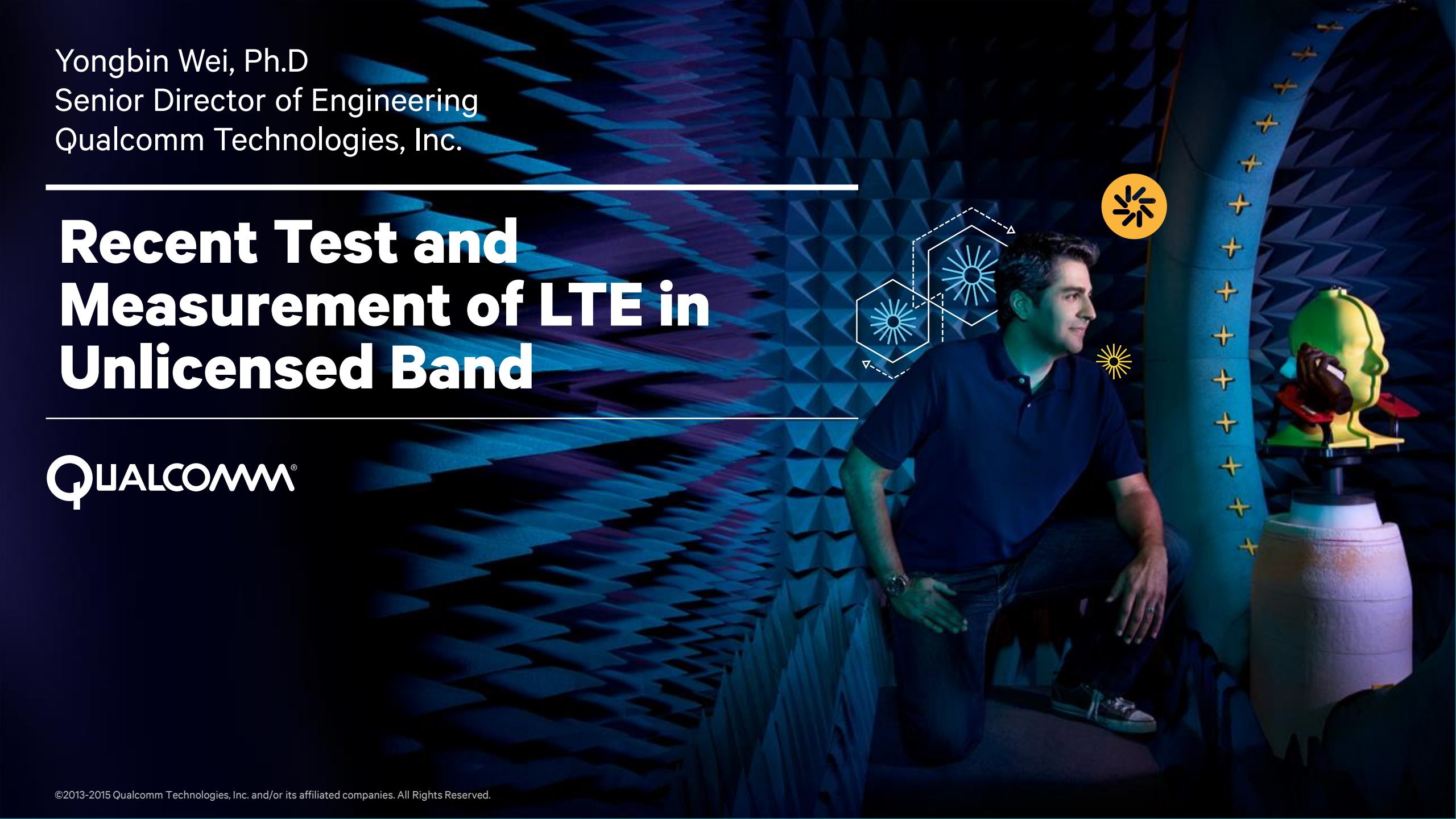
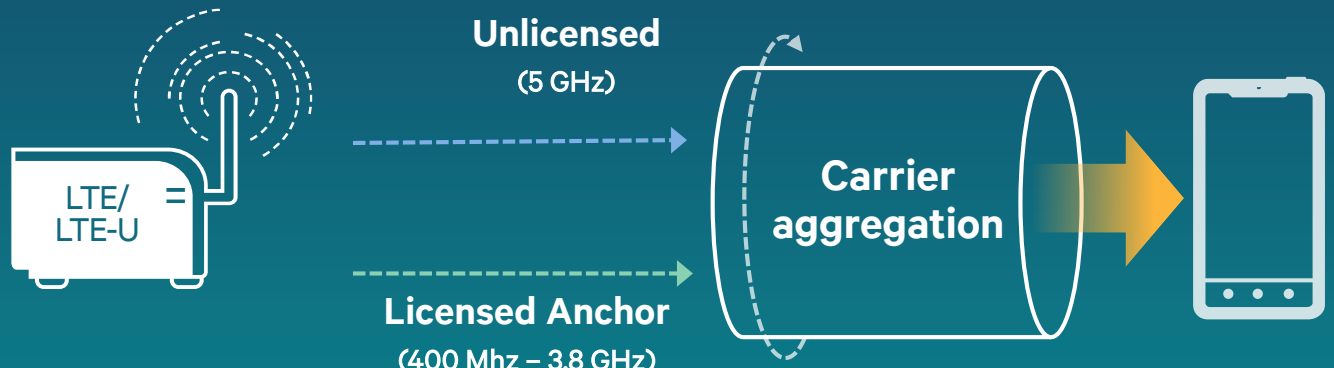
Yongbin Wei, Ph.D
Senior Director of Engineering
Qualcomm Technologies, Inc.

Recent Test and Measurement of LTE in Unlicensed Band

QUALCOMM®



Extending LTE to unlicensed spectrum



LTE-U small cell

- Supplemental Downlink (SDL) to boost downlink [1]
- Carrier aggregation to boost both downlink and uplink [2]

~2x capacity and range

Compared to Wi-Fi[3]

Enhanced user experience

Licensed anchor for control and mobility

Unified LTE network

Common management

A good Wi-Fi neighbor

In many cases, better neighbor to Wi-Fi than Wi-Fi itself

For small cells, leveraging 5 GHz spectrum

[1]Main option for LTE FDD, but the specific band for SDL need to be defined. Either TDD or FDD aggregation is possible with SDL; [2]Using TDD + TDD aggregation, or FDD + TDD aggregation with TDD used for unlicensed spectrum

[3]Assumptions: Two operators. 48 Pico+108 Femto cells per operator. 300 users per operator with 70% indoor. 3GPP Bursty model. 12x40MHz @ 5GHz for unlicensed spectrum; LTE 10 MHz channel at 2 GHz;. 2x2 MIMO, Rank 1 transmission, eICIC enabled; LTE-U – LAA R13, 2x2 MIMO (no MU-MIMO).; Wi-Fi - 802.11ac 2x2 MIMO (no MU-MIMO), LDPC codes and 256QAM).

Ensuring fair coexistence between LTE-U and Wi-Fi

Minimum requirements

Spectrum regulations

- Power and emission levels
- Additional channel occupancy limits: Listen Before Talk (LBT) required in Europe and Japan

Going above and beyond minimum requirements

Standards & specifications

- LTE-U R10 for USA, China, Korea, India and other markets
  - With dynamic channel selection & CSAT[1] for fair coexistence
- LTE-U R13 LAA[2] for Europe, Japan and beyond
  - Modified waveform for LBT

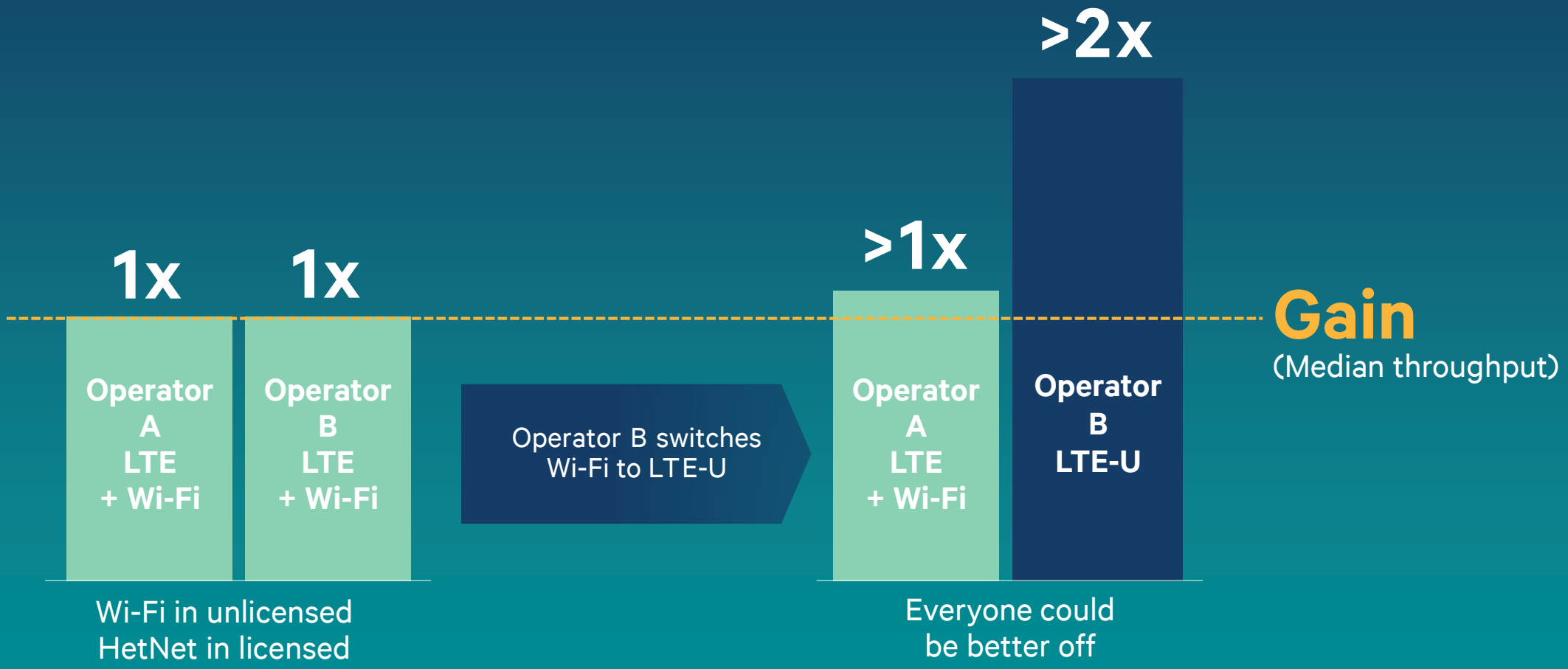
Conformance testing

- Coexistence and fairness test
- Expected to be more rigorous than Wi-Fi testing today
- Still allowing for differentiation

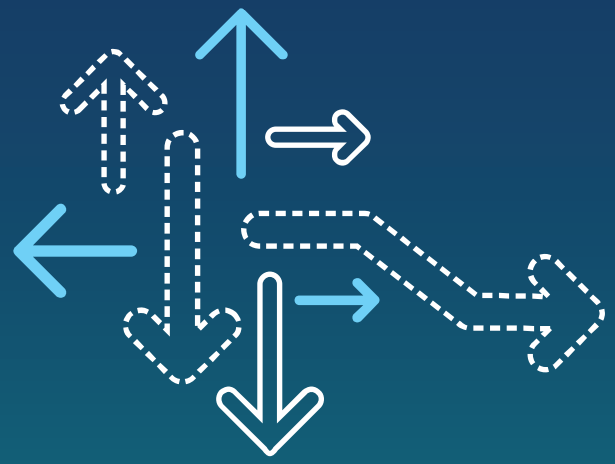
[1] CSAT - Carrier Sensing Adaptive Transmission required in the small cell.. [2] LAA Licensed Assisted Access being standardized in 3GPP Release 13 . In addition, New RF band support (e.g. 5GHz) needed at both device and small cell

LTE-U: Higher capacity while being a good neighbor to Wi-Fi

In many cases a better neighbor to Wi-Fi than Wi-Fi itself



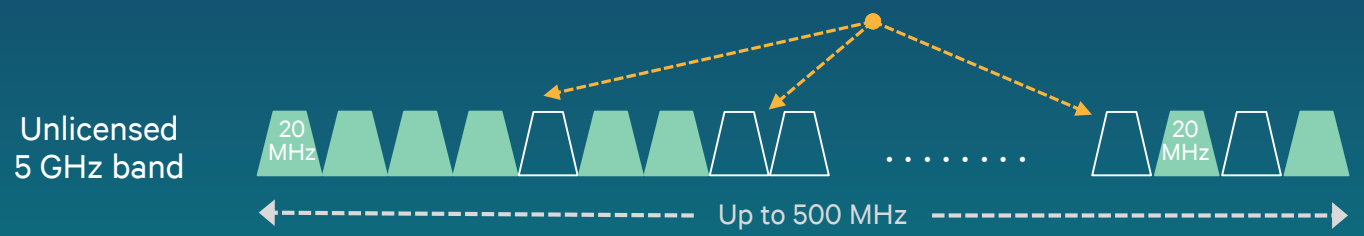
Assumptions: R10-based LTE-U, 802.11ac Wi-Fi. Dense Wi-Fi and small cell outdoor deployment based on 3GPP evaluation methodology macro cell layout. 120 users per macro cell. 3GPP bursty model. 4 or 10 40MHz channels @ 5GHz for unlicensed spectrum. LTE 10 MHz channel at 2 GHz. 2x2 MIMO for Wi-Fi, LTE and LTE in unlicensed with Rank 2 transmission. eICIC enabled for license band.



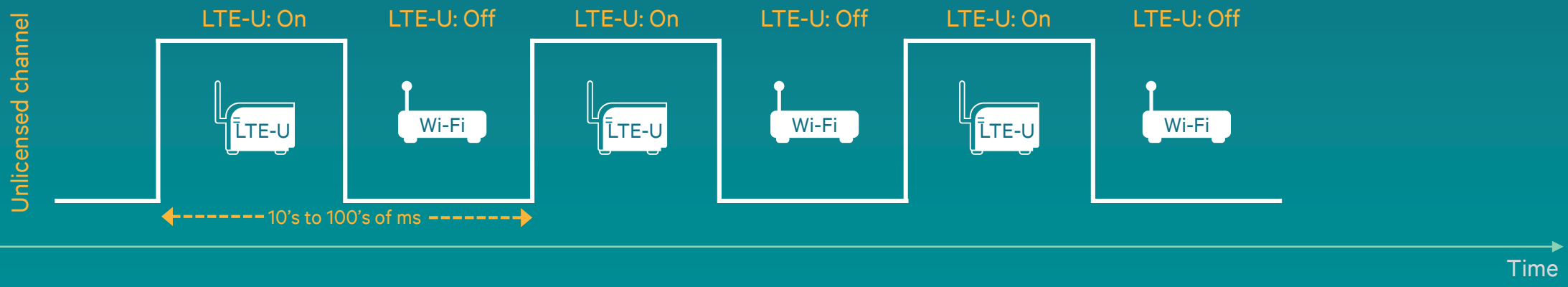
Test and Measurement of Rel-10/11/12 based LTE-U (non-LBT)

Dynamic channel selection and CSAT

1 Select clear channel : Dynamically avoid Wi-Fi



2 If no clear channel : CSAT with Wi-Fi on same channel

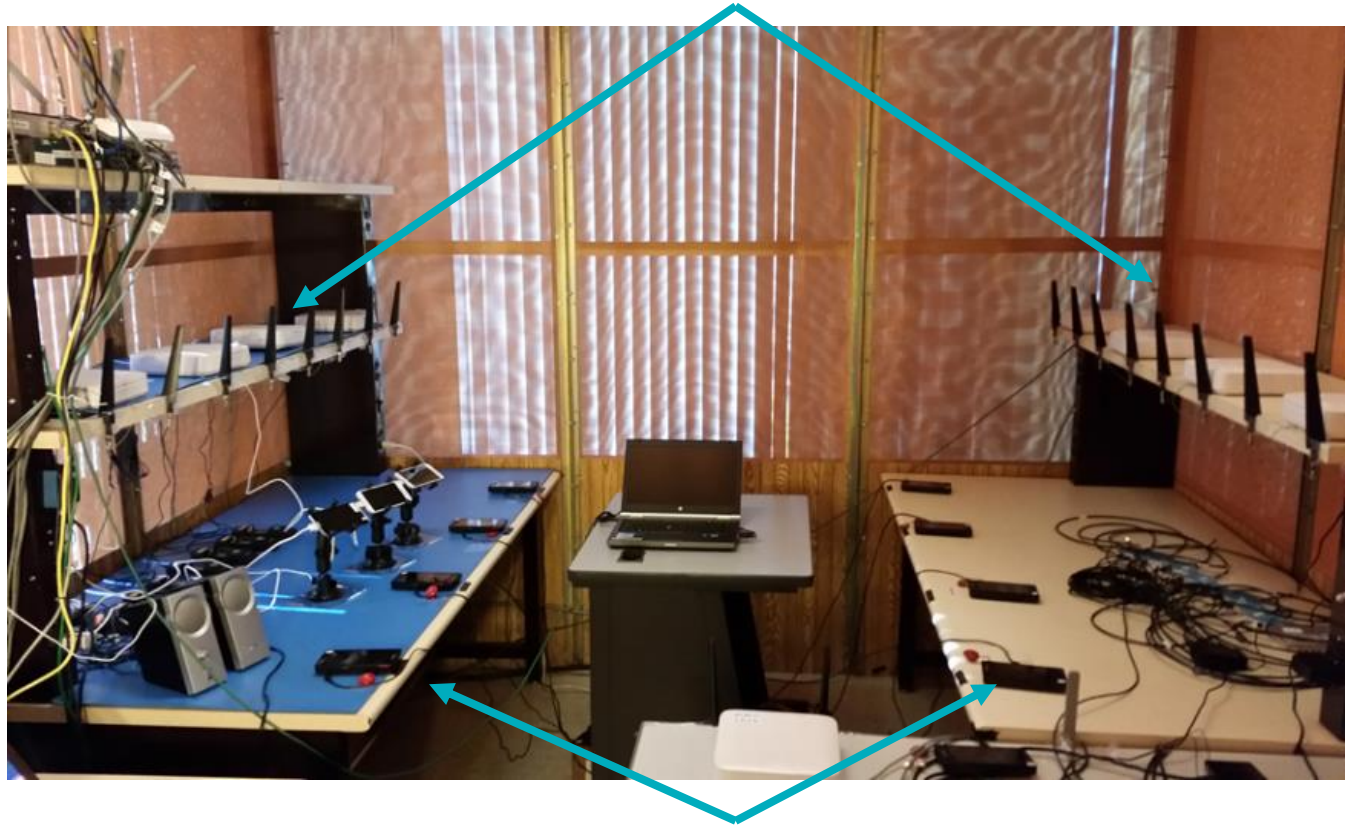


[1] CSAT - Carrier Sensing Adaptive Transmission implemented in eNB's

LTE - Wi-Fi coexistence test chamber

Testing LTE-U in a stressful Wi-Fi environment

Wi-Fi Access Points (AP's)



Wi-Fi Devices

Extremely dense network with harsh interference

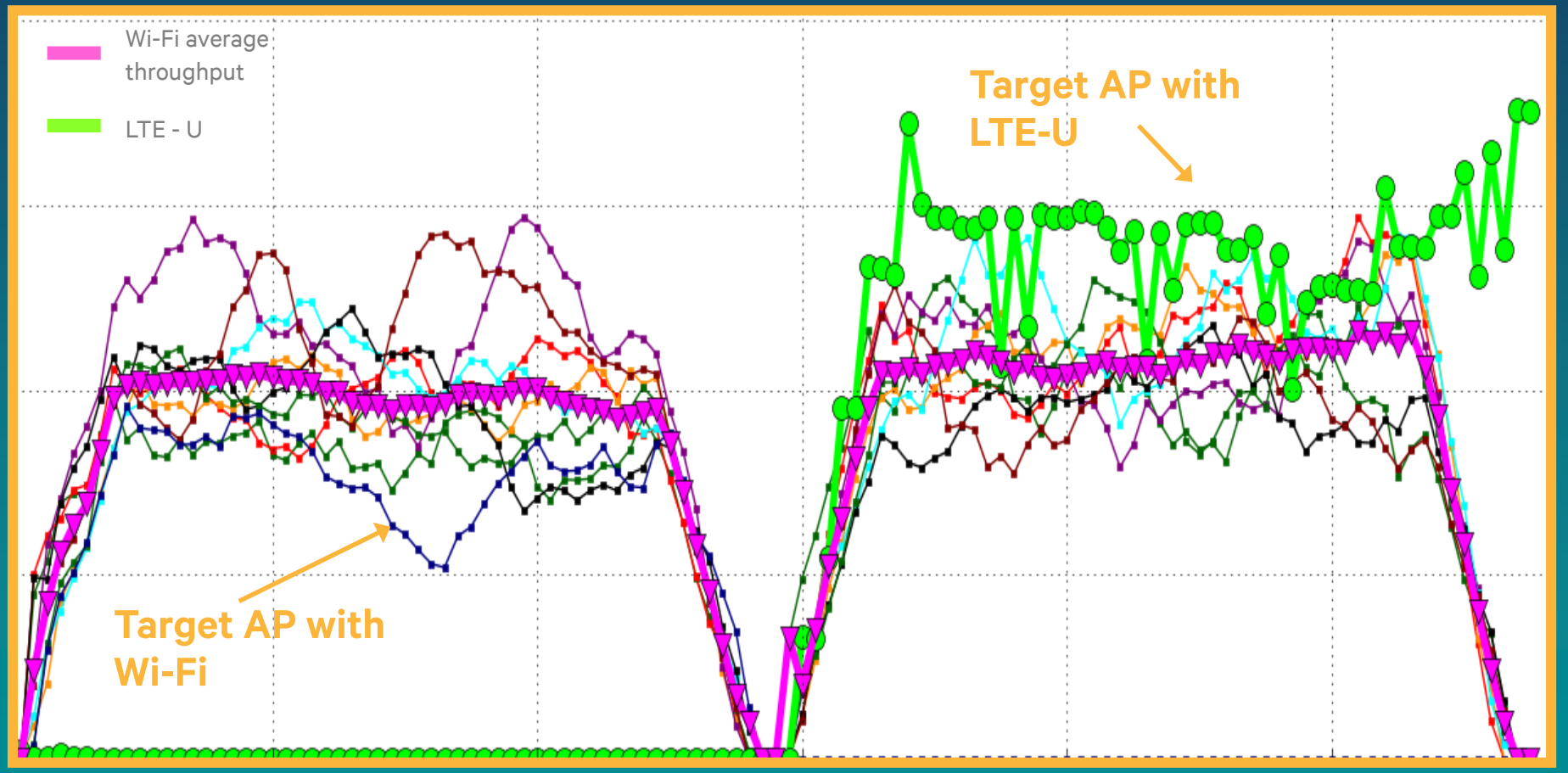
- 8 Wi-Fi Access Points forced on a single 5 GHz channel
- Very high-density scenario in real life, since multiple channels are typically available
- No isolation between neighboring AP's and devices

Equipment

- Commercial, off-the-shelf, carrier-grade Wi-Fi AP's
- Qualcomm test Wi-Fi devices
- Qualcomm test LTE-U small cell and devices

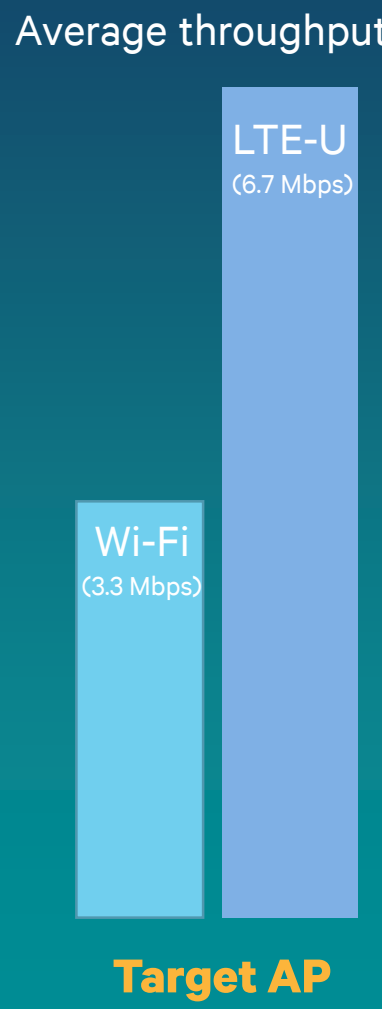
Better performance of LTE-U

Using adaptive duty cycle (CSAT)



8 Wi-Fi + 1 Wi-Fi

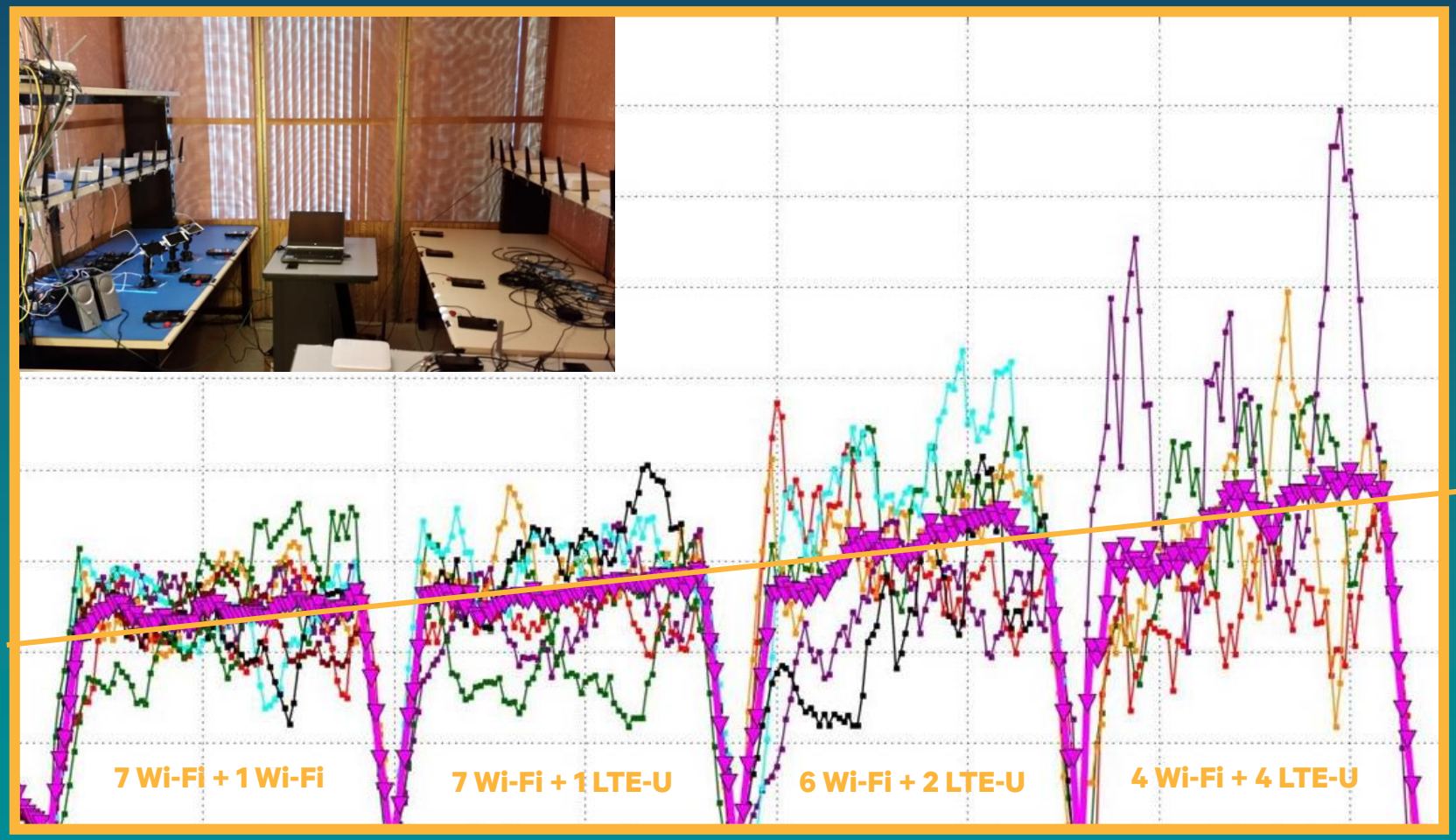
8 Wi-Fi + 1 LTE-U



Target AP

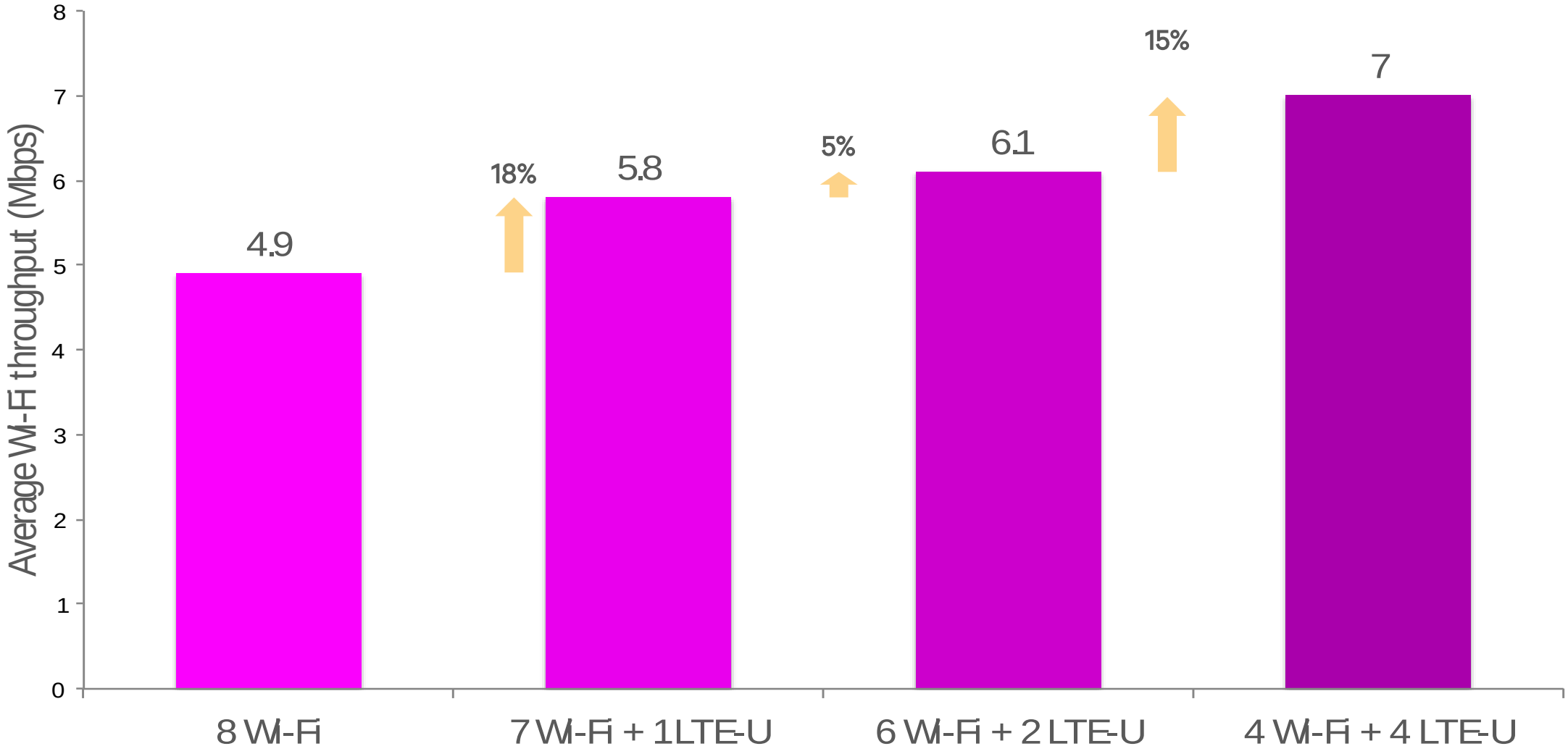
Wi-Fi performance not adversely affected by LTE-U

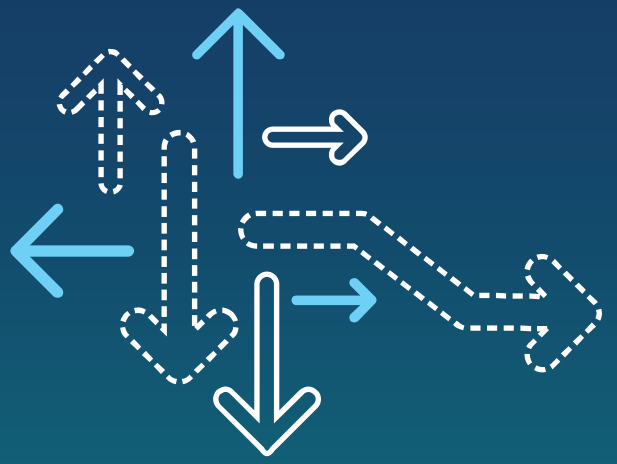
Using adaptive duty cycle (CSAT) for fair coexistence



Replacing Wi-Fi Nodes with LTE-U: Test Results

Average Wi-Fi throughput increases as Wi-Fi nodes are replaced by LTE-U

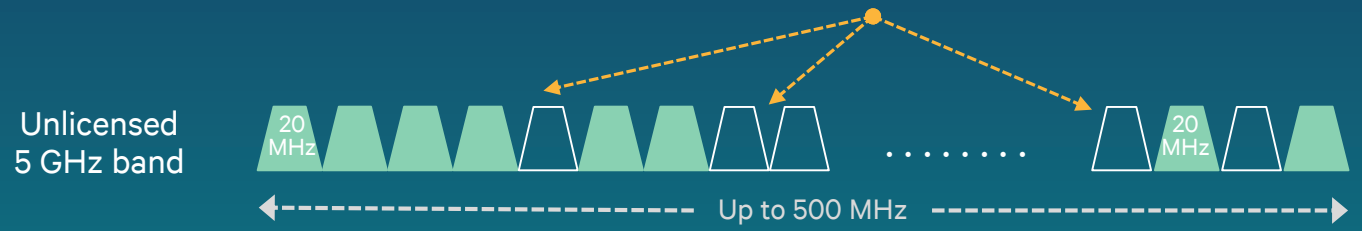




Test and Measurement of Rel-13 LBT based LTE-U

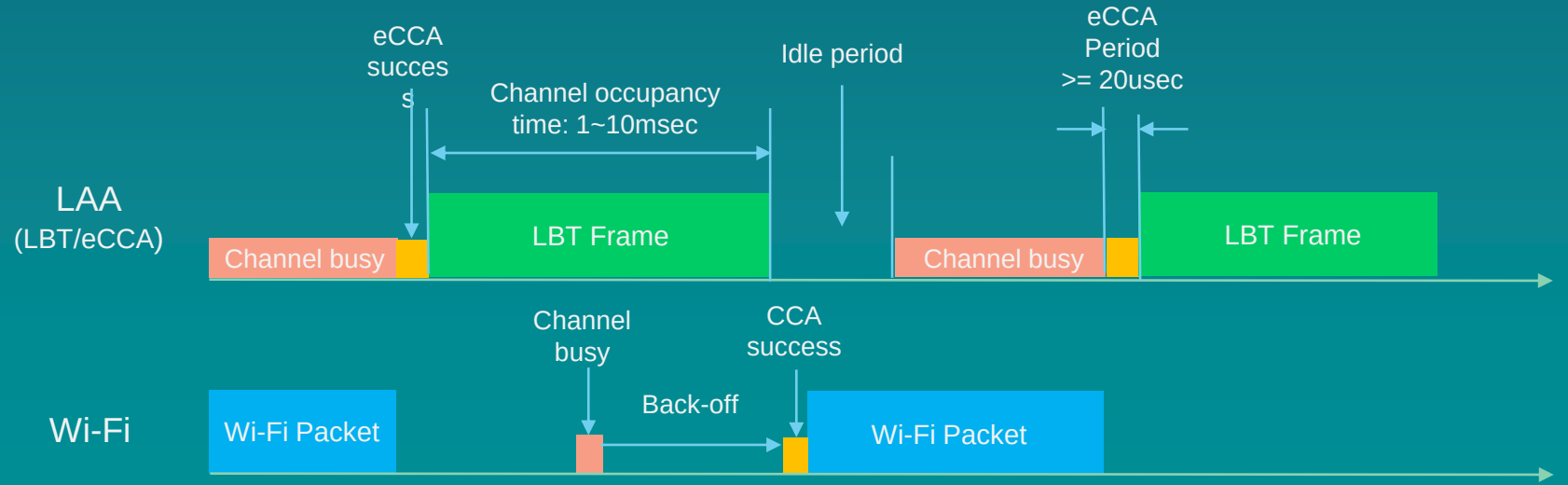
Dynamic channel selection and LBT based LTE-U (LAA)

1 Select clear channel : Dynamically avoid Wi-Fi

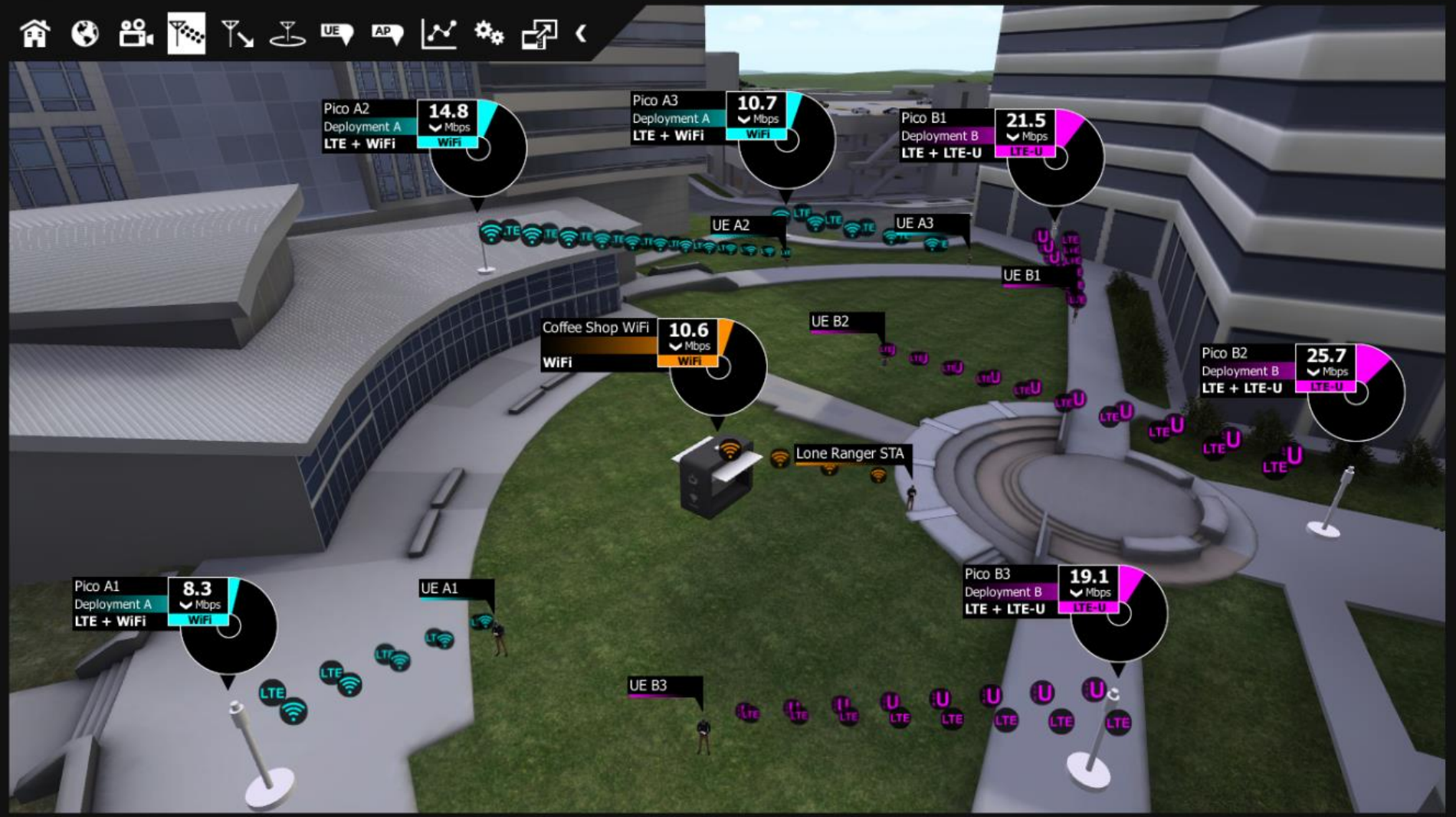


2 If no clear channel : LBT based coexistence with Wi-Fi on same channel

- LAA design conforms to regulations specified in ETSI EN 301 893
- LBT via Enhanced Clear Channel Assessment (eCCA)

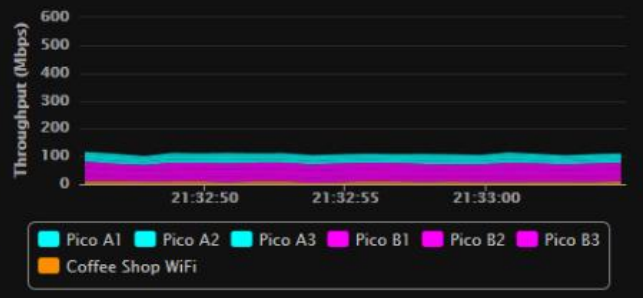


QUALCOMM LTE-U: License Assisted Access (LAA)



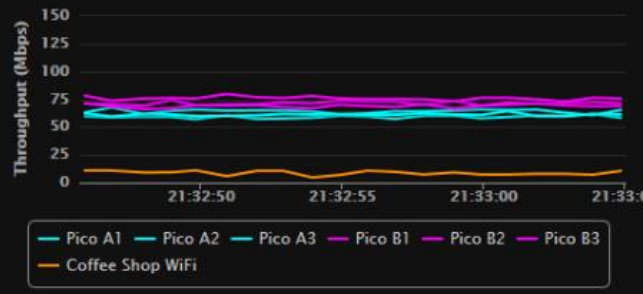
All WiFi: Two Deployments | LTE-U WiFi Coex (1 LTE-U node) | LTE-U WiFi Coex (1 WiFi node) | All LTE-U: Two Deployments | All LTE-U: One Deployment

Overall Network Throughput – Unlicensed Band

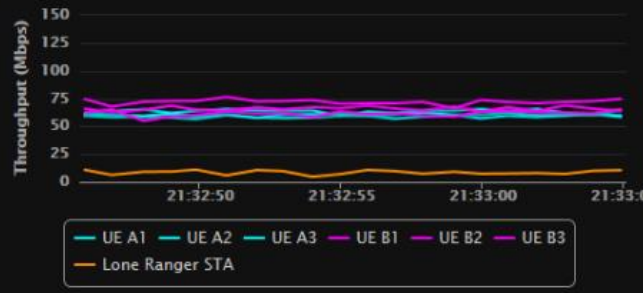


Average Downlink Throughput – Unlicensed Band

Downlink Network Throughput



Downlink UE/STA Throughput



Coexistence and Capacity Tests

- Topology
  - Three categories of nodes
    - Wi-Fi only ⇔ AP plus STA (Coffee shop)
    - LTE+WiFi aggregation ⇔ eNB/AP plus UE/STA
    - LAA ⇔ eNB plus UE
  - Seven node pairs in total in a cabled-up environment
    - All eNBs/APs within energy detection (ED) threshold of each other
    - UEs or STAs do not detect interference from other nodes

- Three deployments
  - Coffee shop (non-operator Wi-Fi, no licensed anchor PCC)
  - Operator A (with licensed anchor PCC)
  - Operator B (with licensed anchor PCC)

Coexistence and Capacity Tests

Step-wise transition of node-pairs from Wi-Fi to LAA in Unlicensed Spectrum

1. All Wi-Fi deployment

2. One node moves to LAA
   - Operator A = LAA (1) plus LWA (2) nodes
   - Operator B = LWA (3) nodes
   - Coffee shop Wi-Fi

3. All operate-A nodes move to LAA
   - Operator A = LAA (3) nodes
   - Operator B = LWA (3) nodes
   - Coffee shop Wi-Fi

4. All operator-A&B nodes move to LAA
   - Operator A = LAA (3) nodes
   - Operator B = LAA (3) nodes
   - Coffee shop Wi-Fi

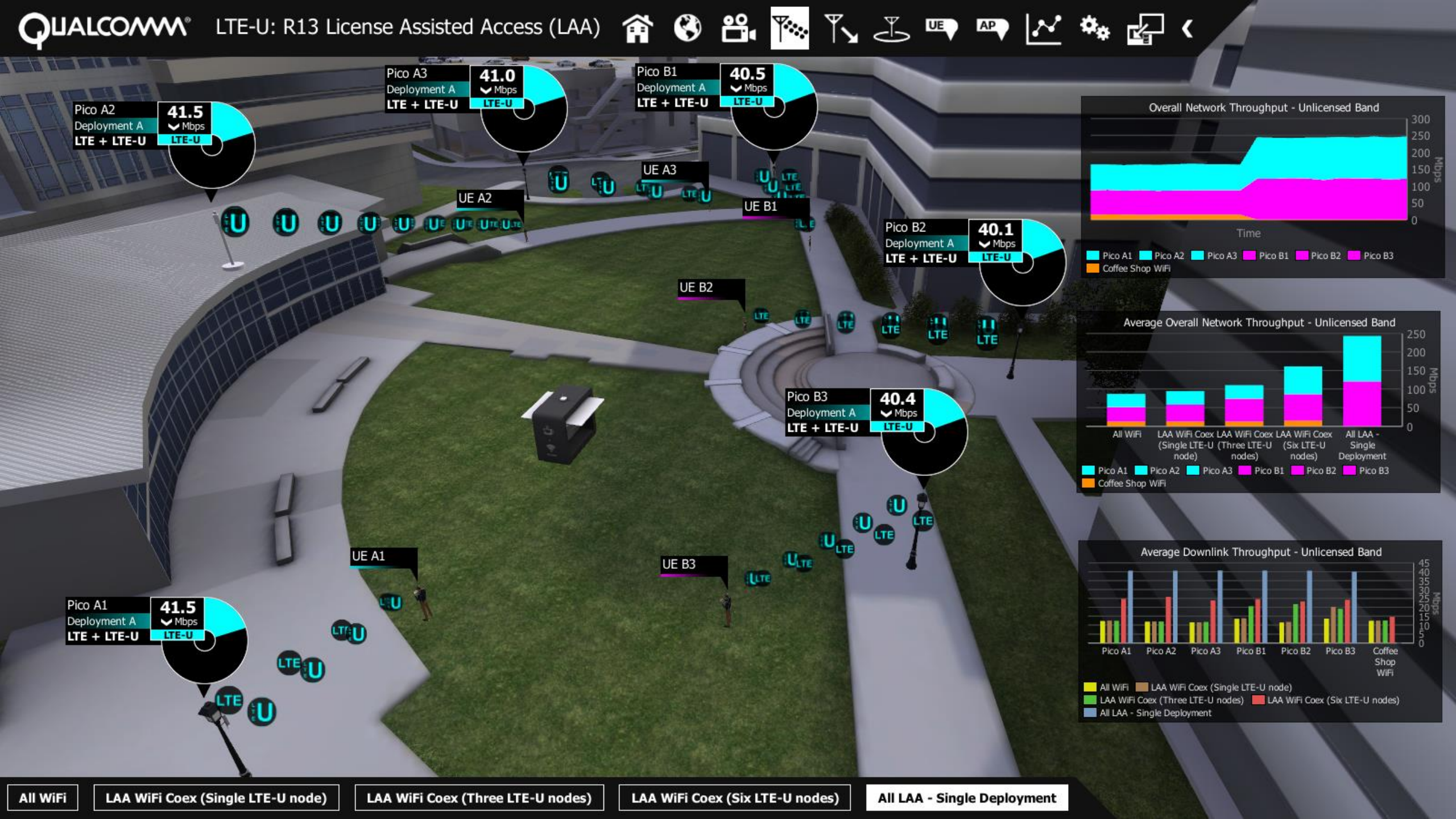
5. Single operator LAA deployment
   - Operator A = LAA (6) nodes
   - No Coffee shop Wi-Fi

* LWA: LTE+WiFi PDCP aggregation

Coexistence and Capacity Tests

Performance, user throughput (Mbps)

Node Index	Step 1	Step 2	Step 3	Step 4	Step 5
A1	12.8	12.5	11.4	24.9	41.5
A2	11.7	12.0	12.1	25.0	41.5
A3	11.0	11.7	11.4	23.6	41.0
B1	13.8	13.6	21.5	24.9	40.5
B2	12.2	12.6	21.7	24.0	40.1
B3	12.7	20.2	19.4	23.9	40.4
Coffee Shop	13.0	12.6	13.1	14.3	--
Total Throughput	87.2	95.2	110.6	160.6	245.0


QUALCOMM
LTE-U: R13 License Assisted Access (LAA)
UE
AP
Pico A2
Deployment A
LTE + LTE-U
41.5
Mbps
LTE-U
Pico A3
Deployment A
LTE + LTE-U
41.0
Mbps
LTE-U
Pico B1
Deployment A
LTE + LTE-U
40.5
Mbps
LTE-U
Pico B2
Deployment A
LTE + LTE-U
40.1
Mbps
LTE-U
Pico B3
Deployment A
LTE + LTE-U
40.4
Mbps
LTE-U
Pico A1
Deployment A
LTE + LTE-U
41.5
Mbps
LTE-U
UE A1
UE A2
UE A3
UE B1
UE B2
UE B3
Overall Network Throughput - Unlicensed Band
300
250
200
150
100
50
0
Mbps
Time
Pico A1
Pico A2
Pico A3
Pico B1
Pico B2
Pico B3
Coffee Shop WiFi
Average Overall Network Throughput - Unlicensed Band
250
200
150
100
50
0
Mbps
All WiFi
LAA WiFi Coex (Single LTE-U node)
LAA WiFi Coex (Three LTE-U nodes)
LAA WiFi Coex (Six LTE-U nodes)
All LAA - Single Deployment
Pico A1
Pico A2
Pico A3
Pico B1
Pico B2
Pico B3
Coffee Shop WiFi
Average Downlink Throughput - Unlicensed Band
45
40
35
30
25
20
15
10
5
0
Mbps
Pico A1
Pico A2
Pico A3
Pico B1
Pico B2
Pico B3
Coffee Shop WiFi
All WiFi
LAA WiFi Coex (Single LTE-U node)
LAA WiFi Coex (Three LTE-U nodes)
LAA WiFi Coex (Six LTE-U nodes)
All LAA - Single Deployment
All WiFi
LAA WiFi Coex (Single LTE-U node)
LAA WiFi Coex (Three LTE-U nodes)
LAA WiFi Coex (Six LTE-U nodes)
All LAA - Single Deployment

Thank you

Follow us on:

For more information, visit us at:
www.qualcomm.com & www.qualcomm.com/blog