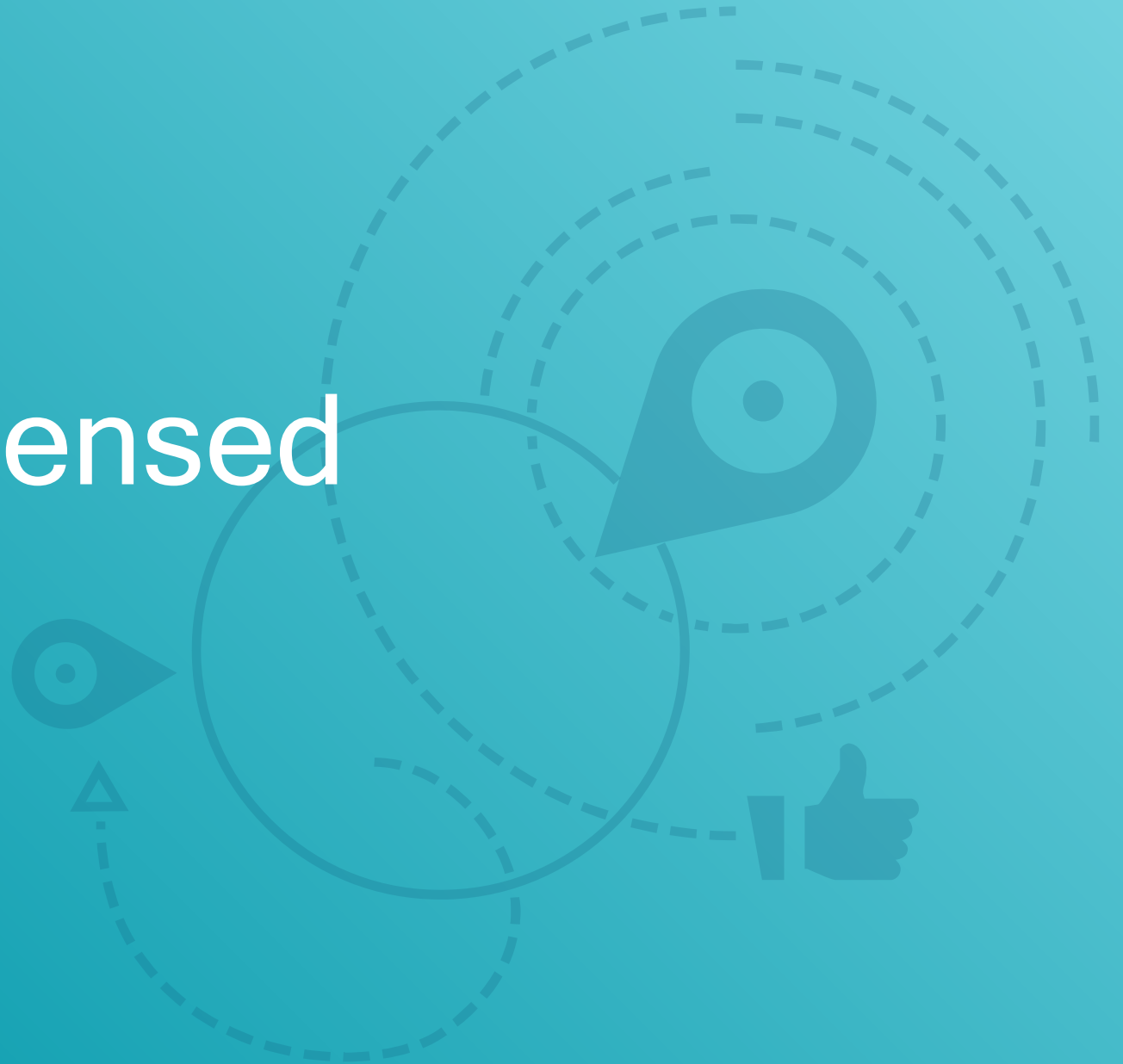


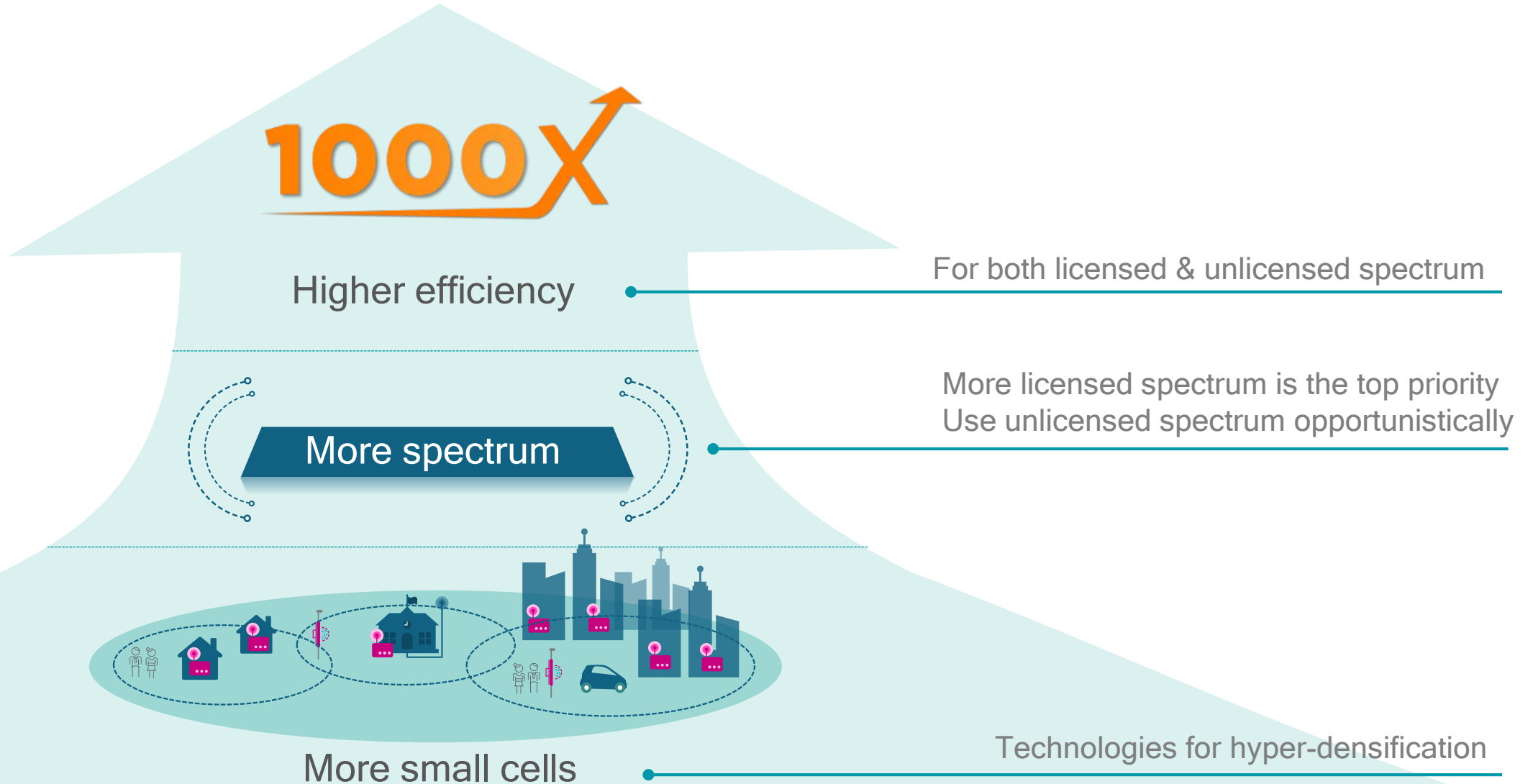


Best use of unlicensed spectrum

Qualcomm Technologies, Inc.
June, 2016



Making the best use of licensed and unlicensed spectrum



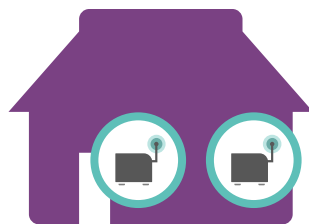
Making best use of 5 GHz unlicensed band

LTE-U/LAA, LWA and 802.11 ac/ax will coexist in 5 GHz

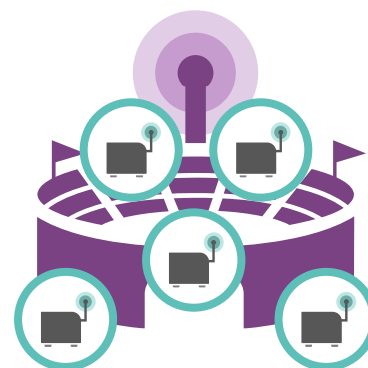
Enterprises



Small Businesses



Venues



Residential/ Neighborhood



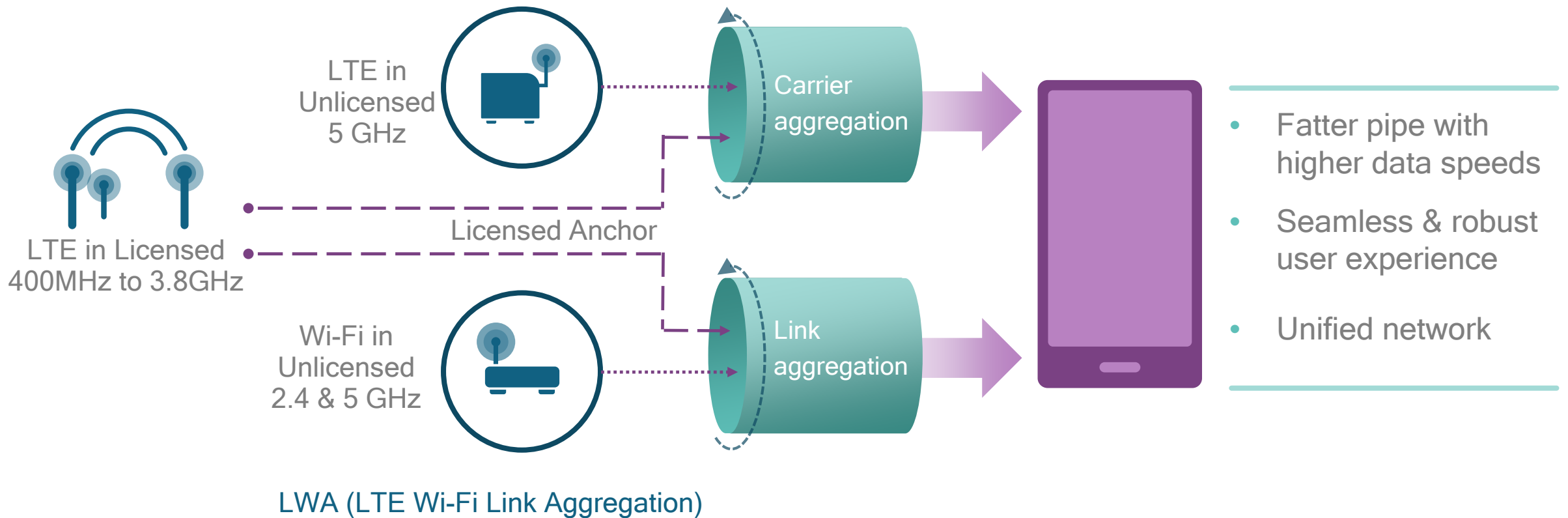
Large amounts of spectrum available globally (~500 MHz¹)

Ideal for small cells thanks to lower mandated transmit power

Global neutral spectrum that can serve any user with same deployment - neutral hosts

Aggregation with licensed anchor for best performance

LAA / LTE-U (Licensed-Assisted Access)



LTE-U / LAA



LAA part of LTE Advanced Pro—a rich roadmap of features

Pushing LTE capabilities towards 5G

5G

Rel-15 and beyond

Advanced MIMO

Unlicensed spectrum

eLAA

FeICIC

256QAM

Internet of Things

Enhanced CA

Carrier aggregation

FDD-TDD CA

LAA

Massive/FD-MIMO

SON+

CoMP

Device-to-device

V2X

Shared Broadcast

Dual connectivity

Low Latency



Rel-10/11/12

LTE Advanced



Rel-13 and beyond

LTE Advanced Pro

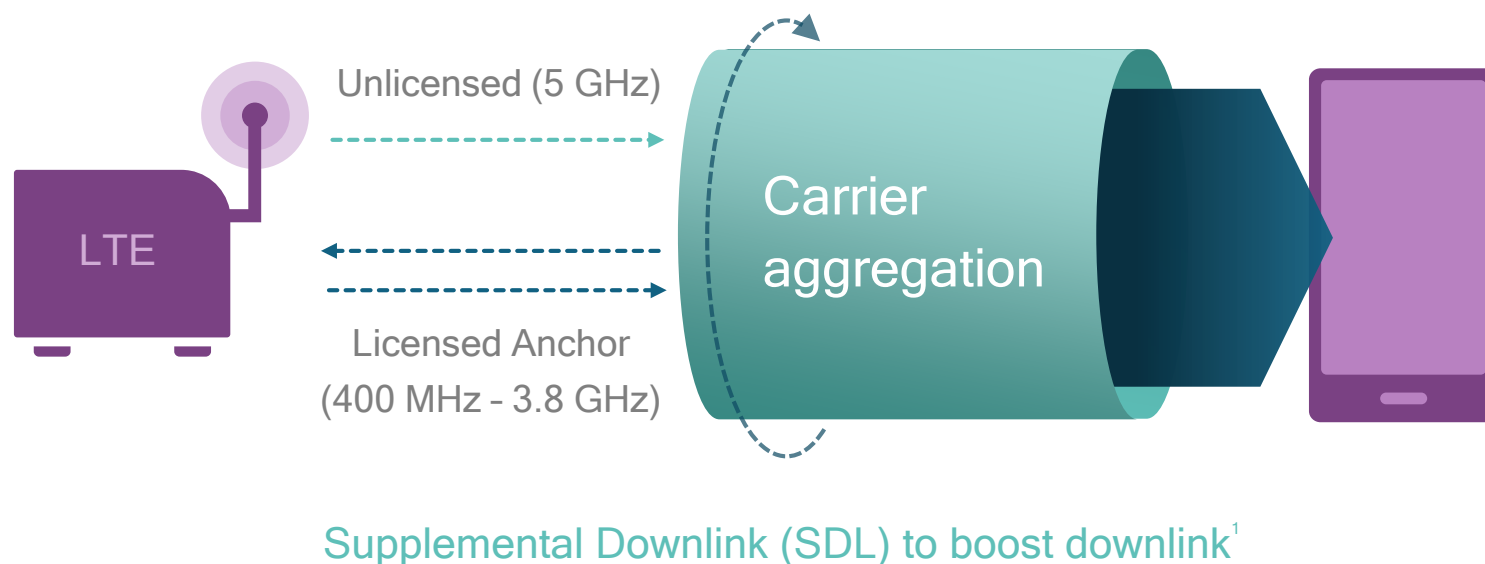
2015

2020+

Note: Estimated commercial dates. Not all features commercialized at the same time

Extending LTE to unlicensed spectrum

LTE-U and Licensed Assisted Access (LAA)

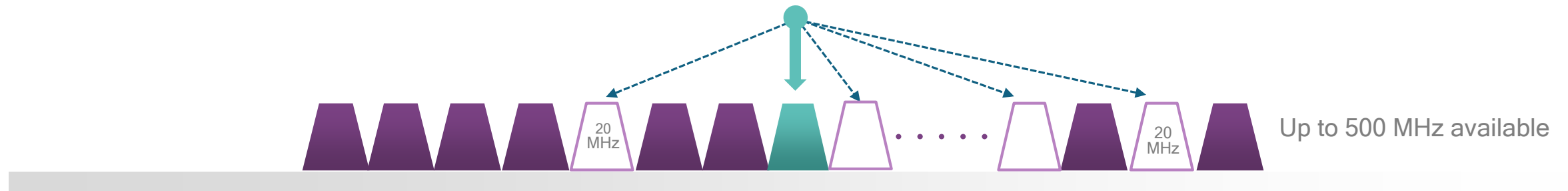


- **Path to Gbps speeds**
By aggregating licensed and unlicensed
- **Seamless and robust user experience**
With reliable licensed spectrum anchor
- **2x capacity and range**
Over Wi-Fi capacity in dense deployments²
- **Single unified LTE network**
Common management
- **Fair Wi-Fi coexistence**
Fundamental design principle

¹ Aggregating with either licensed TDD or licensed FDD is possible with SDL; ² Assumptions: 3GPP LAA evaluation model based on TR 36.889, two operators, 4 small-cells per operator per macro cell, outdoor, 40 users on same 20 MHz channel in 5 GHz, both uplink and downlink in 5 GHz, 3GPP Bursty traffic model 3 with 1MB file, LWA using 802.11ac, DL 2x2 MIMO (no MU-MIMO), 24dBm + 3dBi Tx power in 5 GHz for LAA eNB or Wi-Fi AP.

LAA is designed to protect Wi-Fi

Select clear channel: Dynamically avoid Wi-Fi



If no clear channel then share fairly: “Listen before talk” (LBT)



Release unlicensed channel at low traffic

LTE-U and LAA part of the same evolution

LTE-U

Time to market for certain regions: USA, Korea, India

Based on 3GPP R12

- Supplemental downlink (SDL) to boost downlink
- Dynamic channel selection to avoid Wi-Fi and adaptive duty cycle (CSAT) to fairly coexist
- Support for migration to LAA

LAA

Includes LBT required for global deployments

3GPP R13

- Supplemental downlink (SDL)
- Dynamic channel selection
- Listen before talk (LBT) complying with global regulations

eLAA and beyond

Enhancements to LAA

3GPP R14 and beyond¹

- Adds uplink aggregation: Boost uplink data rates and capacity²
- Dual Connectivity: Aggregation across non-collocated nodes
- Complexity reduction³

¹ UL aggregation part of Rel. 14—other features proposed; ² Aggregation of unlicensed downlink and uplink is possible with either licensed TDD or licensed FDD; ³ Complexity/cost reduction is also applicable to licensed LTE

World's first over-the-air LAA trial during November 2015

Joint effort by Qualcomm Technologies, Inc. with Deutsche Telekom AG

Completed a wide range of test cases

- Indoor and outdoor deployment scenarios
- Different combinations of LAA, LWA and Wi-Fi
- Single and multiple users
- Stationary and mobile users
- Handover between multiple small cells
- Range of radio conditions



Screenshot of live results from trial in Nuremberg, Germany



A combined test cell with LTE, LAA, LWA and Wi-Fi

A big milestone towards commercial deployment

Over-the-air trial demonstrates LAA advantages



Imagery ©2016 Google. Map data ©2016 GeoBasis-DE/BKG (©2009). Google

Increased coverage

Demonstrated LAA's extended range and improved performance in 5 GHz compared to Wi-Fi

Increased capacity

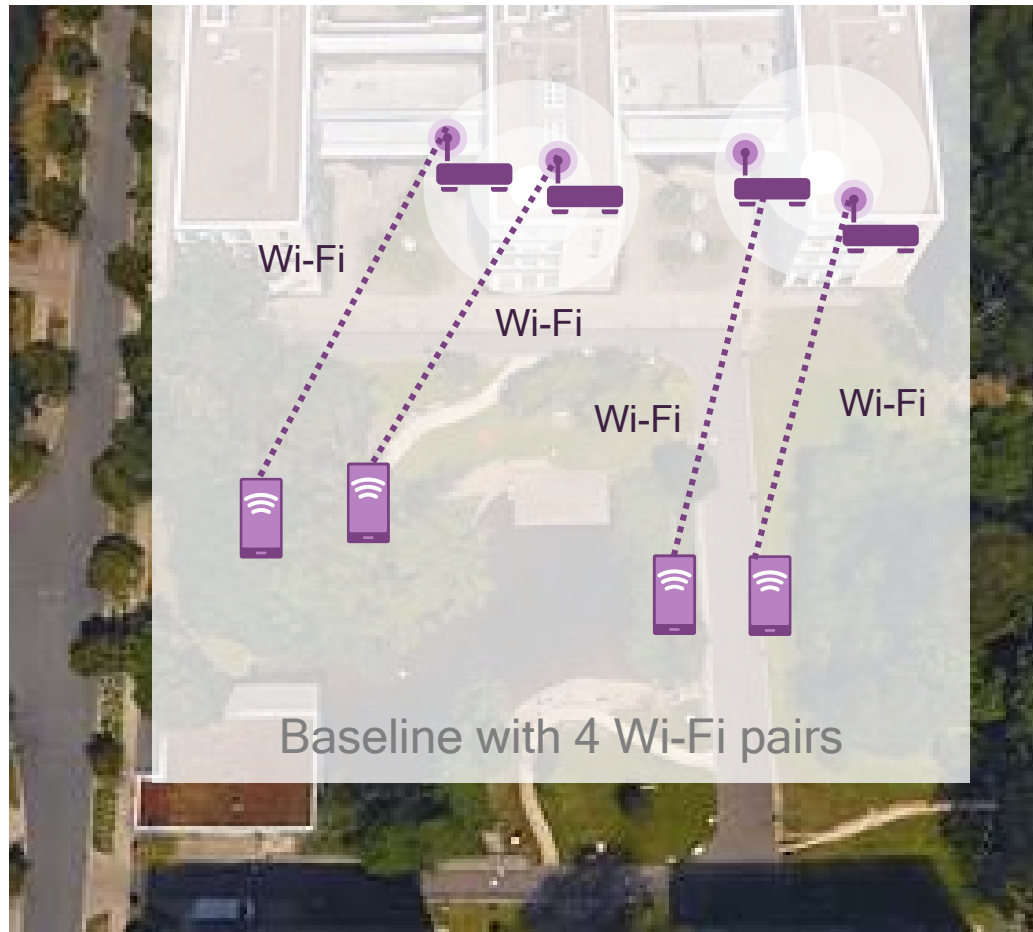
Demonstrated downlink throughput gains over Wi-Fi.

Co-existence that benefits everyone

Demonstrated fair co-existence between LAA, LWA and Wi-Fi with improved performance for everyone sharing the same 5 GHz channel.

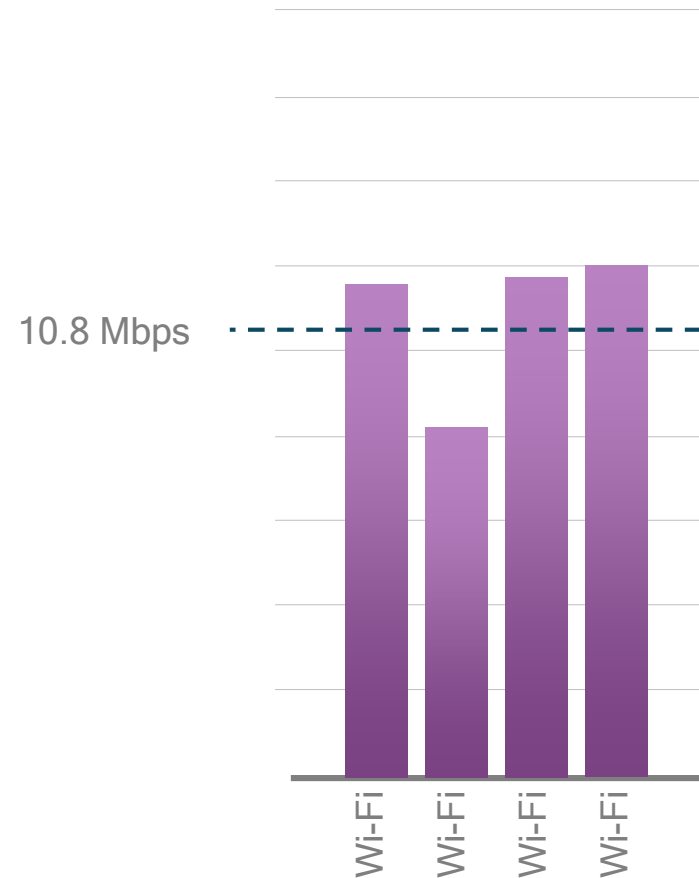
LAA benefits everyone sharing the same 5 GHz channel

A better neighbor to Wi-Fi than Wi-Fi itself



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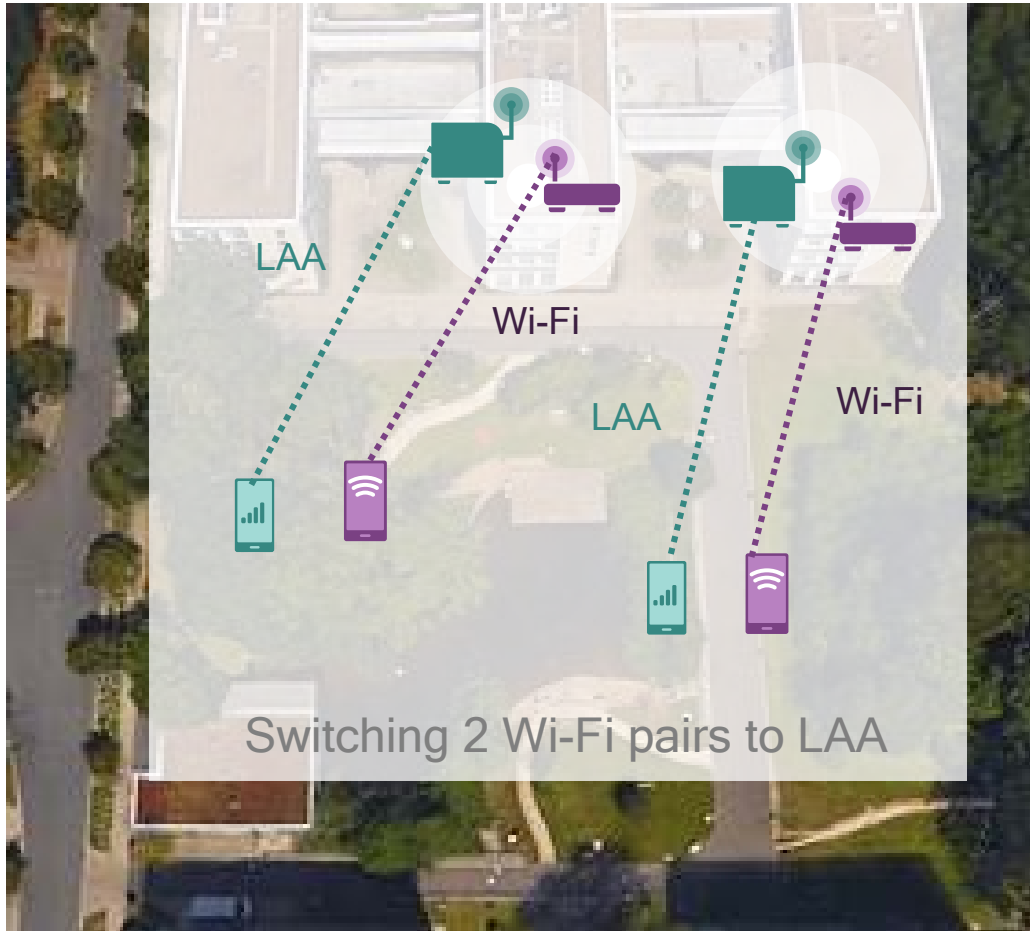
Downlink throughput in 5 GHz¹



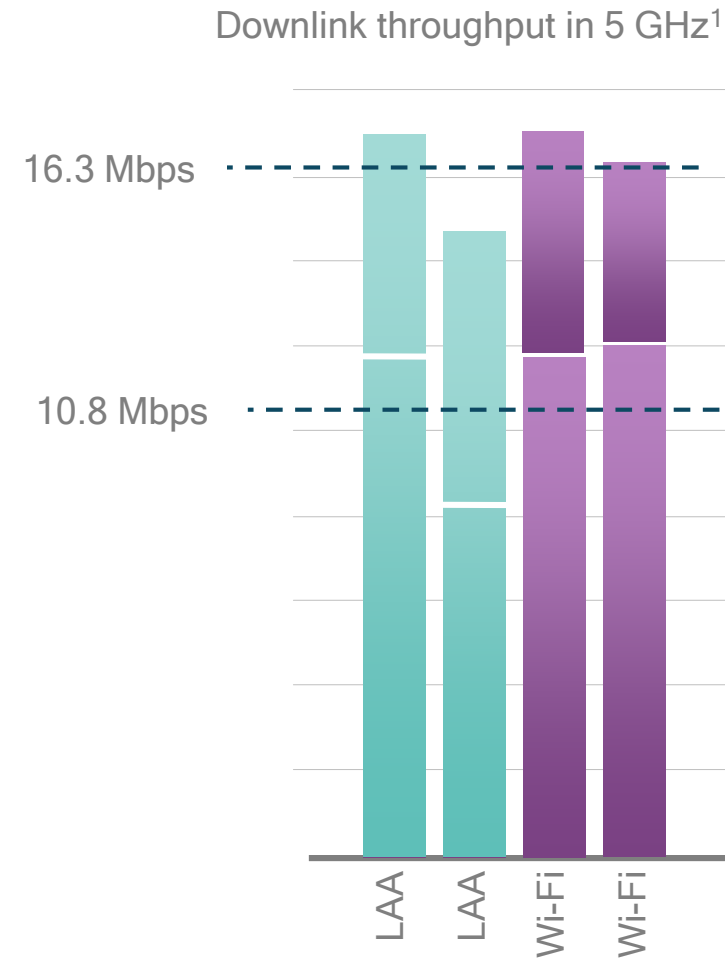
¹ Outdoor, 4 users on 4 different AP/cells, Mix of above and below ED, strong signal level with some interference, LAA based on 3GPP rel. 13; LWA using 802.11ac; LTE on 10 MHz channel in 2600 MHz licensed spectrum with 4W transmit power; the following conditions are identical for LAA and Wi-Fi: 2x2 downlink MIMO, sharing same 20 MHz channel in 5 GHz unlicensed spectrum with 1W transmit power, terminal transmit power 0.2W

LAA benefits everyone sharing the same 5 GHz channel

A better neighbor to Wi-Fi than Wi-Fi itself



Imagery ©2016 Google. Map data ©2016 GeoBasis-DE/BKG (©2009). Google



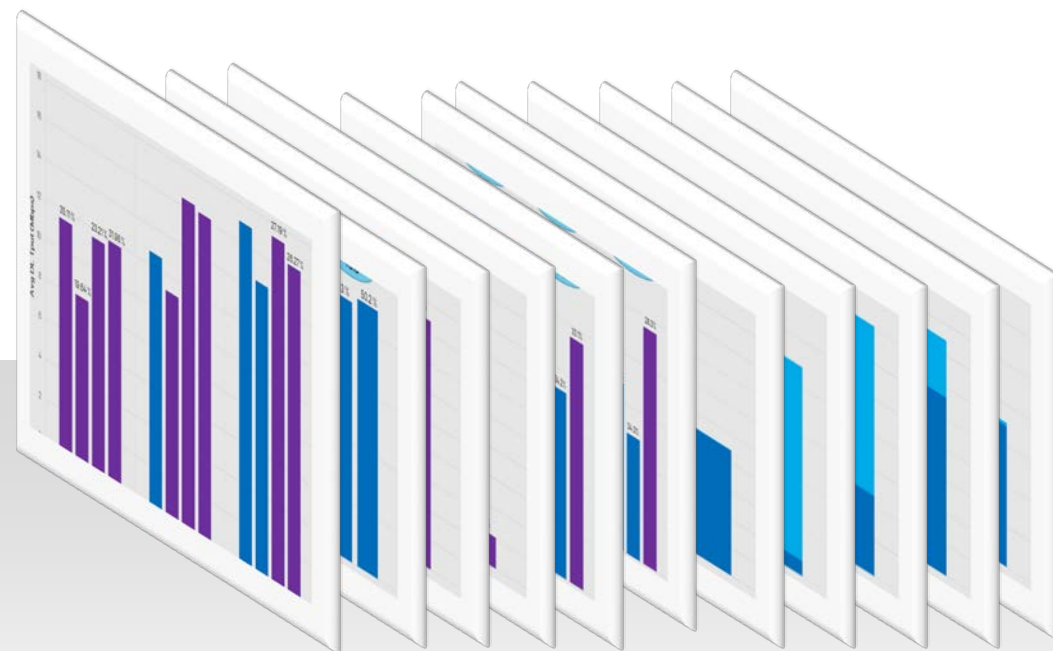
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LAA fairly coexists with Wi-Fi

Summary from a large number of test cases over a diverse set of conditions

1 Switching a Wi-Fi AP with a LAA small-cell results in overall **increased network capacity** and higher throughput for all users.

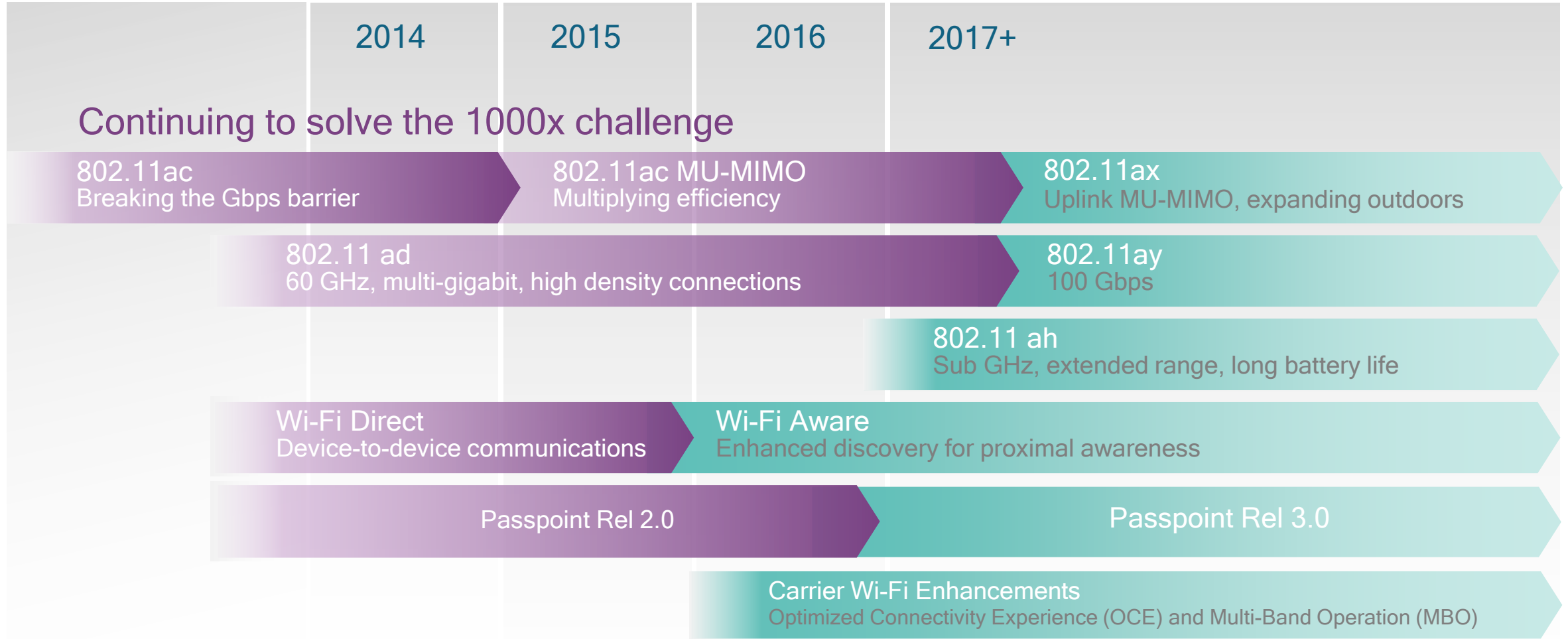
2 LBT ensures that the channel is **shared fairly between the users** and LAA is overall a better neighbor to Wi-Fi than Wi-Fi itself.



WiFi and LWA



Strong Wi-Fi evolution



Providing the connectivity fabric for everything

802.11ax: Enabling carrier-class deployments



Multi-user efficiency

Higher spectral efficiency –
especially in multi-user scenarios

OFDMA, uplink MU-MIMO,
1024QAM & more

Outdoor deployments

Improved outdoor performance

Longer cyclic prefix and longer
OFDM symbol duration

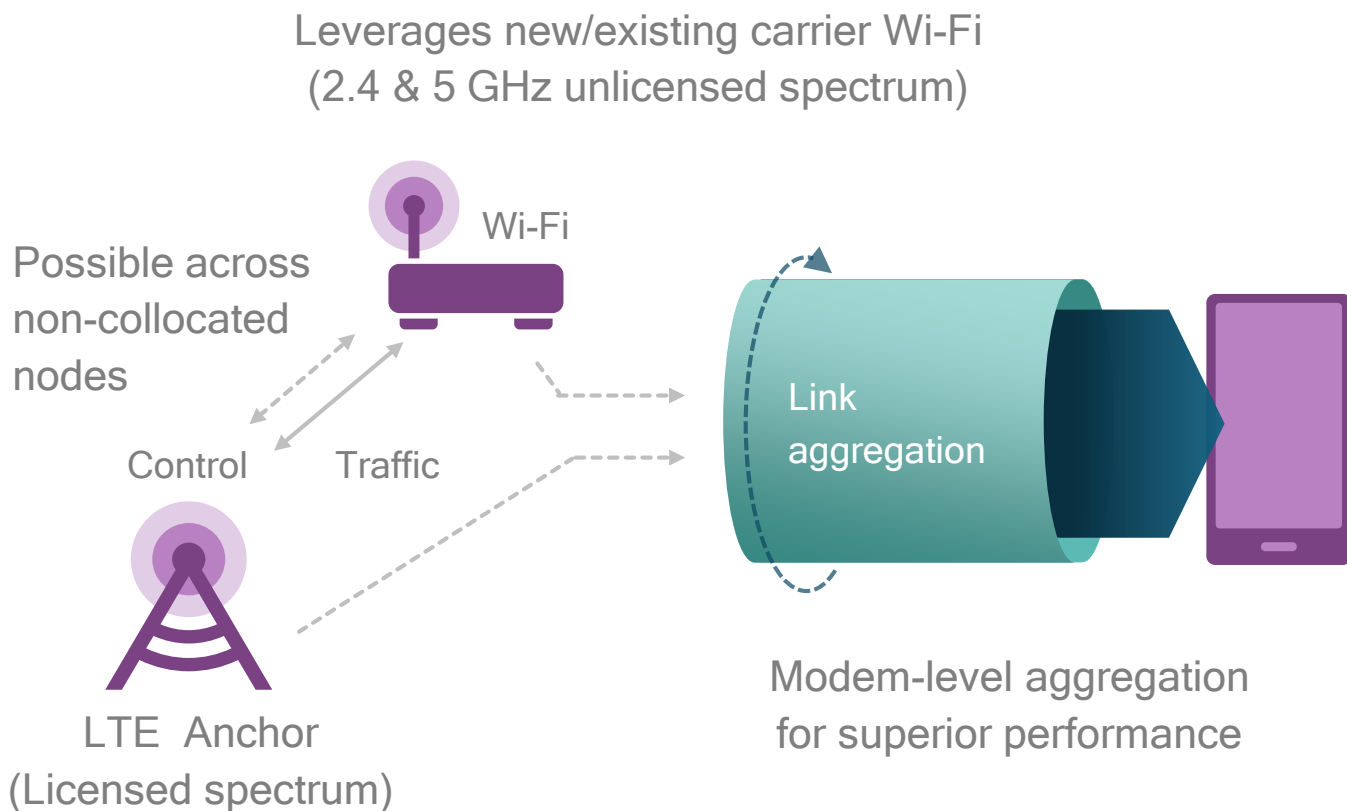
Backward compatible

Supports both 2.4 GHz and 5 GHz

Backward compatible
with legacy 802.11 (n/ac)

LWA for existing and new carrier Wi-Fi

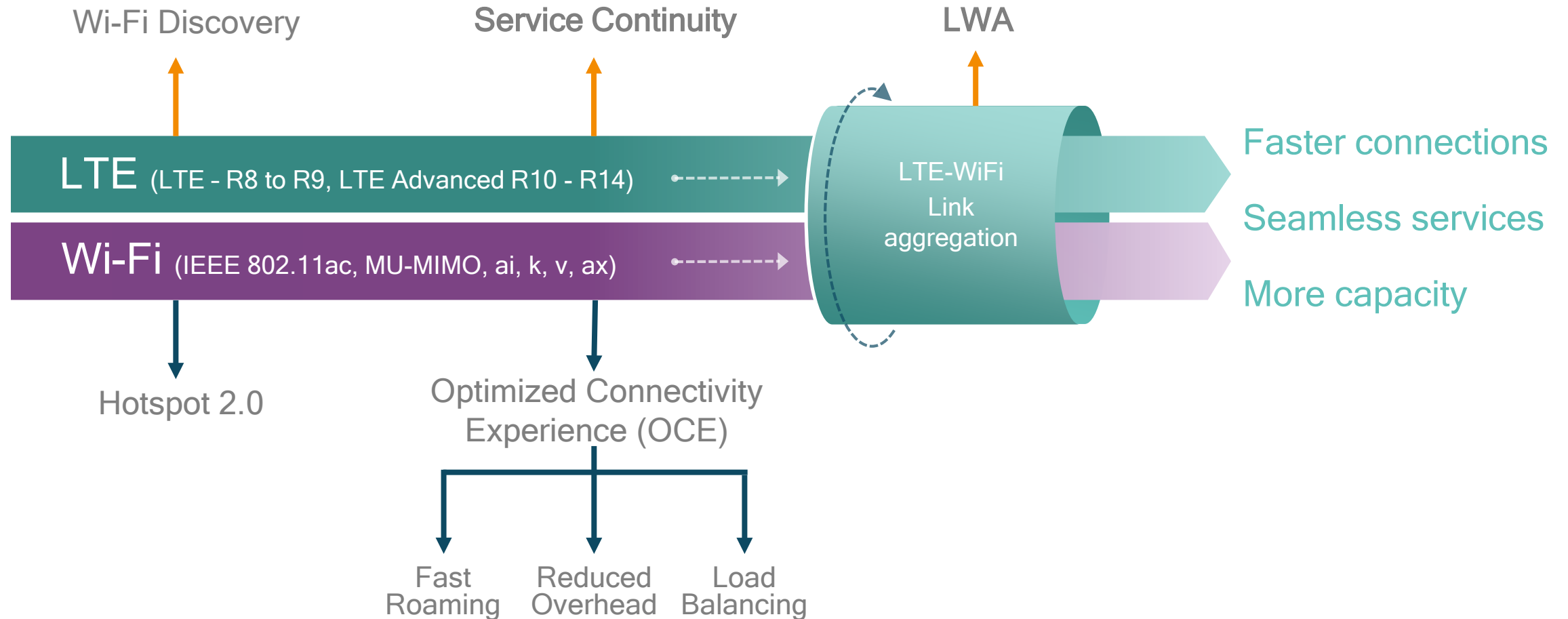
LTE - Wi-Fi link aggregation part of 3GPP Release 13



- **Seamless & robust 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 and Wi-Fi links

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

Also going beyond standards features—driving convergence down to the modem level



Qualcomm Product Commitment





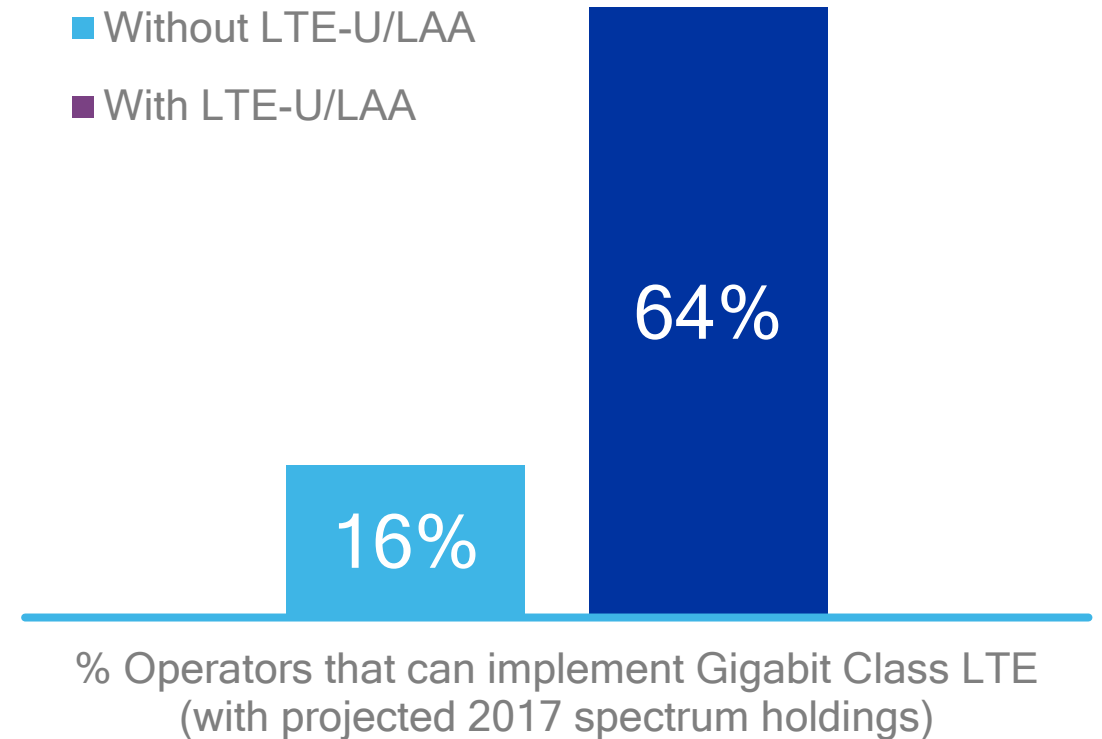
The first* cellular modem to support

Gigabit^{class} LTE

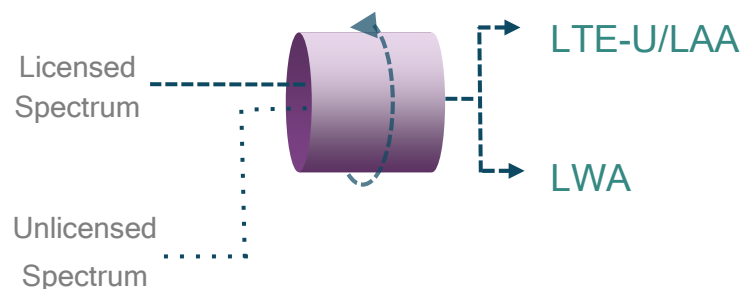
With Category 16 peak download speeds
of up to 1 Gbps

LTE-U/LAA globalize the possibility of Gigabit Class LTE

Operators with as little one block of 20 MHz licensed spectrum can deploy Gigabit Class LTE



Summary



Multiple solutions will coexist in unlicensed

Different solutions for different deployment scenarios with converged LTE - Wi-Fi solutions.

Fair coexistence between LTE and Wi-Fi is verified

LTE in unlicensed is designed to coexist fairly with Wi-Fi as shown in comprehensive over-the-air trials.

Gigabit Class LTE within reach

LTE in unlicensed spectrum will be supported in Qualcomm X16 LTE Modem solution

Thank you

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