February, 2015

Qualcomm Technologies, Inc.

# Making best use of unlicensed spectrum for 1000x

QUALCOMM®

# The wireless evolution

## Redefined Telephony
By mobilizing communications

2002

Surpassed fixed voice

## Redefined Computing
By mobilizing Internet

2010

Surpassed fixed BB

## Redefining Everything
By transforming the role of wireless

# Inventing technologies to transform the edge of the Internet

## Solving the 1000x data challenge

Innovative small cells and spectrum solutions


More capacity, better user experience

- LTE in unlicensed spectrum
- LTE Advanced evolution
- LTE Broadcast
- Small cells and self organizing technology
- Wi-Fi 802.11ac / ax
- LTE and Wi-Fi convergence
- 3G

## Transforming the role of wireless

New ways of connecting, new services, and convergence

Beyond capacity & peak rates

- LTE Direct and LTE Broadcast
- LTE machine-type communications
- Wi-Fi Aware / Wi-Fi Direct / DSRC
- Wi-Fi 802.11ah
- 802.11ad
- Bluetooth
- 5G

## Bringing cognitive technologies to life

Devices and things that perceive, reason and act intuitively

Inspired by the human brain

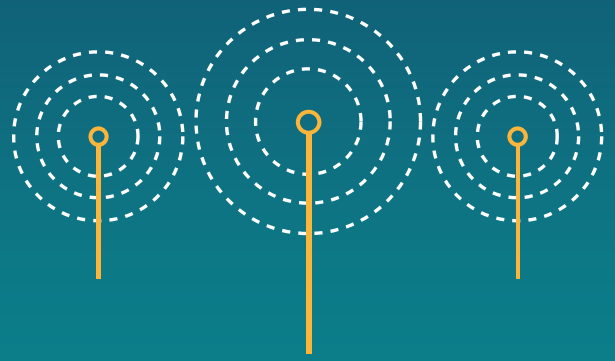
- Machine learning
- Computer vision
- Always-on sensing
- Immersive multimedia
- Intelligent connectivity
- Intuitive security
- Heterogeneous computing

# Beyond 1000x—transforming the role of wireless

## Connecting in new, intelligent ways

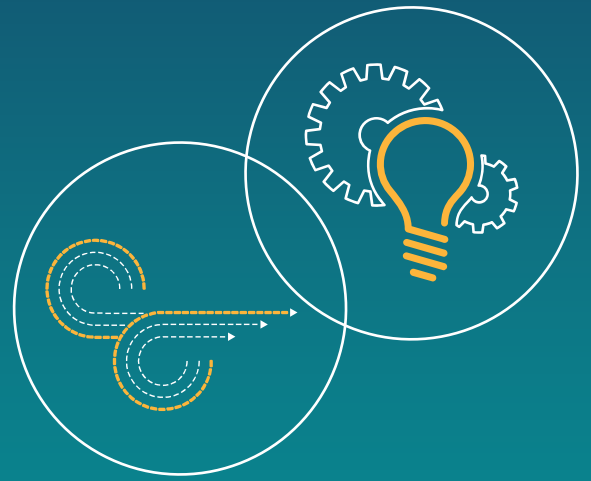

Bringing connectivity closer to the user to scale for billions of connections and empower new experiences

## Enabling new wireless services



Optimizing wireless to scale and adapt to a wider variation of devices/things, and new classes of use cases

## Creating a unified connectivity platform



Converging spectrum types, networks, and deployment models to enhance user experience and efficiency

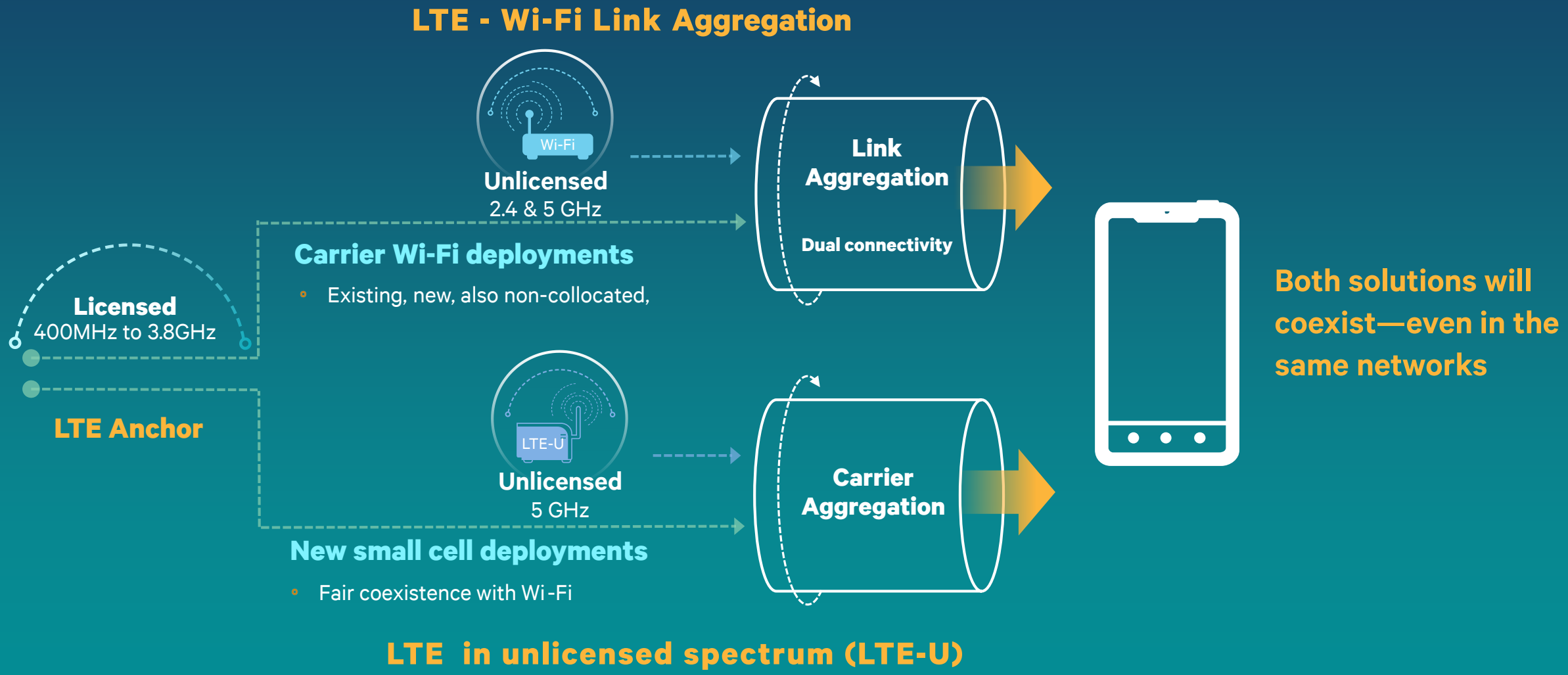
# Licensed spectrum is the foundation to 1000x


For both licensed & unlicensed spectrum (evolving LTE Advanced and Wi-Fi)

More licensed spectrum is the top priority
Use unlicensed spectrum opportunistically

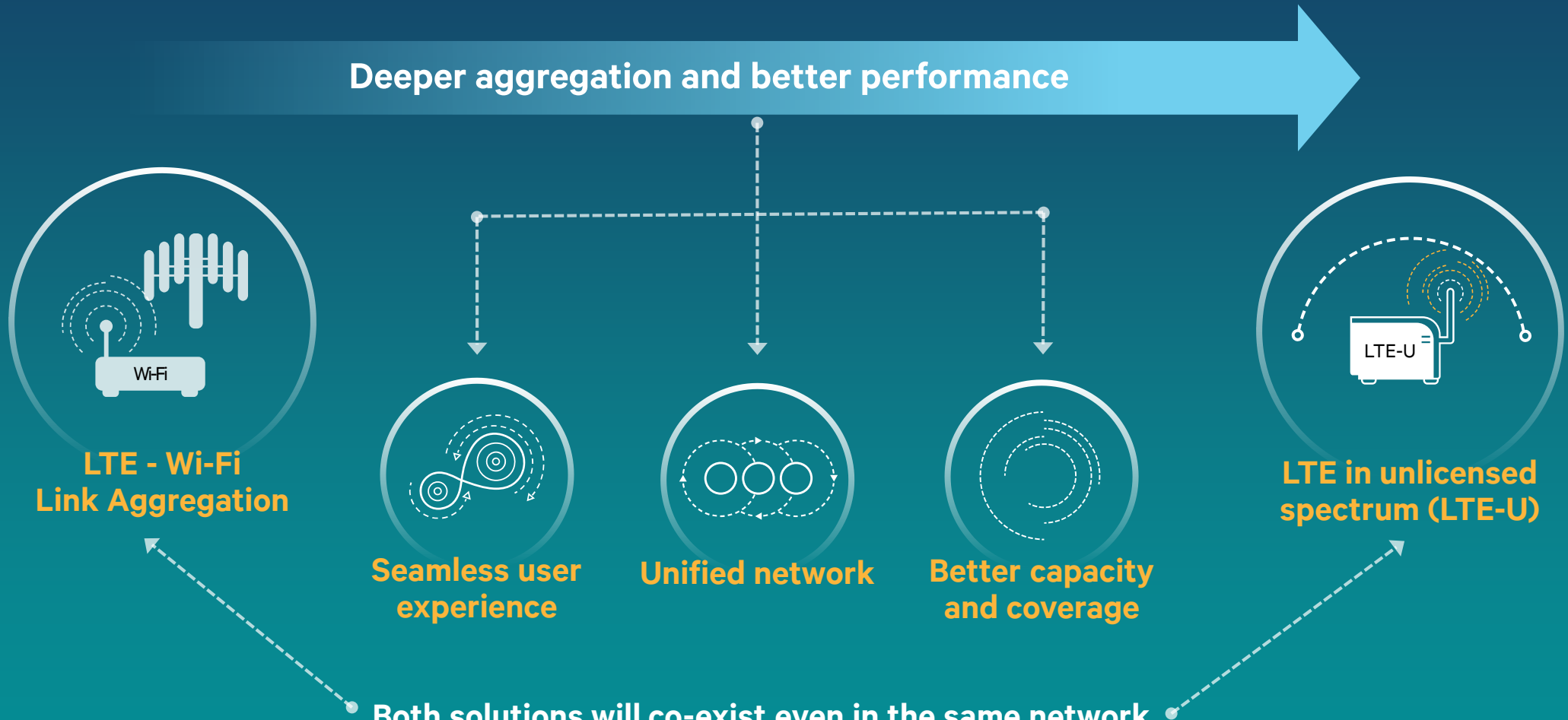
- LTE - Wi-Fi aggregation for carrier Wi-Fi
- LTE-U for new small cells

# Making best use of unlicensed spectrum for 1000x



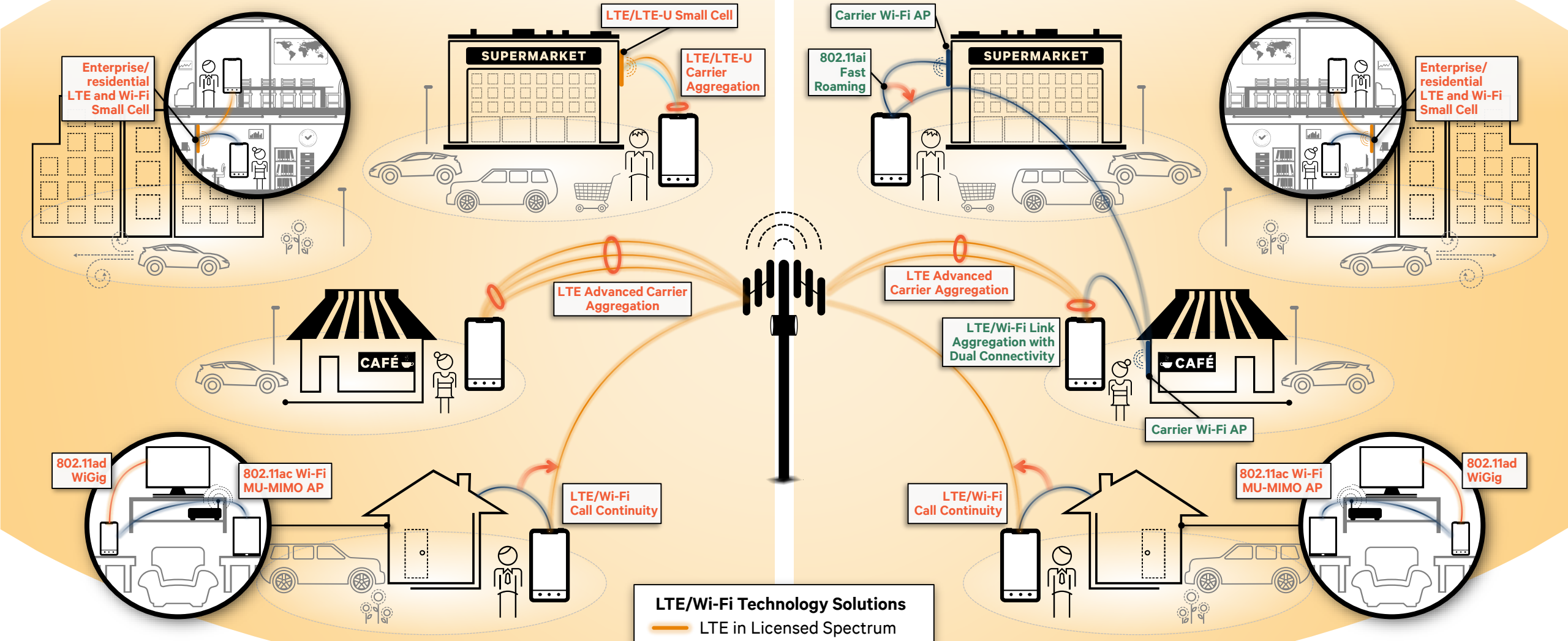

LTE-U in 3GPP Rel 13 is referred to as Licensed Assisted Access (LAA)

# Operator’s assets determine solution—many will do both




Notes: Aggregation at modem-level (PDCP level) is a R13 candidate, (dual connectivity defined in R12 for licensed) ; LTE-U based on R10 for certain countries, defined as LAA R13 for other countries

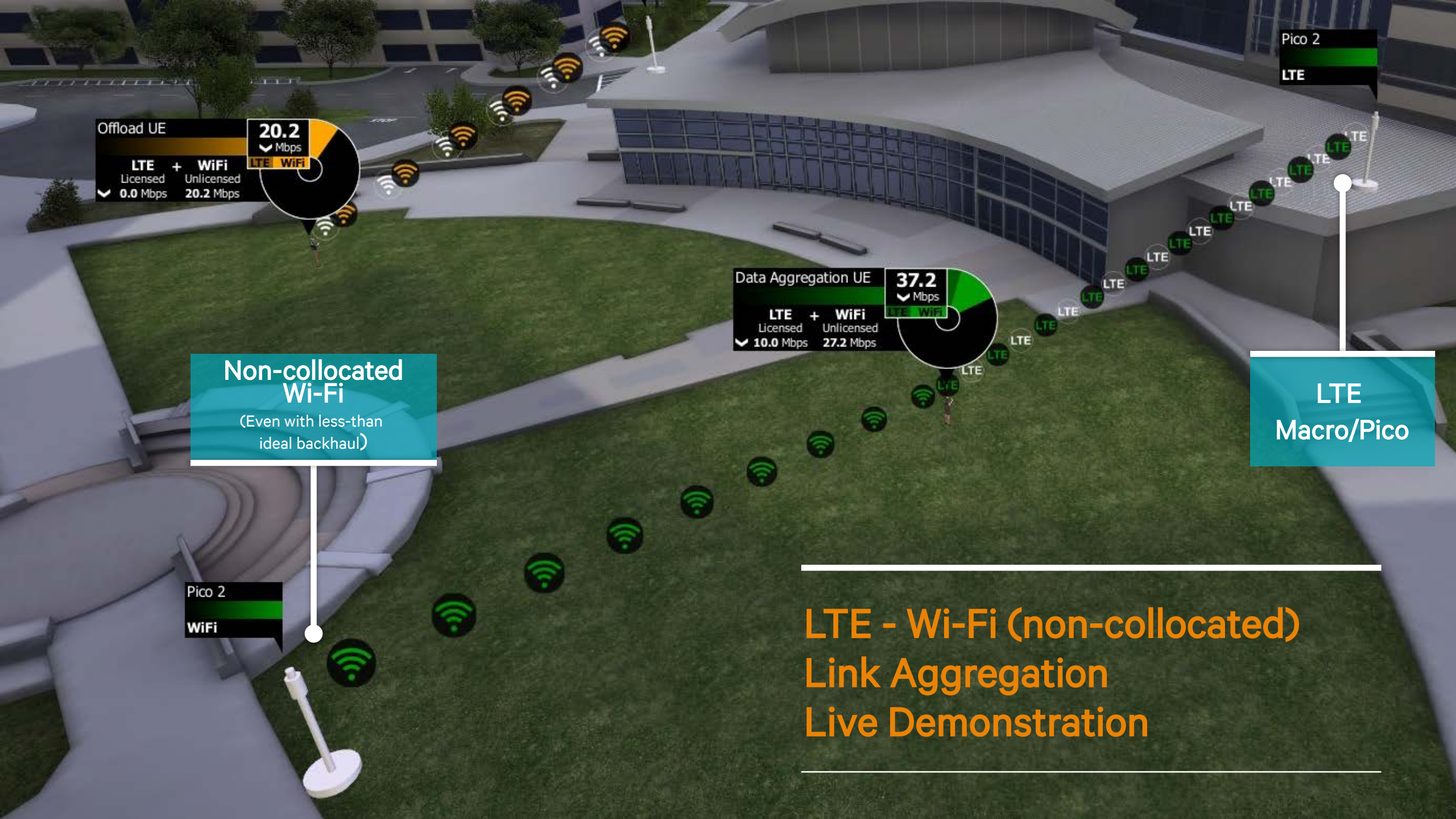
# Deployment Scenarios for Licensed and Unlicensed Access



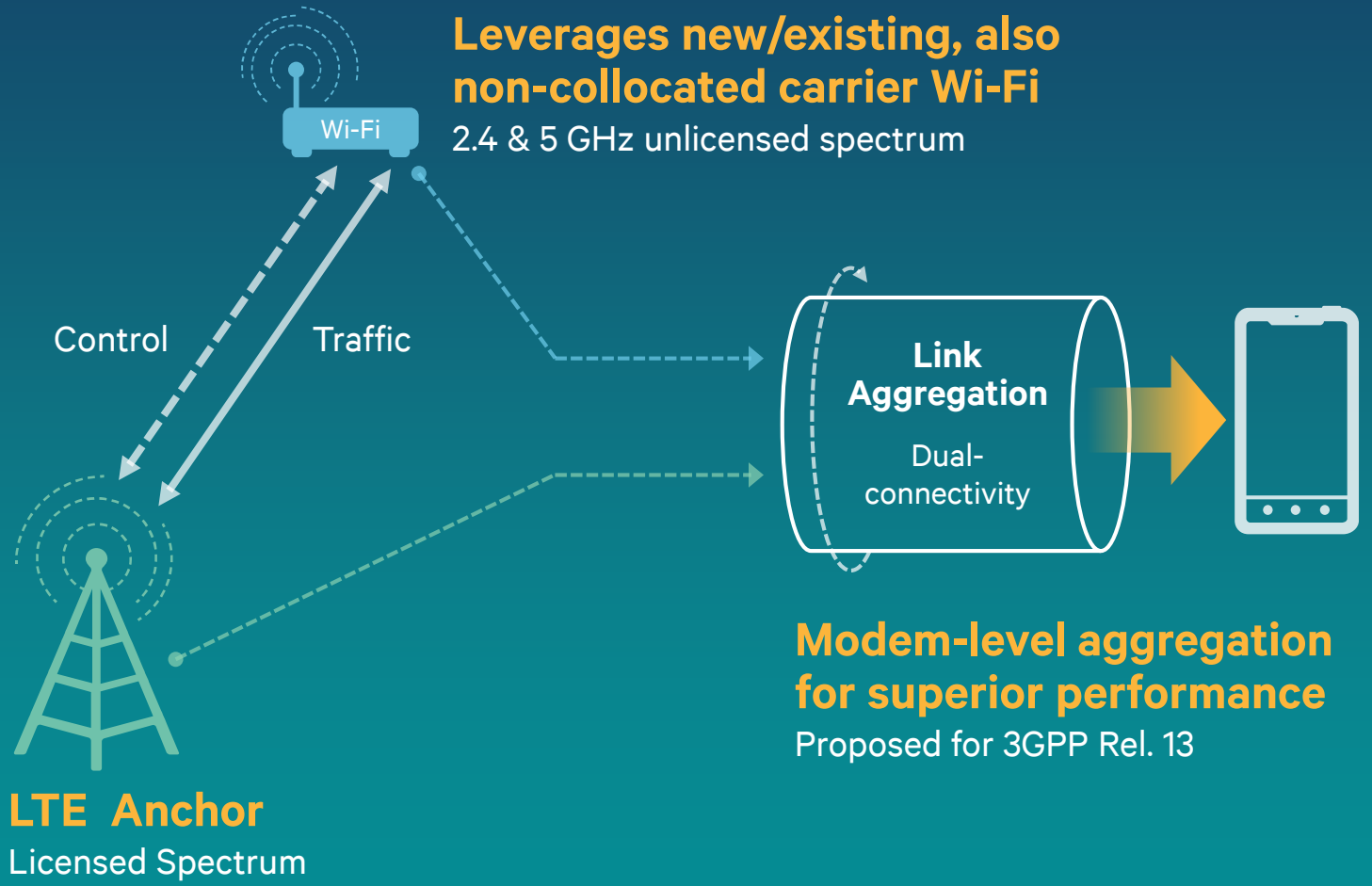

**LTE/LTE-U Solutions**

**LTE/Operator Wi-Fi Solutions**

# LTE - Wi-Fi link aggregation —Part of larger LTE - Wi-Fi convergence


Offload UE
20.2
Mbps
LTE WiFi
LTE
Licensed
0.0 Mbps
+
WiFi
Unlicensed
20.2 Mbps
Data Aggregation UE
37.2
Mbps
LTE WiFi
LTE
Licensed
10.0 Mbps
+
WiFi
Unlicensed
27.2 Mbps
Pico 2
LTE
Non-collocated
Wi-Fi
(Even with less-than
ideal backhaul)
Pico 2
WiFi
LTE
Macro/Pico
LTE - Wi-Fi (non-collocated)
Link Aggregation
Live Demonstration

# LTE - Wi-Fi link aggregation for existing and new carrier Wi-Fi




**Leverages new/existing, also non-collocated carrier Wi-Fi**

2.4 & 5 GHz unlicensed spectrum

**Modem-level aggregation for superior performance**

Proposed for 3GPP Rel. 13

**Enhanced user experience**

Licensed anchor for control and mobility

**Unified network**

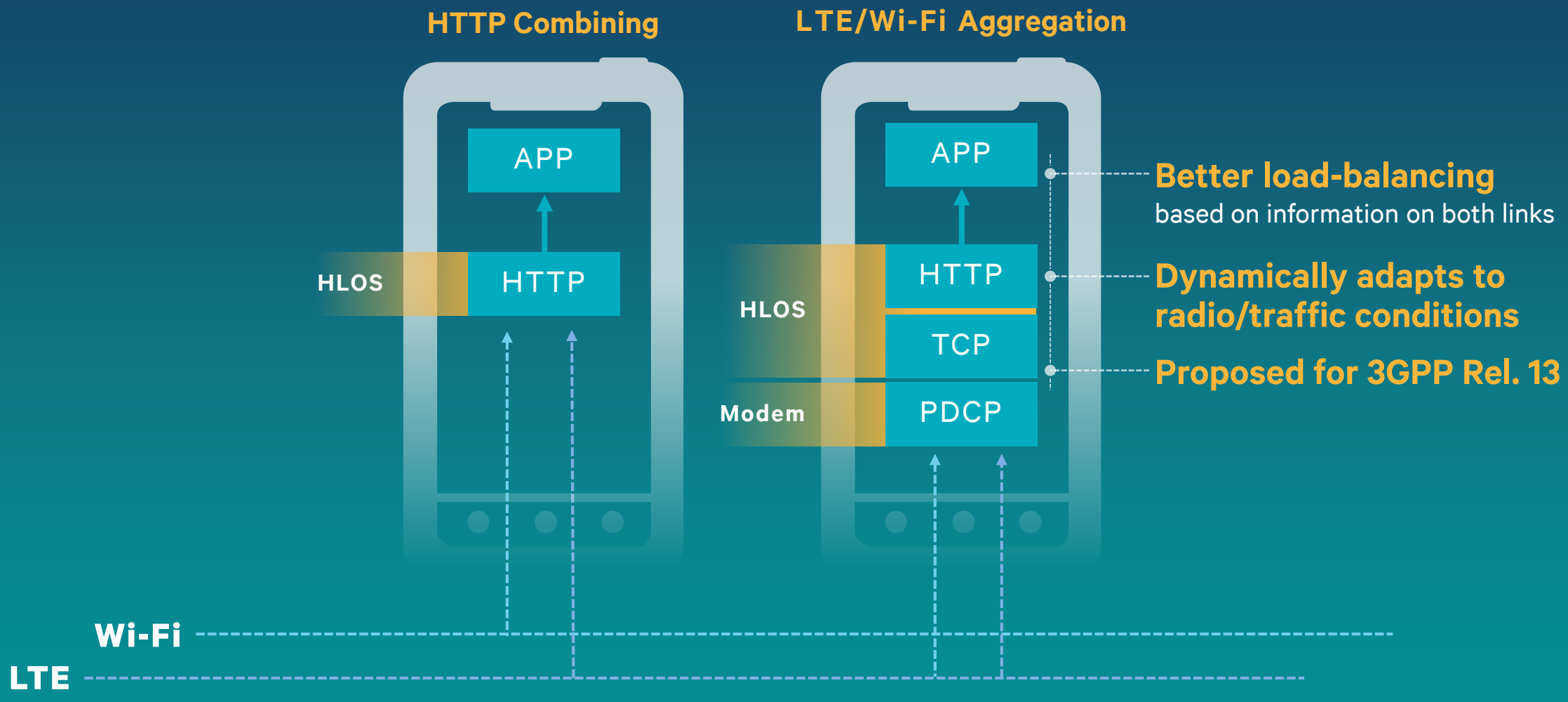
Operator LTE network in full control of Wi-Fi

**Better performance**

Simultaneously using both LTE & Wi-Fi links

Notes: Aggregation on modem level (PDCP level), also leveraging dual connectivity defined inR12; Control over X2-like interface needs to be supported by Wi-Fi AP. No change to LTE & WiFi PHY/MAC. No change to core network

# Modem-level aggregation for superior performance

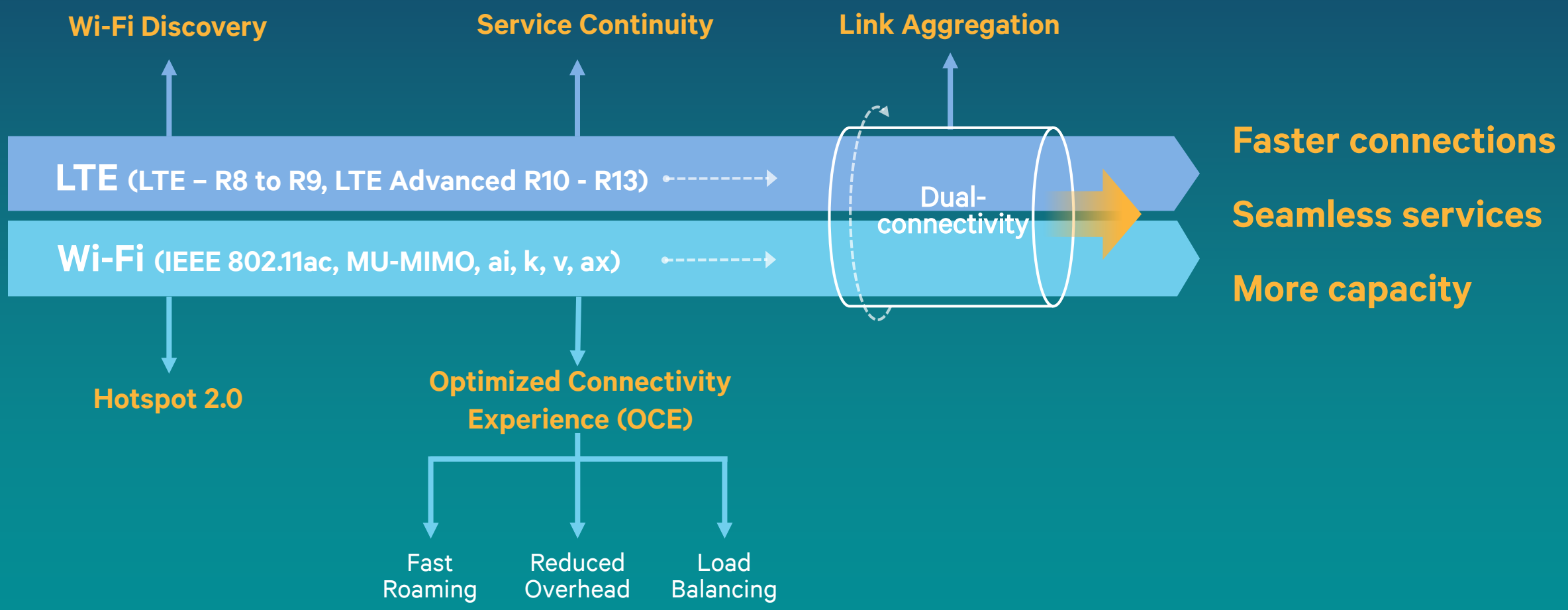



**Better load-balancing**
based on information on both links

**Dynamically adapts to radio/traffic conditions**

**Proposed for 3GPP Rel. 13**

# Aggregation part of the larger LTE - Carrier Wi-Fi convergence



# Continuing to improve carrier Wi-Fi

**802.11 g/n**

**802.11 ac**
Breaking the Gbps barrier

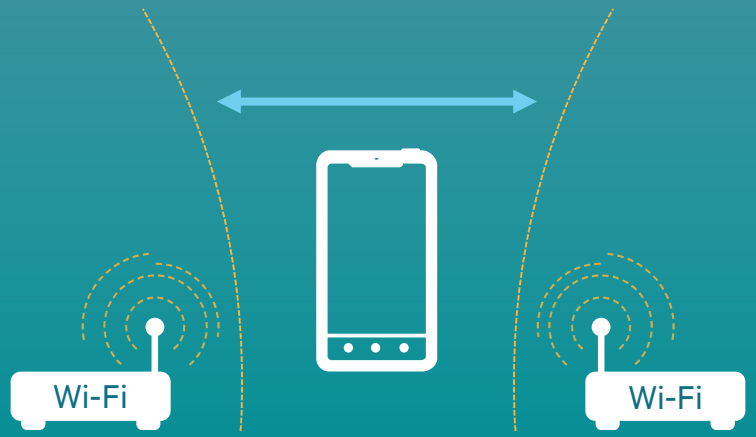
**MU - MIMO**
Next wave of efficiency

**802.11 ax**

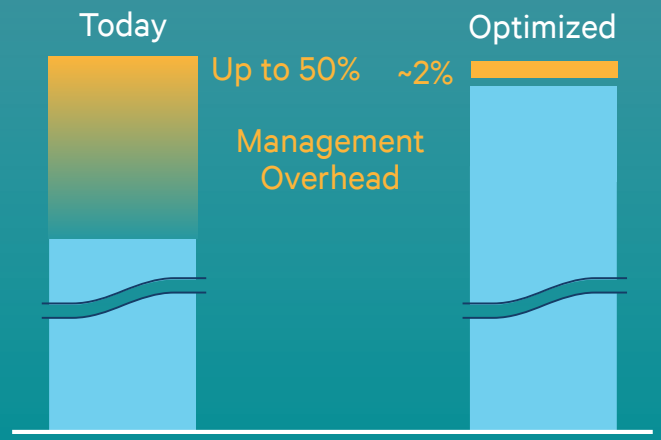
**Hotspot 2.0**

**Carrier Wi-Fi Enhancements**
Optimized Connectivity Experience (OCE) based on 11ai,k,v

## 20-30x faster roaming
Enabling seamless real-time services




## Reduced overhead
In dense Wi-Fi deployments

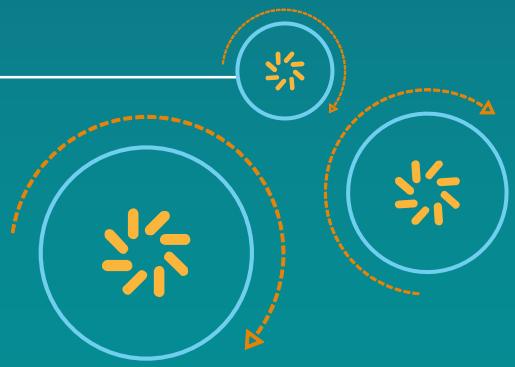



## Load balancing
Steering Wi-Fi connection based on signal quality & load

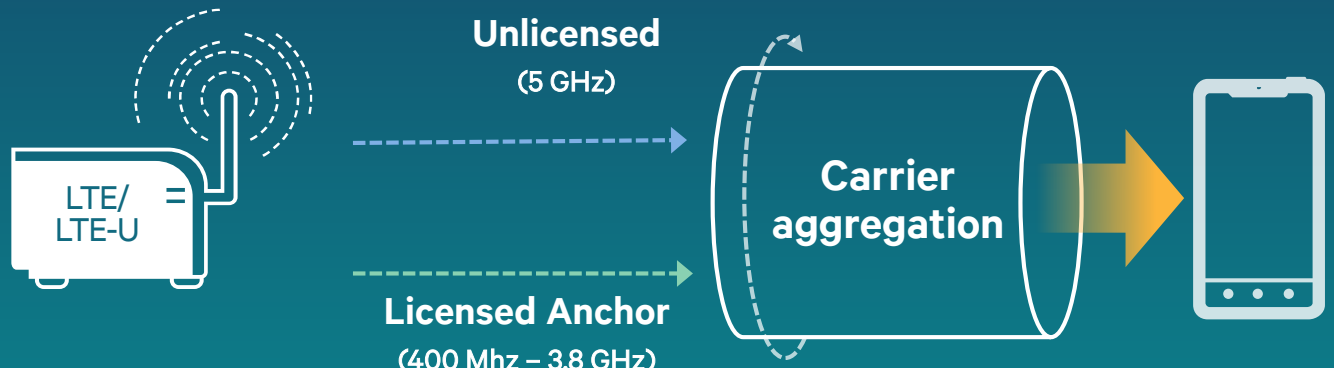



Notes: Faster roaming: Based on Qualcomm Technologies prototype, in typical conditions, after full authentication with the target operator; Reduced overhead: Scenario such as airport/train stations/conferences (100s of users), 4 to 16 APs visible per STA, 2.4GHz band, 1 Mbps management traffic

# LTE-U for 5 GHz unlicensed spectrum



# LTE-U in 5 GHz for new small cell deployments




**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

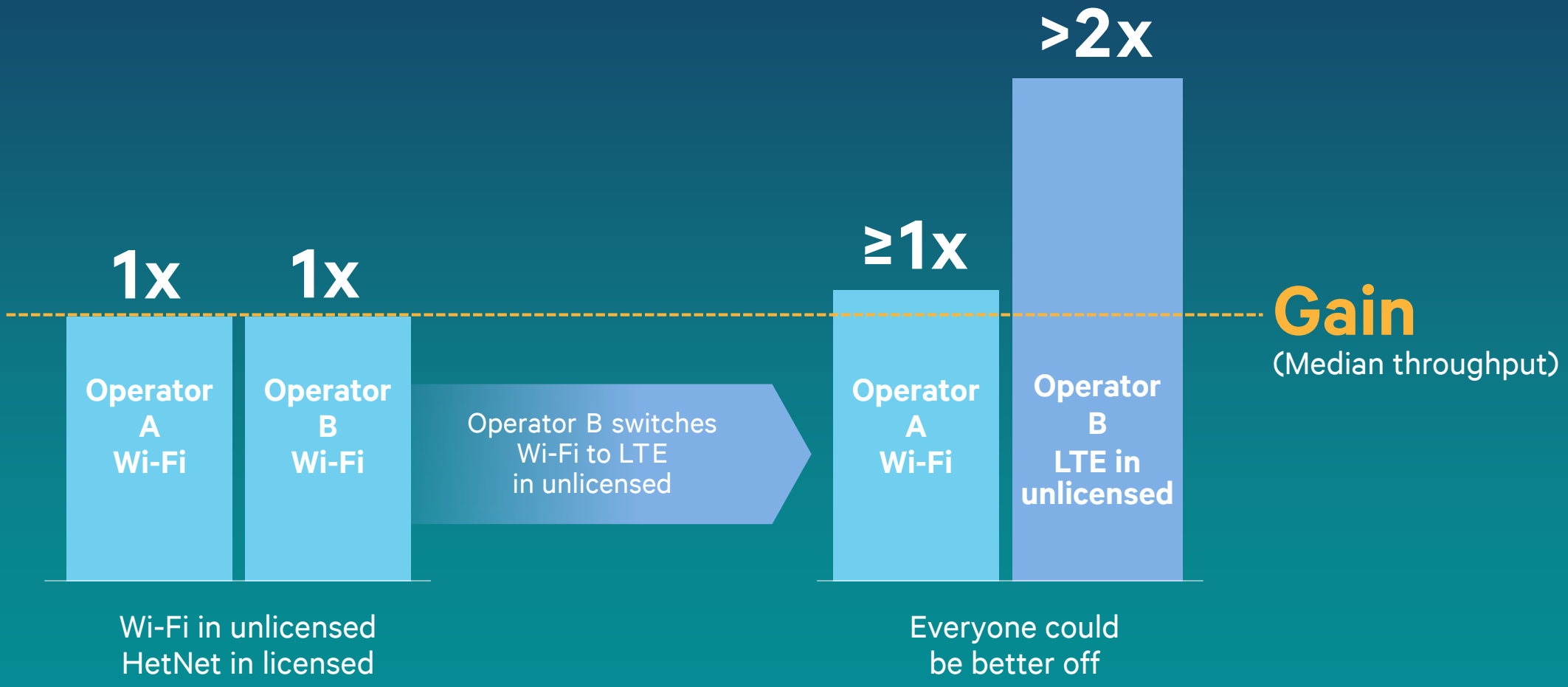
In many cases, better neighbor to Wi-Fi than Wi-Fi itself

[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).

# 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: 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 - Phase II., 2x2 MIMO (no MU-MIMO).; Wi-Fi - 802.11ac 2x2 MIMO (no MU-MIMO), LDPC codes and 256QAM).

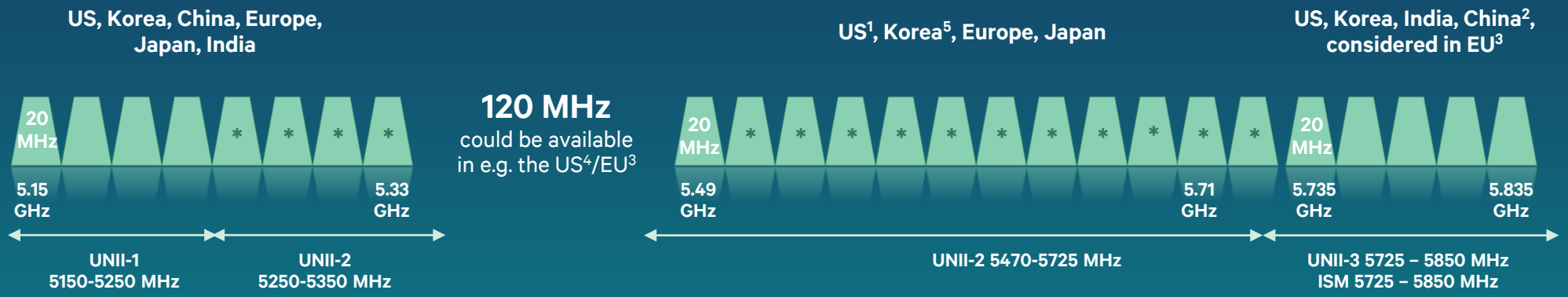
# LTE-U improves coverage

## Compared to Wi-Fi


LTE Thrpt (Mbps) / Wi-Fi Thrpt (Mbps)

Source: Qualcomm Research. Example from our LTE-U testing in San Diego to validate coverage and performance advantages.

# Unlicensed 5 GHz spectrum is ideal for small cells with LTE-U




## Opportunistic use

Unlicensed spectrum is shared but “free”

## ~500 MHz spectrum available

Even more in pipeline, to complement licensed

## Shorter range

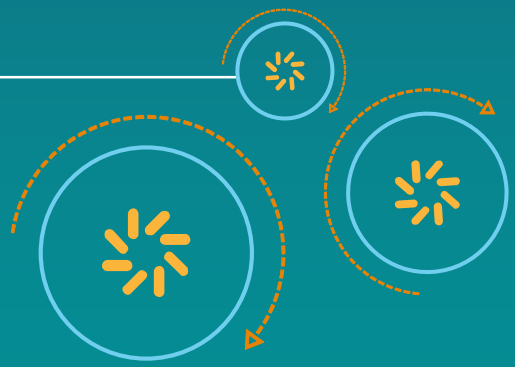
Lower transmit power per regulations

## Wide bands available for sharing

Efficiently shared amongst multiple users

[1] Channel 120, 124 and 128 (5.6-5.65 GHz) currently not permitted in the US. [2] 5725MHz-5850MHz has been assigned to ISM services in China [3] Study of 5350MHz-5470MHz and 5725MHz-5925MHz use for license exempt is being planned in EU'.
[4] 5470-5650 MHz in Korea* These 5GHz channels typically require DFS, Dynamic Frequency Selection

# LTE-U is a good neighbor: coexists fairly with Wi-Fi



# 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

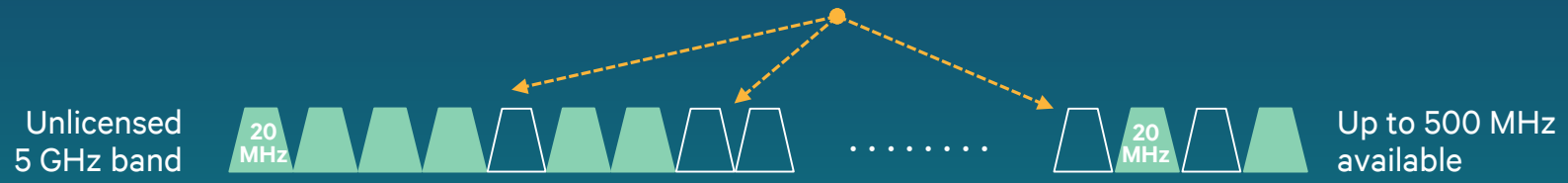
### Conformance testing

- 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 protects Wi-Fi to ensure fair sharing of spectrum

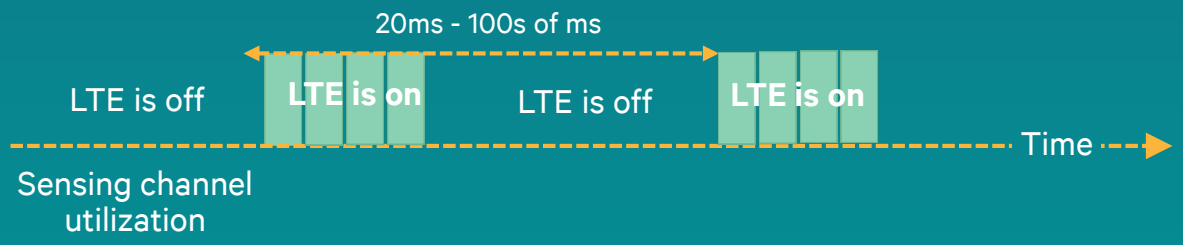
## 1 Select clear channel : Dynamically avoid Wi-Fi




## 2 If no clear channel : Fair sharing with Wi-Fi on the same channel

### Adaptive duty cycle (CSAT) based[1]

for early deployments in USA, Korea, China, India etc. using 3GPP Rel. 10/11/12




### Listen Before Talk (LBT) based[2]

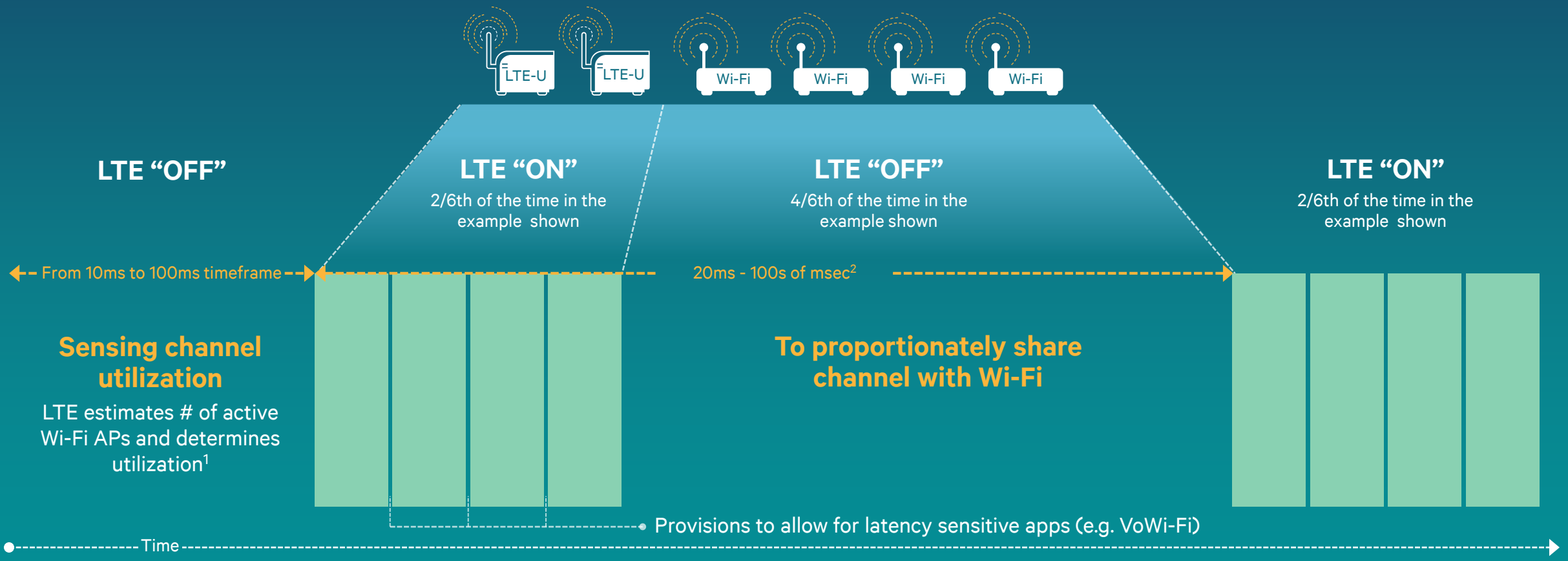
for deployments in Europe, Japan and beyond using 3GPP Rel. 13 LAA


[1] CSAT - Carrier Sensing Adaptive Transmission required in the small cell Meeting regulatory requirements, in addition ensures fairness.
[2] Part of 3GPP Rel 13, Licensed Assisted Access (LAA) for regions with short channel occupancy requirements, aka Listen Before Talk (LBT)

# LTE/Wi-Fi co-channel fair coexistence using adaptive duty cycle

## Enabling early LTE-U deployments using Rel 10/11/12 in countries such as USA, Korea & China

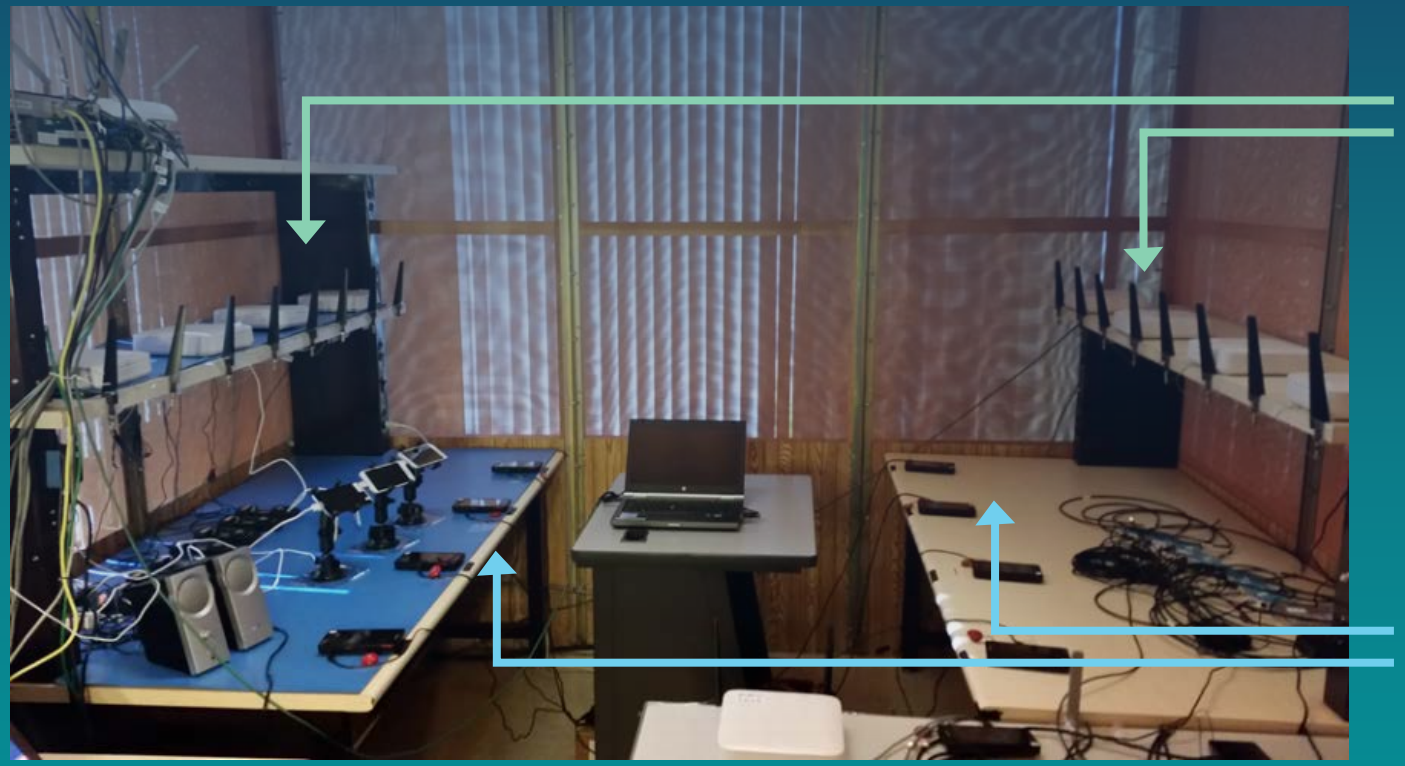
### Carrier Sensing Adaptive Transmission (CSAT) example




[1]LTE reads Wi-Fi preamble to determine # of Wi-Fi APs and their usage; [2]20ms or more for primary channel, 100s of ms for secondary channel

# Stress testing LTE/Wi-Fi co-channel in very harsh conditions

## Qualcomm Technologies' LTE/Wi-Fi coexistence test chamber



### Hyper dense network

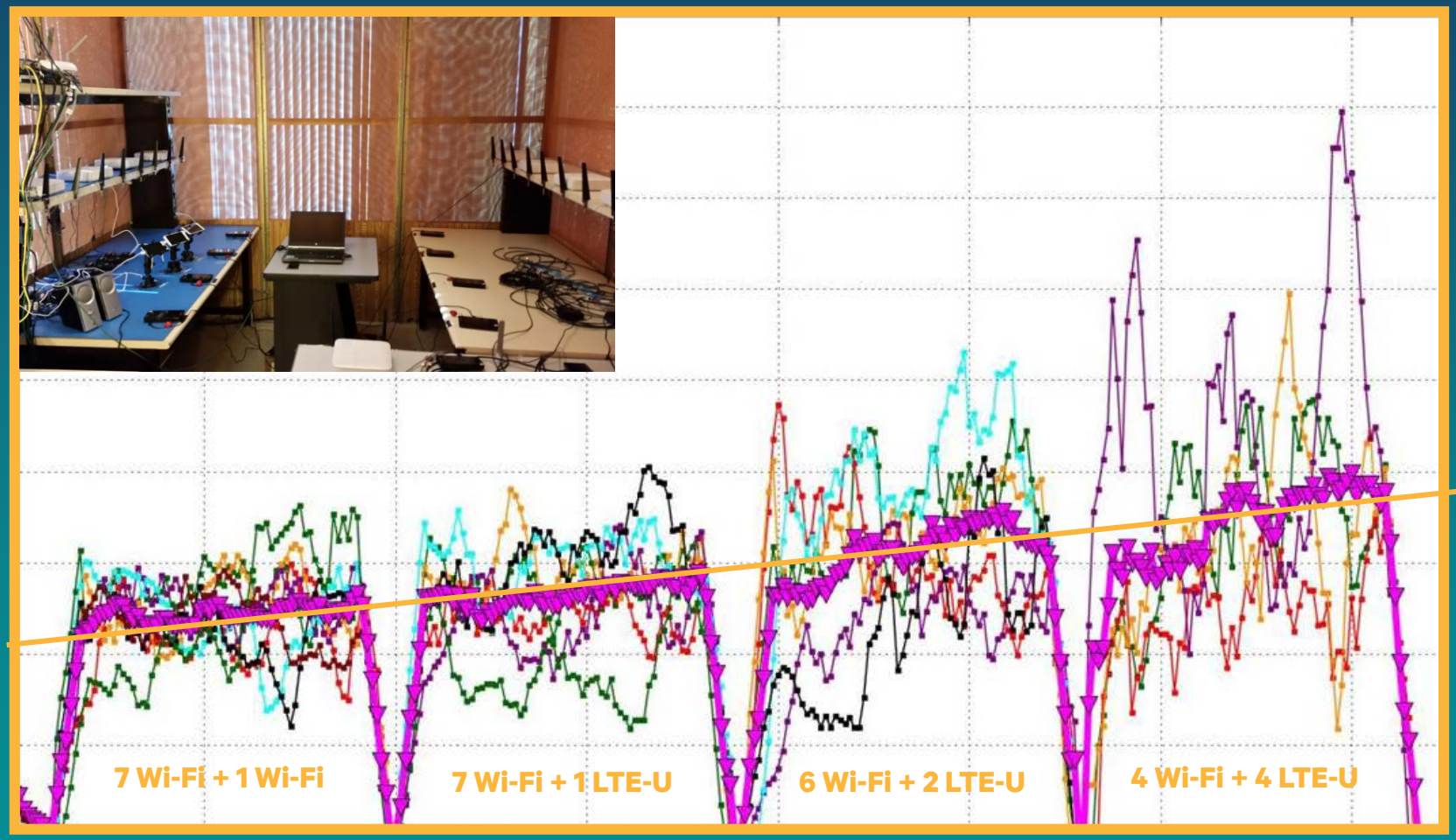
- Up to 9 Access Points (AP) placed ~1m apart
- All APs set to the same channel
- Commercial, off-the-shelf Wi-Fi and test LTE-U APs

### Extreme interference for devices

- No isolation between neighboring APs and devices

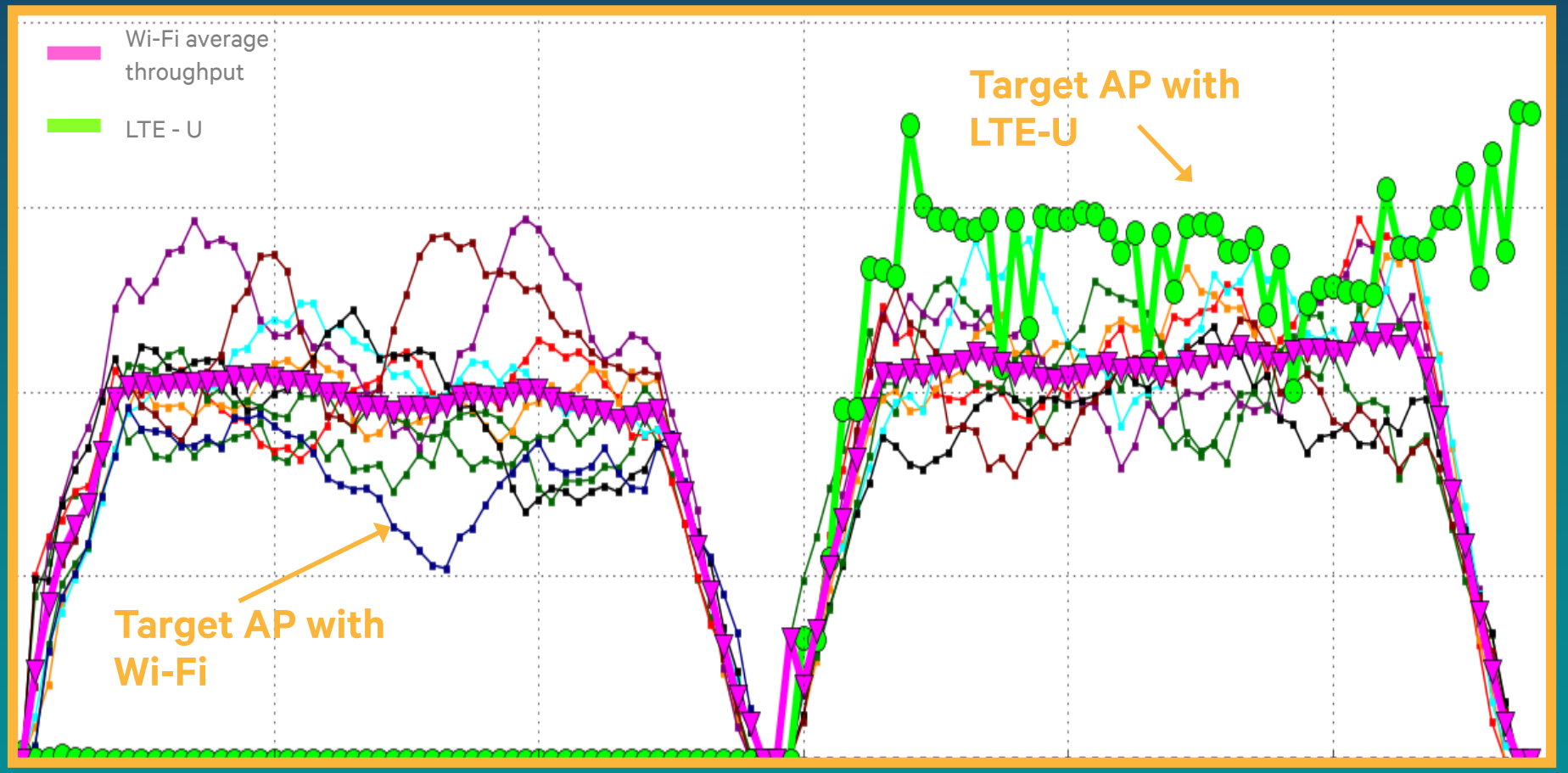
# Wi-Fi performance not adversely affected by LTE-U

## Using adaptive duty cycle (CSAT) for fair coexistence



# Better performance of LTE-U

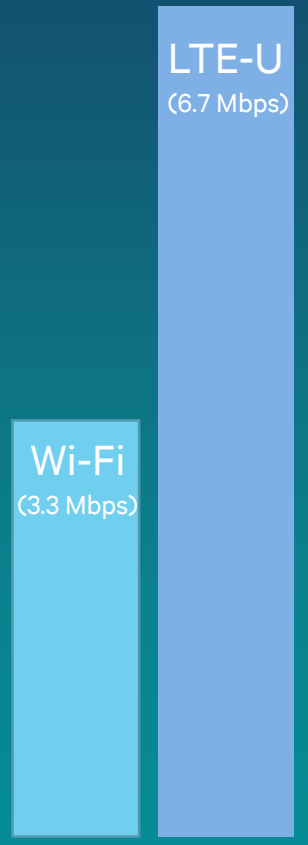
## Using adaptive duty cycle (CSAT)




8 Wi-Fi + 1 Wi-Fi

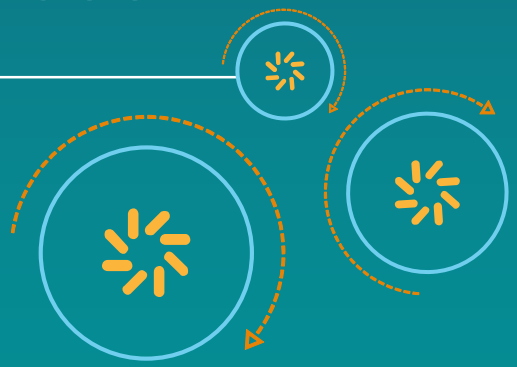
8 Wi-Fi + 1 LTE-U

Average throughput



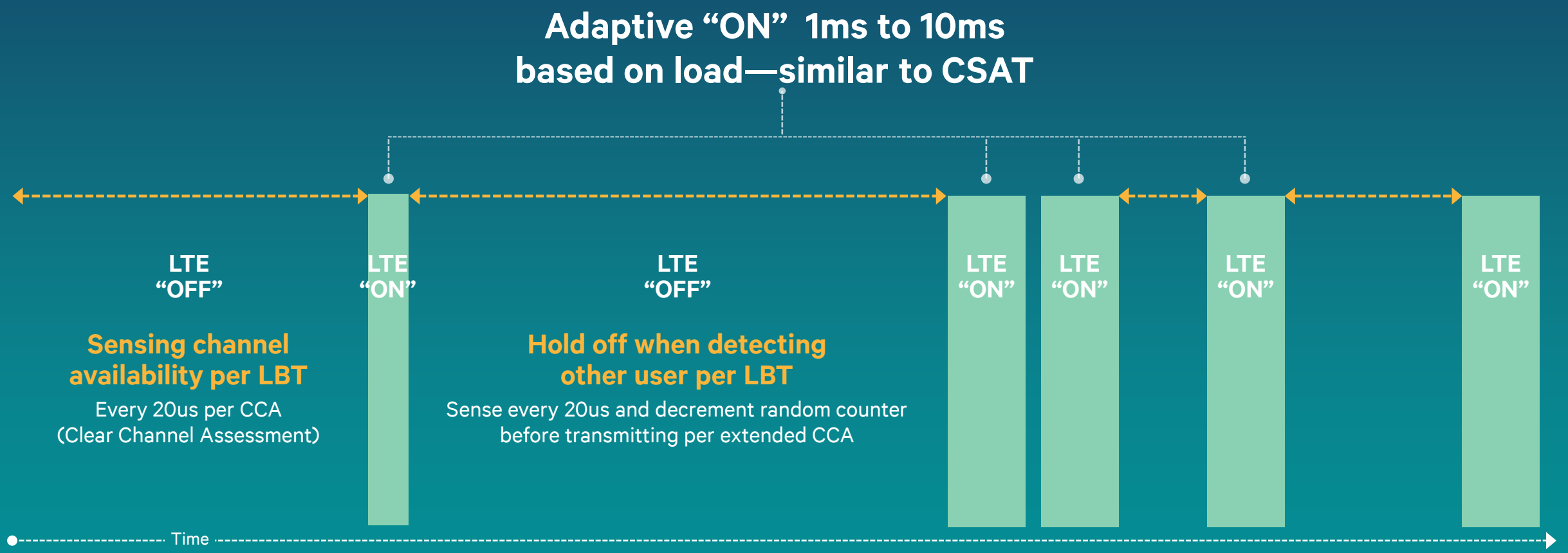

Target AP

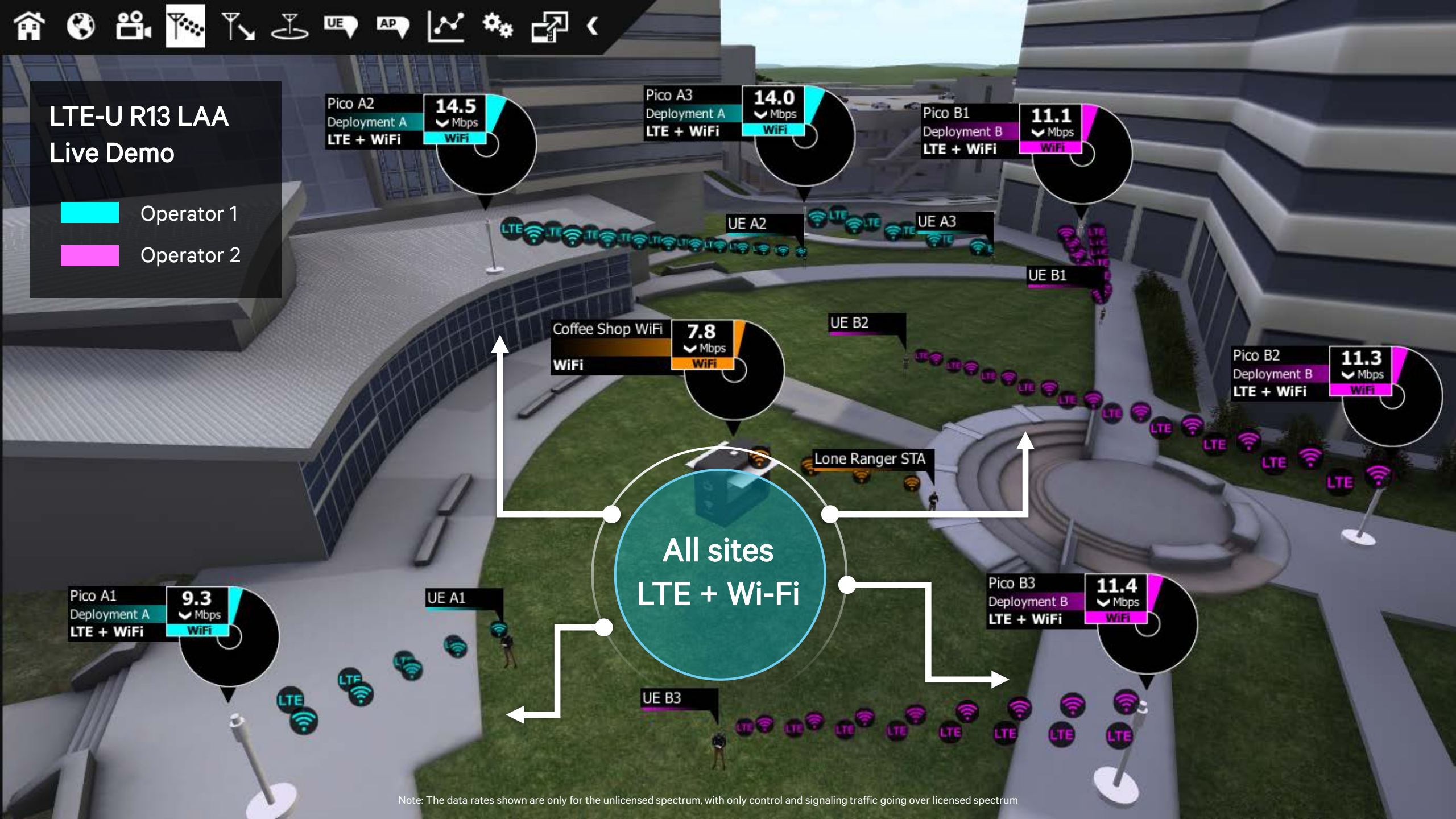
# LTE-U coexistence
# 3GPP R13 LAA - Licensed Assisted Access



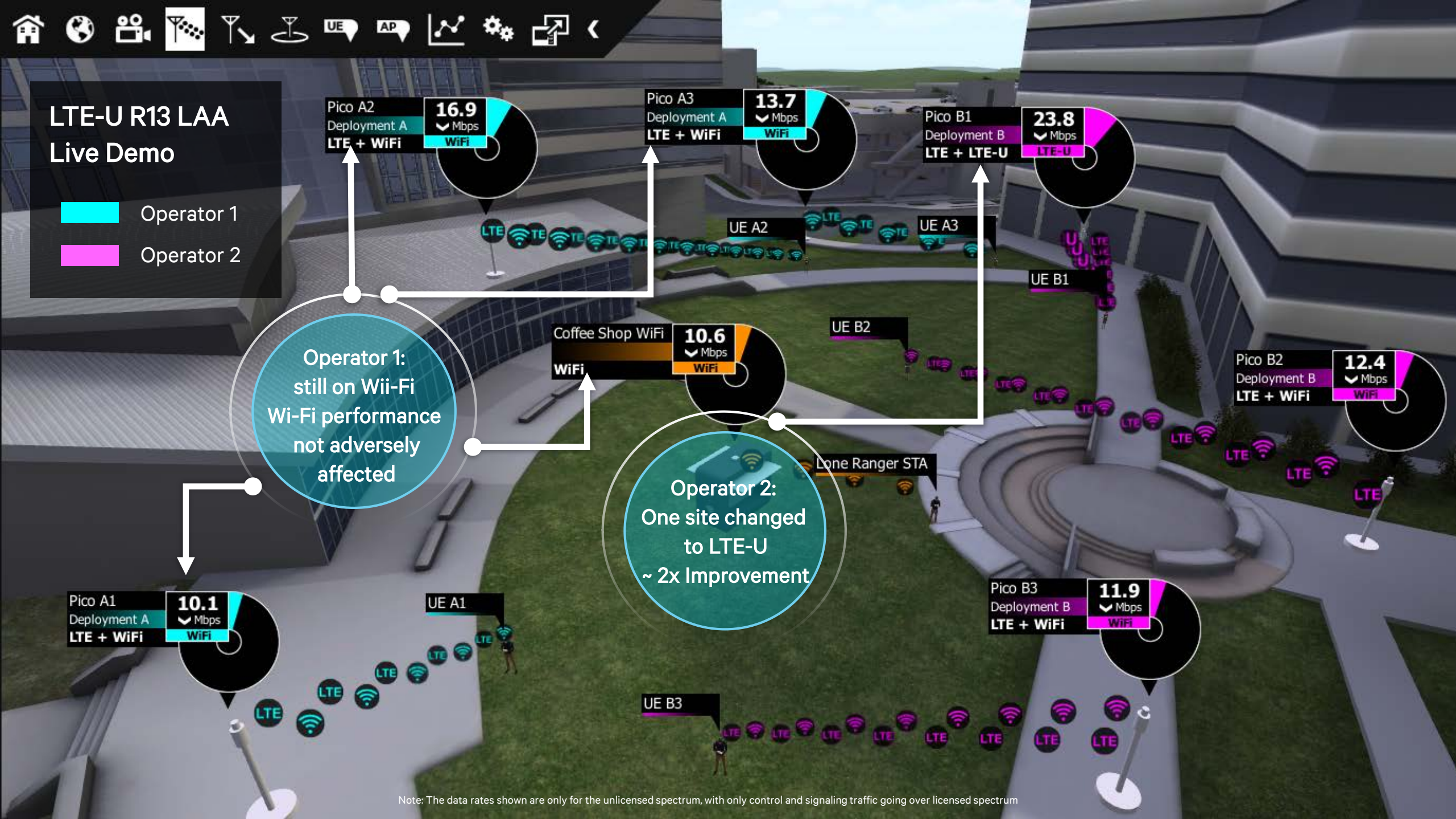
# Going beyond Listen Before Talk (LBT) for fair sharing with Wi-Fi

## For LTE-U deployments using 3GPP Rel. 13—Licensed Assisted Access (LAA)






Note: The data rates shown are only for the unlicensed spectrum, with only control and signaling traffic going over licensed spectrum

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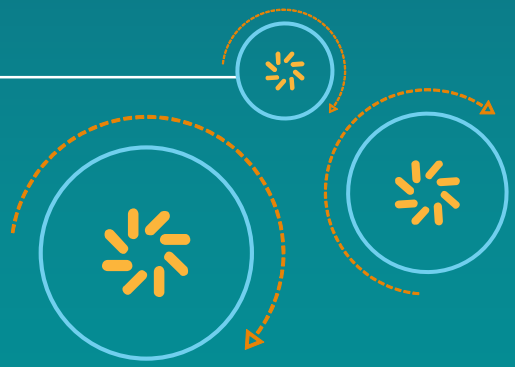
# LTE-U traction



# Strong mobile industry support for LTE-U

## Operator Announcements

“And, we’ve already begun work with our …. partners to bring LAA production trials to life this year and bring the technology to our customers in the near-future.”

**- Neville Ray, CTO, T-Mobile**

"We are very pleased to have confirmed that LAA is a viable technology for LTE and future LTE-Advanced,"

**- Seizo Onoe, EVP & CTO,  NTT DOCOMO.**

## Vendor Support

“..Ericsson first to give smartphone users indoor boost with License Assisted Access..”

**- Press release, 1.5.15**

"We are pleased to see successful joint field results on deploying LAA in partnership with NTT DOCOMO,"

**- Ryan Ding, Executive Director of Board, Huawei.**

## Standardization

**Study item in Rel 13 (LAA)**

Supported by many operators, vendors and other industry participants

3GPP A GLOBAL INITIATIVE

## Public Demos/Trials

- DoCoMo/Huawei – joint tests
- Qualcomm Technologies at MWC 2014, 2015
- Many non-public tests and demos

Sources: http://newsroom.t-mobile.com/issues-insights-blog/unleashing-lte-potential-integrating-new-spectrum.htm ; https://www.nttdocomo.co.jp/english/info/media_center/pr/2014/0821_00.html ; http://www.ericsson.com/news/1884277

# Qualcomm Technologies, Inc. (QTI) advances LTE-U ecosystem

## Industry's first small cell SoCs with LTE-U support, from QTI

- FSM99xx SoCs for enterprise and metro small cells – available 2H CY15
- Helping operators make the best use of all available spectrum
- FSM99xx also supports concurrent 3G/4G operation, dual-carrier 4G with carrier aggregation, and hosted Wi-Fi.

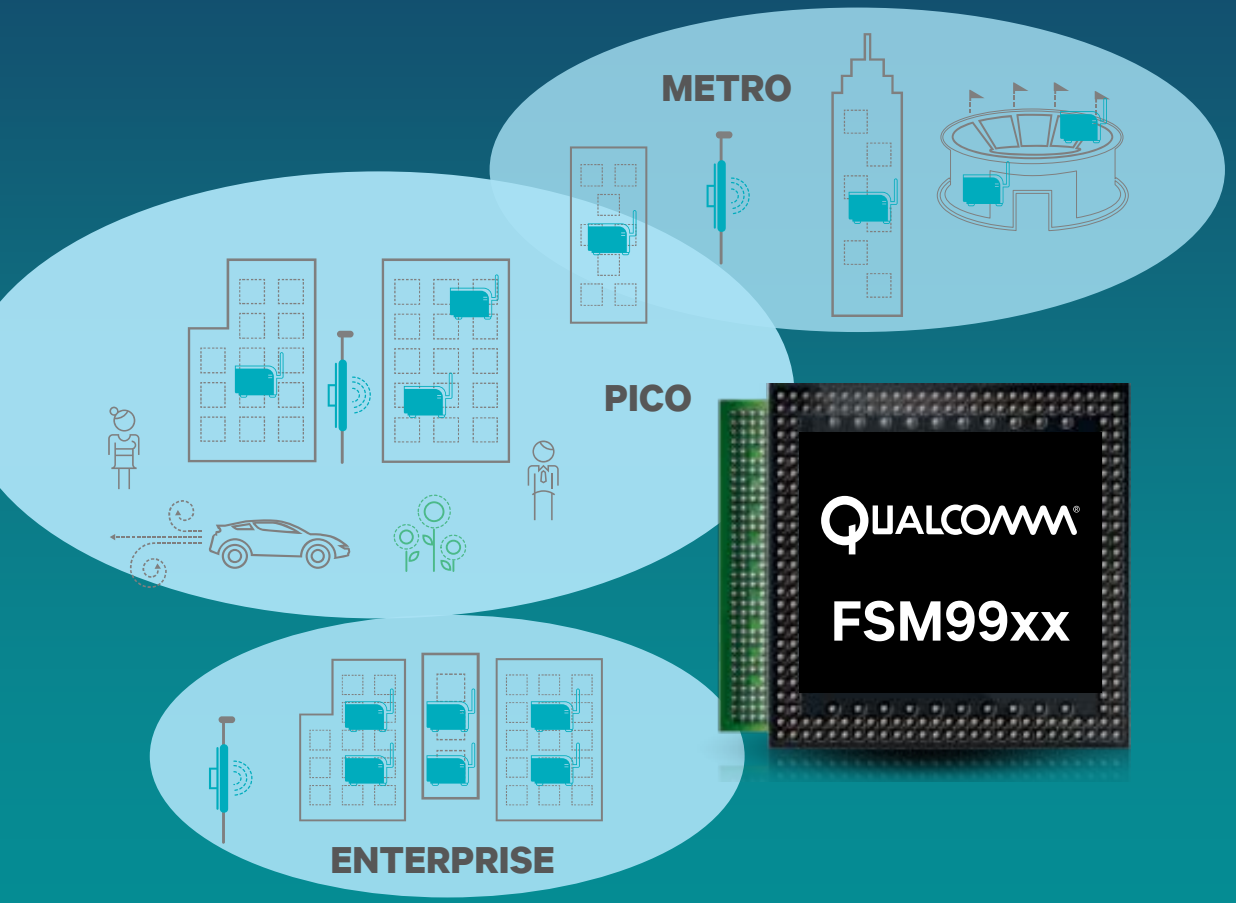
## Industry's first RF transceiver with LTE-U for mobile devices

- Extending QTI's RF leadership in LTE Advanced
- QTI's WTR3950 is the first 28nm RF for single-chip Cat 6 carrier aggregation – available 2H CY15
- Optional WTR4905 transceiver, to support up to 3x20 MHz CA across licensed & unlicensed bands

## Proven Coexistence with Wi-Fi

- QTI over the air testing not only proved co-existence between multiple LTE-U and Wi-Fi access points, but also revealed that LTE-U can actually improve Wi-Fi performance under extreme load conditions.
- QTI solutions exceed minimum requirements with standard and pre-standard coex features
  - Dynamic Channel Selection, Listen Before Talk (LBT), Carrier Sensing Adaptive Transmissions (CSAT), etc.

# FSM99xx brings LTE-U to small cells




## Complete multi-mode SoCs

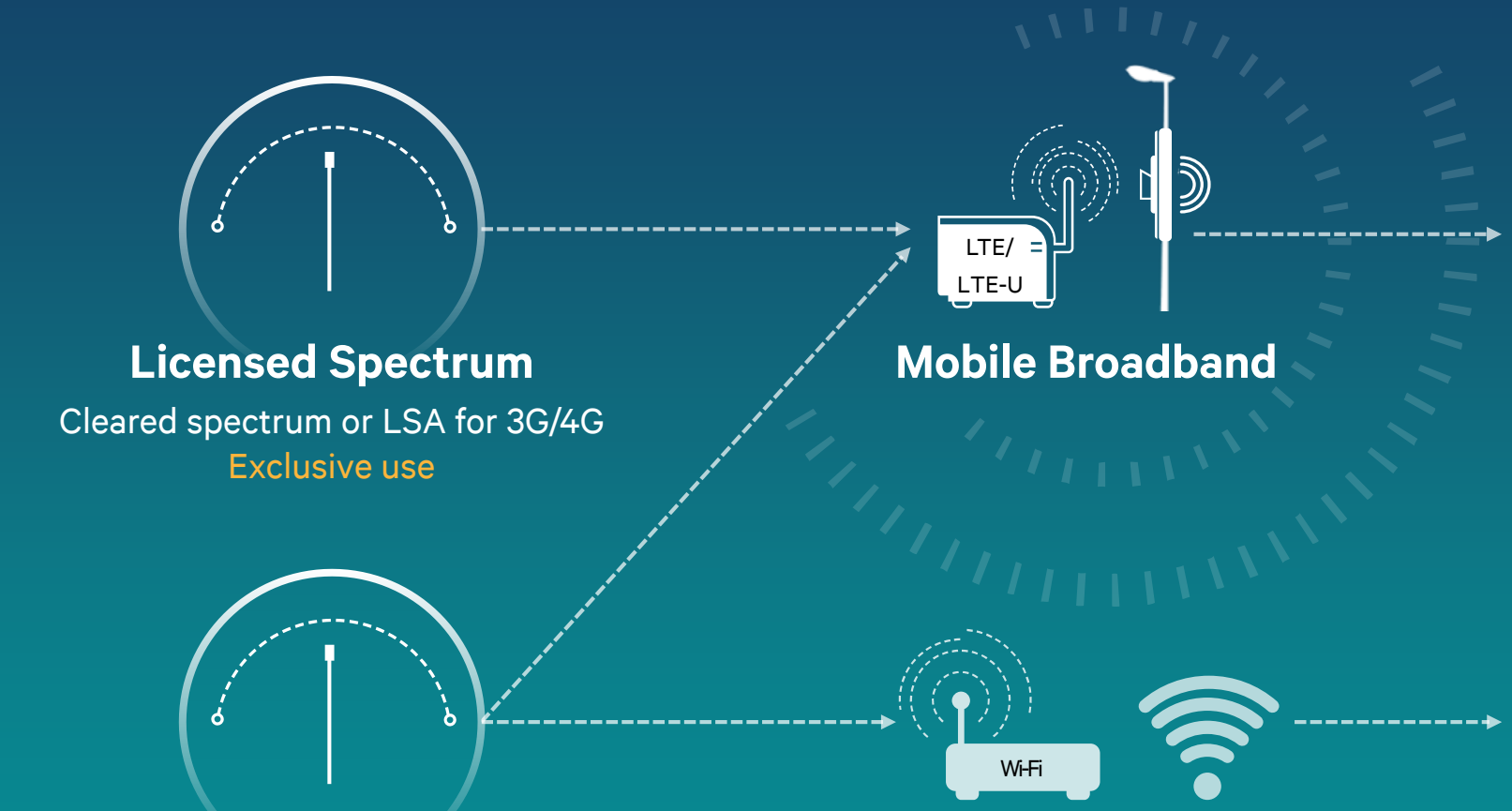
- Global 3G / 4G modem (with LTE-U)
- Quad-core 2 GHz Krait processor
- Hosted 802.11ac Wi-Fi
- Dedicated network listen
- Industry-leading RF, power management, GNSS, security, and more...

## Software for easier deployment & management

- UltraSON™ interference & mobility management
- LTE-U / Wi-Fi coexistence features
- Digital pre-distortion (DPD)
- eICIC
- Hotspot 2.0

FSM small cell solutions and UltraSON are products of Qualcomm Technologies, Inc..
eICIC is enhanced Inter Cell Interference Coordination defined by 3GPP.

# Committed to making best use of licensed and unlicensed




**Licensed Spectrum**

Cleared spectrum or LSA for 3G/4G

Exclusive use

**Unlicensed Spectrum**

Multiple technologies (Wi-Fi, BT, LTE-U)

Shared use

**Mobile Broadband**

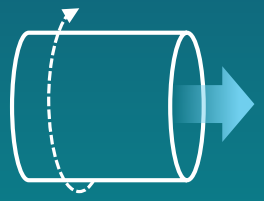
**Local Area Access**

- **LTE Advanced for 5 GHz unlicensed spectrum**
- **Carrier Wi-Fi and aggregation with LTE**
- **Wi-Fi in 2.4 & 5GHz unlicensed spectrum**
- **Private/residential, enterprise users and more**

# Summary: making best use of unlicensed spectrum for 1000x

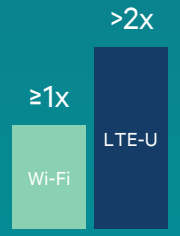
1000X

1



- LTE - Wi-Fi link aggregation for carrier Wi-Fi
- LTE-U in 5GHz for new small cells

2




- Improved coverage and capacity; creates a unified network for all spectrum

3

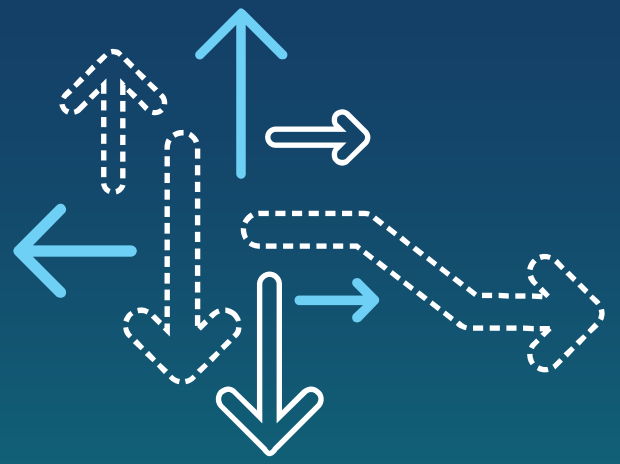

- LTE-U is a good neighbor: coexists fairly with Wi-Fi

4

3GPP
A GLOBAL INITIATIVE

- Strong industry support for LTE-U, and LTE – Wi-Fi convergence; both will coexist

# Questions? - Connect with Us



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# Thank you

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