Background on LTE-Unlicensed

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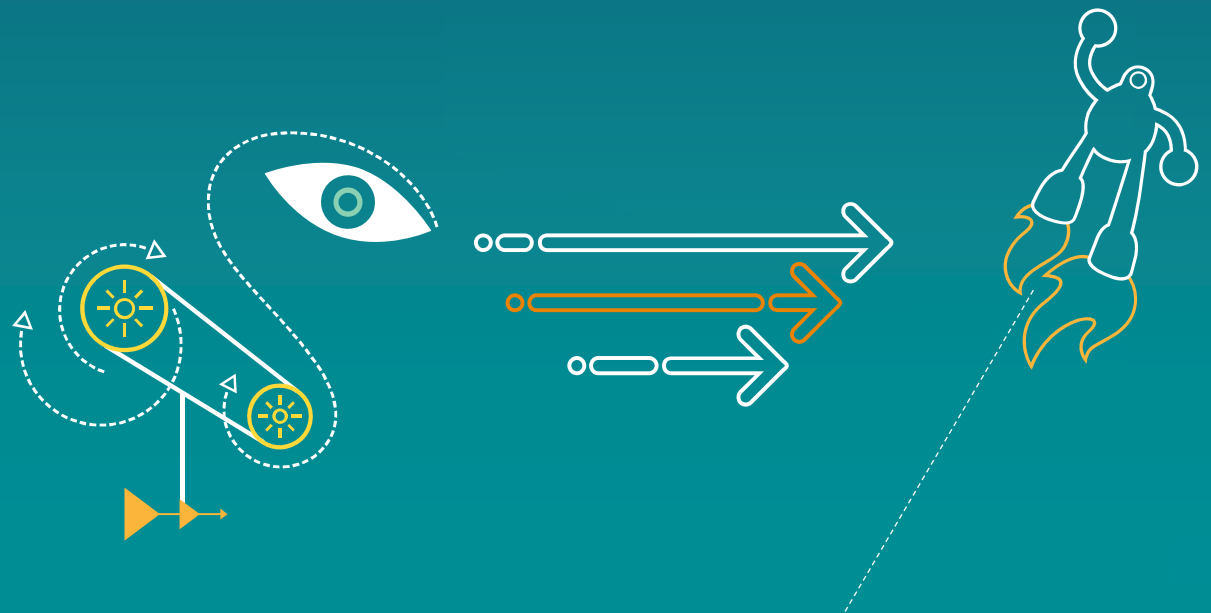
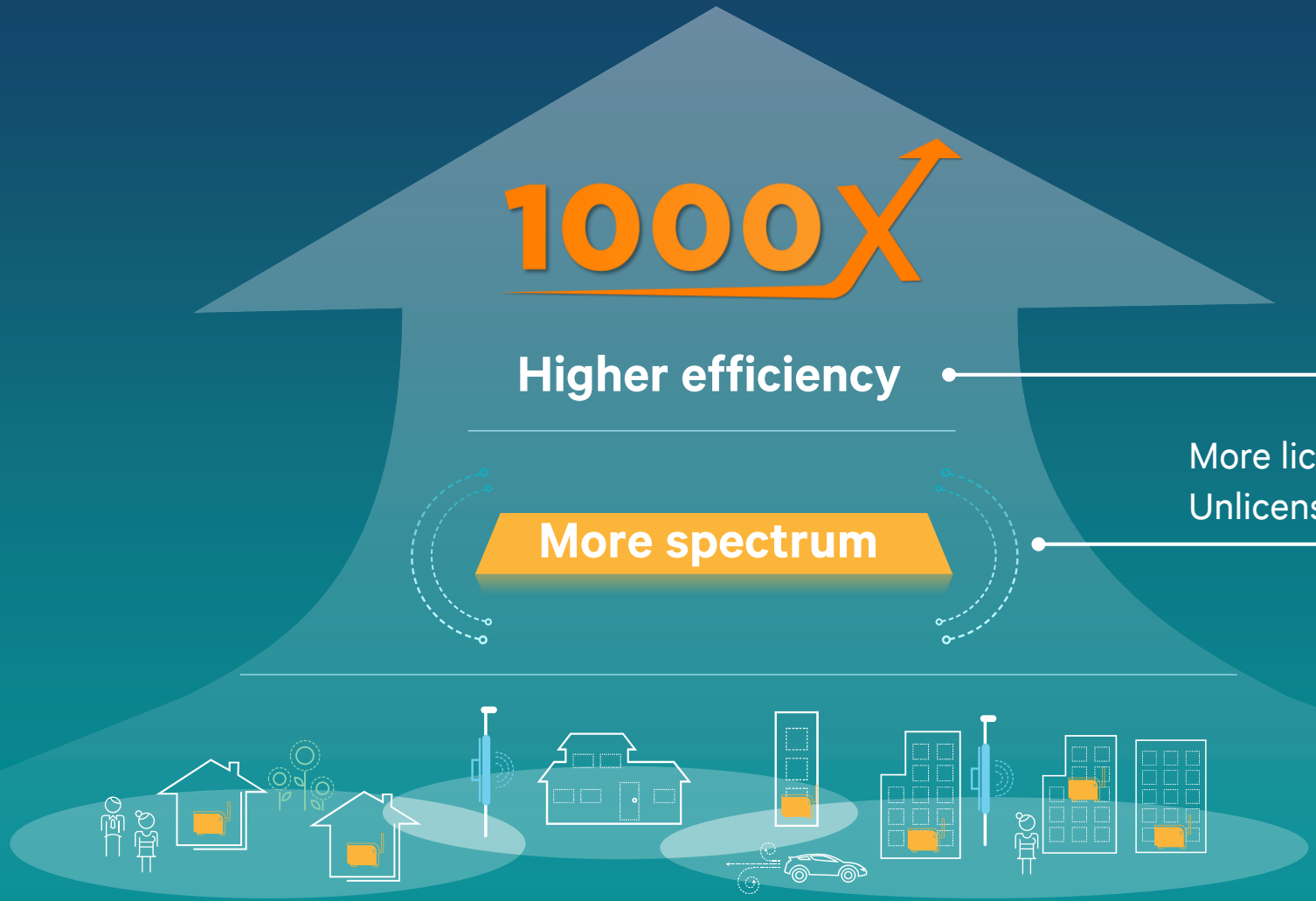


Making the best use of licensed and unlicensed spectrum



For both licensed & unlicensed spectrum

More licensed spectrum is top priority
Unlicensed also needed due to heavy usage

Technologies for hyper-densification

Multiple technologies will co-exist for best use of all spectrum

LTE in Licensed Spectrum

Licensed spectrum foundation, augmented with unlicensed spectrum solutions

Mobile broadband services for best performance and quality-of-experience

LTE Unlicensed

LTE-based technologies in unlicensed spectrum, LTE-U, LAA, MuLTEfire™

Broadens LTE ecosystem to enhanced and new deployment opportunities

Wi-Fi ac/ad/ax

802.11-based technology solely operating in unlicensed spectrum

Also evolving for enhanced performance and expanding to new usage models

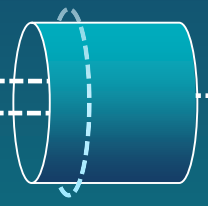
LTE Unlicensed: LTE-U/LAA aggregation with an LTE licensed spectrum anchor, whereas MuLTEfire can operate solely in unlicensed spectrum MuLTEfire is an initiative of Qualcomm Technologies, Inc.

Extending the benefits of LTE to unlicensed spectrum

Licensed Spectrum

Exclusive use

LTE Carrier Aggregation
with licensed anchor channel



Unlicensed Spectrum

Shared use

LTE-based technology
without licensed anchor channel

LTE-U[1] to boost downlink

Targeting mobile operators deployments in USA, Korea, India, etc. based on 3GPP Rel. 10/11/12

LAA (Licensed-Assisted Access)

Targeting mobile operator deployments in Europe, Japan, and beyond[2] based on 3GPP Rel. 13 and beyond

MuLTEfire

Broadening LTE technology and ecosystem to new deployment opportunities

[1] Downlink only in unlicensed spectrum (SDL). RF specs and coexistence tests defined by LTE-U forum: coexistence and fair sharing can be obtained using techniques such as channel selection and CSAT (Carrier Sensing Adaptive Transmission). [2] These regions mandate specific access procedures, including Listen Before Talk (LBT),. LAA R14 targets enhancements to support aggregation for both uplink and downlink

Ensuring fair coexistence between LTE unlicensed and Wi-Fi

Working together across the mobile and Wi-Fi industries

Minimum requirements → **Going above and beyond minimum requirements**

Spectrum regulations

- Power, bandwidth and emission levels
- Additional specific access procedures required in Europe and Japan (Listen Before Talk features)

Standards & specifications

- LTE-U for USA, Korea, India, other markets based on LTE R10/11/12[1]
- LAA for Europe, Japan and beyond defined in 3GPP R13[2]

Conformance testing

- Coexistence and fairness test
- Expected to be more rigorous than Wi-Fi testing today
- Still allowing for differentiation
- Example: LTE-U forum specifications

1 With dynamic channel selection and CSAT - Carrier Sensing Adaptive Transmission required in the small cell..
2 LAA Licensed Assisted Access, Work item approved in 3GPP R13 June 15. In addition, New RF band support (e.g. 5GHz) needed at both device and small cell

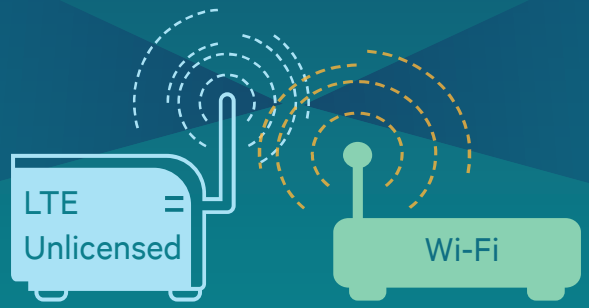
LTE Unlicensed development through industry collaboration

LTE-U Forum

Founding members Alcatel-Lucent, Ericsson, LGE, Qualcomm Technologies Inc., Samsung, Verizon all have stakes in LTE and Wi-Fi

Coexistence specs published March 2nd 2015, updated June based on feedback, e.g. adding uplink and VoIP test cases

Fair co-existence between Wi-Fi and LTE unlicensed



3GPP LAA

Being standardized in 3GPP release 13 for completion 1H 2016 (ASN.1 freeze)

Enhancements planned for release R14 and beyond

3GPP will develop coexistence / performance requirements and tests

Collaboration and engagement

- Presented LTE-U to Wi-Fi Alliance and IEEE at standards meetings
- An LTE-U workshop for key cellular and Wi-Fi vendors/operators was held on May 28, 2015 with deep dive of technology
- Further collaboration on coexistence with industry is ongoing—one-on-one and in industry groups
- Dialogue between 3GPP and IEEE802.11 & WFA throughout the LAA standard's development via presentations & liaison statements
- Open industry LAA workshop held 8/29/2015 in Beijing with presentations from IEEE 802.11, WFA and other key stakeholders
- Started dialogue between 3GPP and WFA on coexistence testing

Mingxi Fan
VP, Engineering
Qualcomm Technologies, Inc.

Achieving fair coexistence for LTE Unlicensed and Wi-Fi

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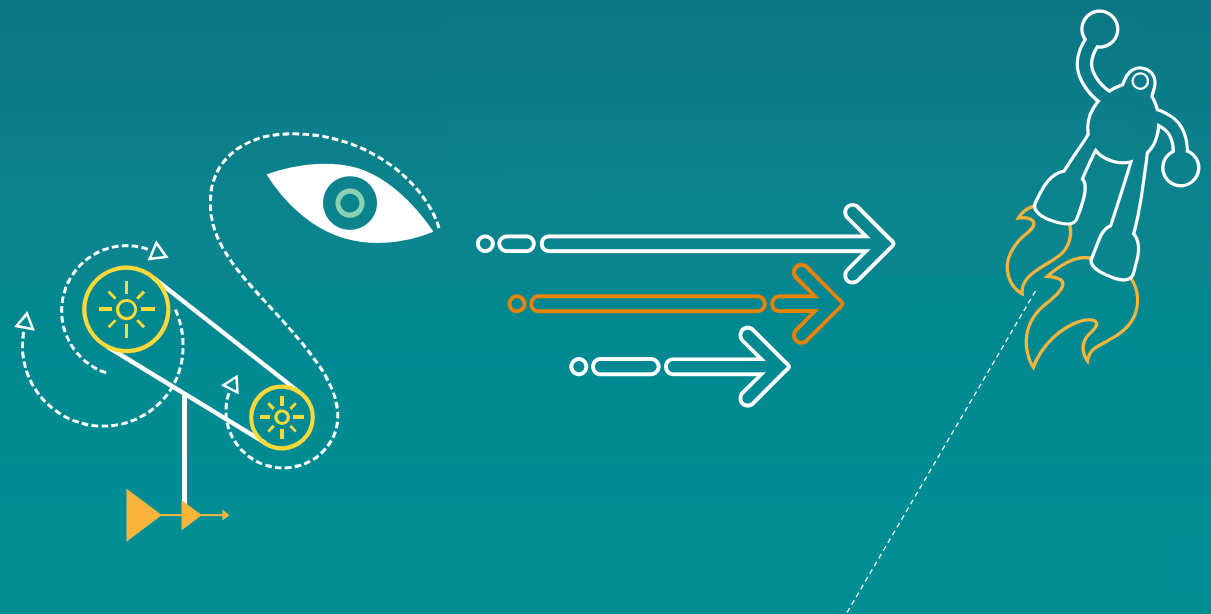
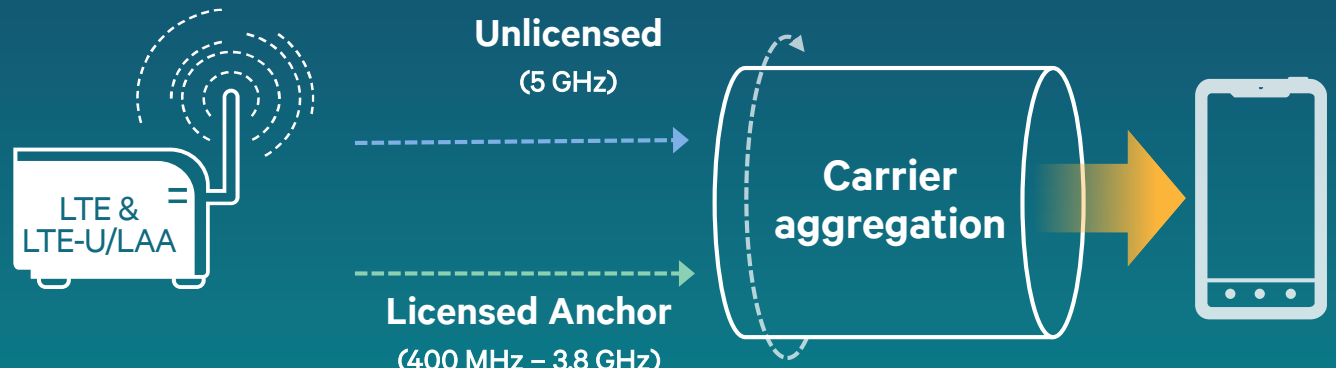


LTE Unlicensed in 5 GHz benefits consumers



LTE Unlicensed small cell

- LTE-U: Supplemental Downlink (SDL) to boost downlink [1]
- LAA: Carrier aggregation to boost downlink initially, then both downlink and uplink [2]
- Later LAA phases: aggregation across non-collocated nodes with dual-connectivity

~2x capacity and range
Compared to Wi-Fi[3]

Enhanced user experience
Licensed anchor for control and mobility

Single unified LTE network
Common management

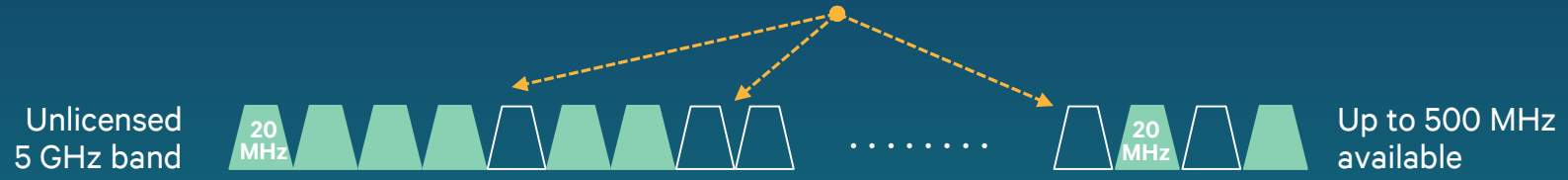
A good Wi-Fi neighbor
In many cases, better neighbor to Wi-Fi than Wi-Fi itself

[1] LTE-U and LAA R-13 will be downlink only. Both TDD or FDD aggregation is possible with SDL; [2] Target for R14 LAA using TDD + TDD aggregation, or FDD + TDD aggregation using TDD 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 Unlicensed protects Wi-Fi & shares spectrum fairly

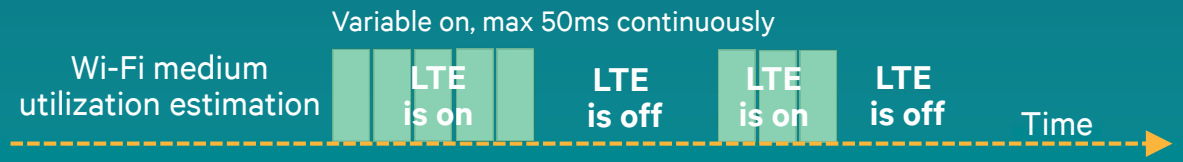
1 Select clear channel: Dynamically avoid Wi-Fi



2 If no clear channel: Fair sharing with Wi-Fi

LTE-U adaptive duty cycle (CSAT)[1]

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



LAA Listen Before Talk (LBT) with adaptive utilization[2]

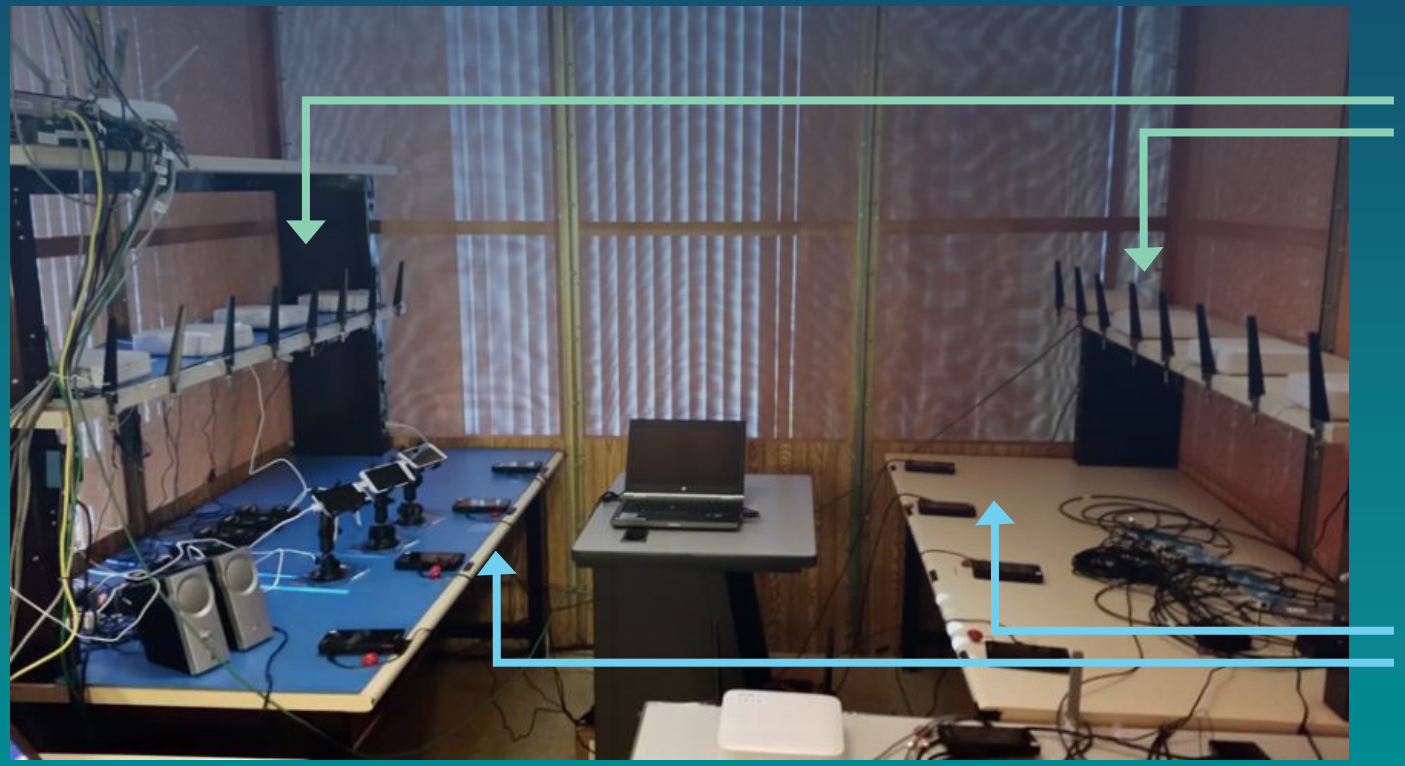
for deployments in Europe, Japan and beyond using 3GPP Rel. 13 LAA

3 Release unlicensed channel at low traffic

[1] CSAT - Carrier Sensing Adaptive Transmission required in the small cell Meeting regulatory requirements, in addition ensures fairness as defined by LTE-U forum
[2] Part of 3GPP Rel 13, Licensed Assisted Access (LAA) for regions with specific access procedures and CCA Clear Channel Assessment, aka Listen Before Talk (LBT)

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

Qualcomm Technologies' LTE/Wi-Fi coexistence test chamber



Hyper dense network

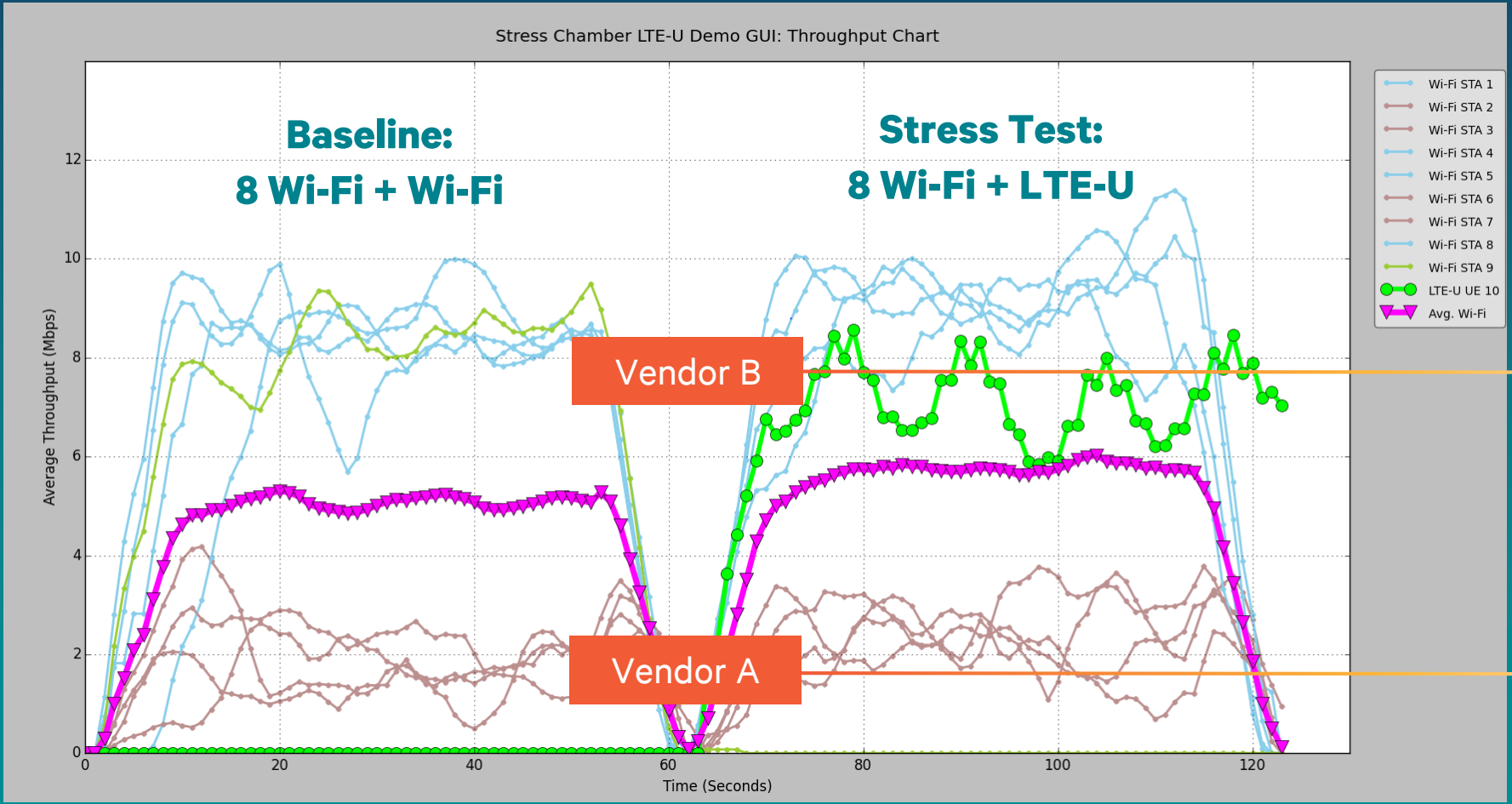
- Up to 9 Access Points (AP) placed ~1m apart
- All APs set to the same channel
- Commercial, off-the-shelf Wi-Fi and test LTE-U APs

Extreme interference for devices

- No isolation between neighboring APs and devices

Implementation variation among Enterprise Wi-Fi vendors

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



Mixture of Vendor A and B's enterprise Wi-Fi APs

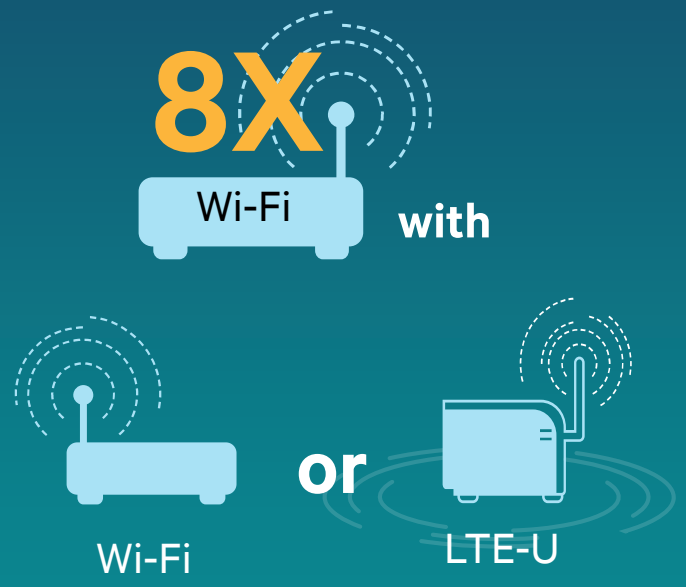
Wi-Fi vendor B more aggressive

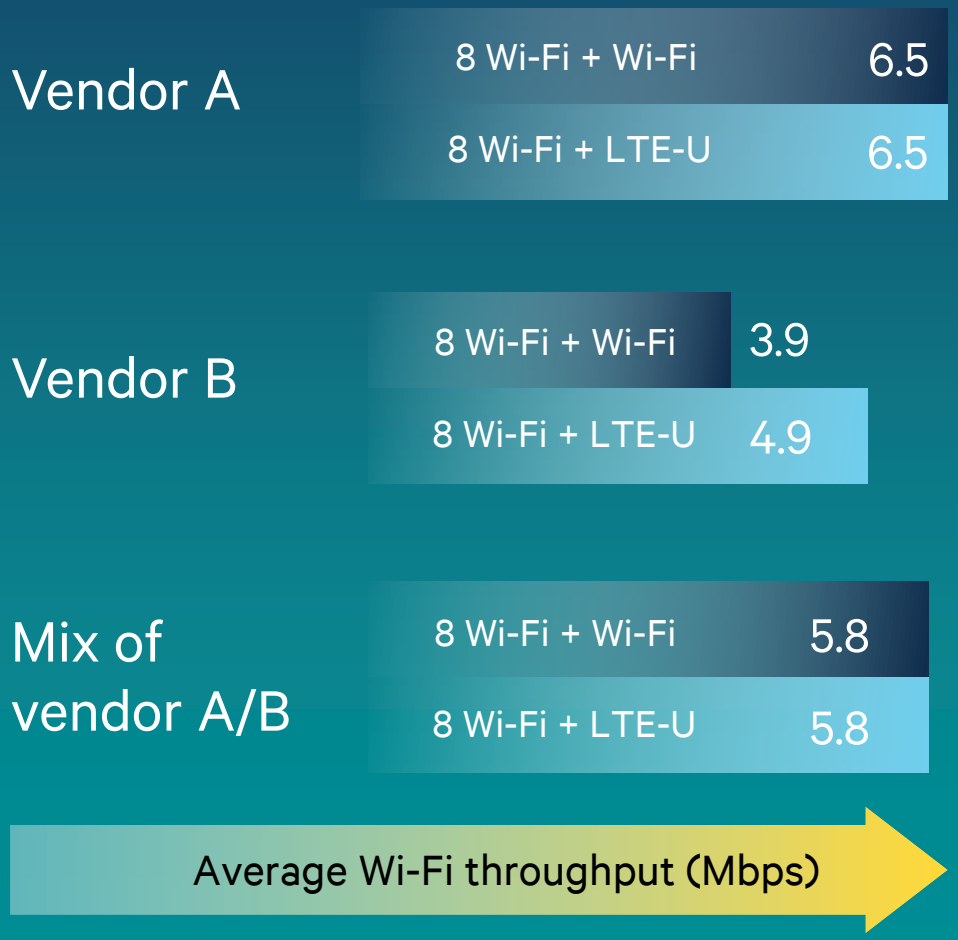
Wi-Fi vendor A less aggressive

Vendor A and B enterprise grade Wi-Fi APs with controller. 8 Aps with test AP—Wi-Fi or LTE-U

LTE-U is a good neighbor regardless of Wi-Fi vendor

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





LTE-U maintains overall Wi-Fi performance

Vendor A and B enterprise grade Wi-Fi APs with controller. 8 Aps with test AP—Wi-Fi or LTE-U

Significant implementation variation in retail Wi-Fi access point

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

Mix of vendors in a network of 4 Wi-Fi APs

Wide variation—also without most aggressive Wi-Fi AP

5 top-selling retail APs determined from top industry magazines and online-retailers

APs				Throughput (Mbps)				Aggregate (Mbps)
AP 1	AP 2	AP 3	AP 4	AP 1	AP 2	AP 3	AP 4	
A	B	C	D	40.9	3.9	5.6	3.4	53.7
B	C	D	E	19.4	8.2	7.4	12.9	47.9
C	D	E	A	3.7	2.2	3.6	49.8	59.3
D	E	A	B	4.8	4.6	40.8	4.7	54.9
E	A	B	C	3.9	49.0	2.4	4.3	59.6

One Wi-Fi AP grabbing ~10x more resources

Product diversity of 5 OEMs and 3 chipset-vendors. One common STA (11ac, 1x1) – a top-selling mobile-device used for all cases

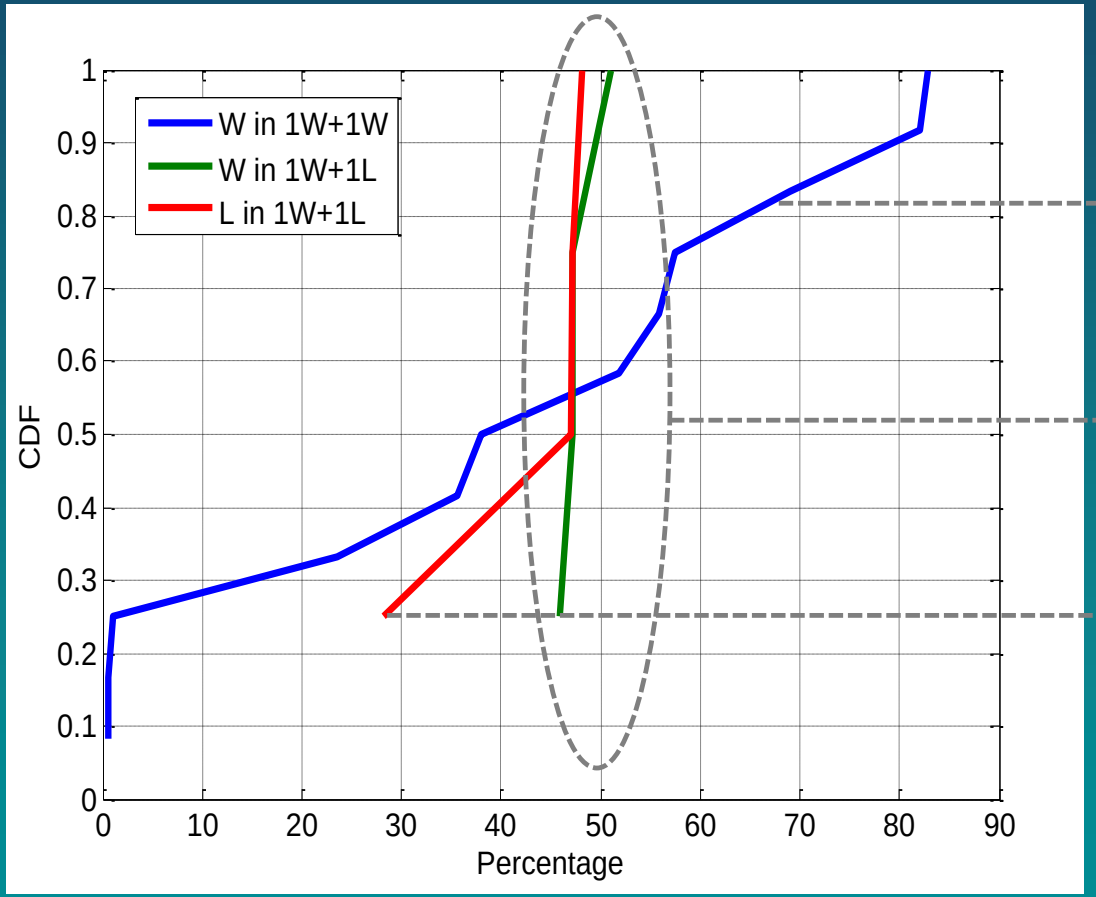
LTE-U ensures fair time sharing of the unlicensed channel

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

Or

Average across 4 Wi-Fi AP models

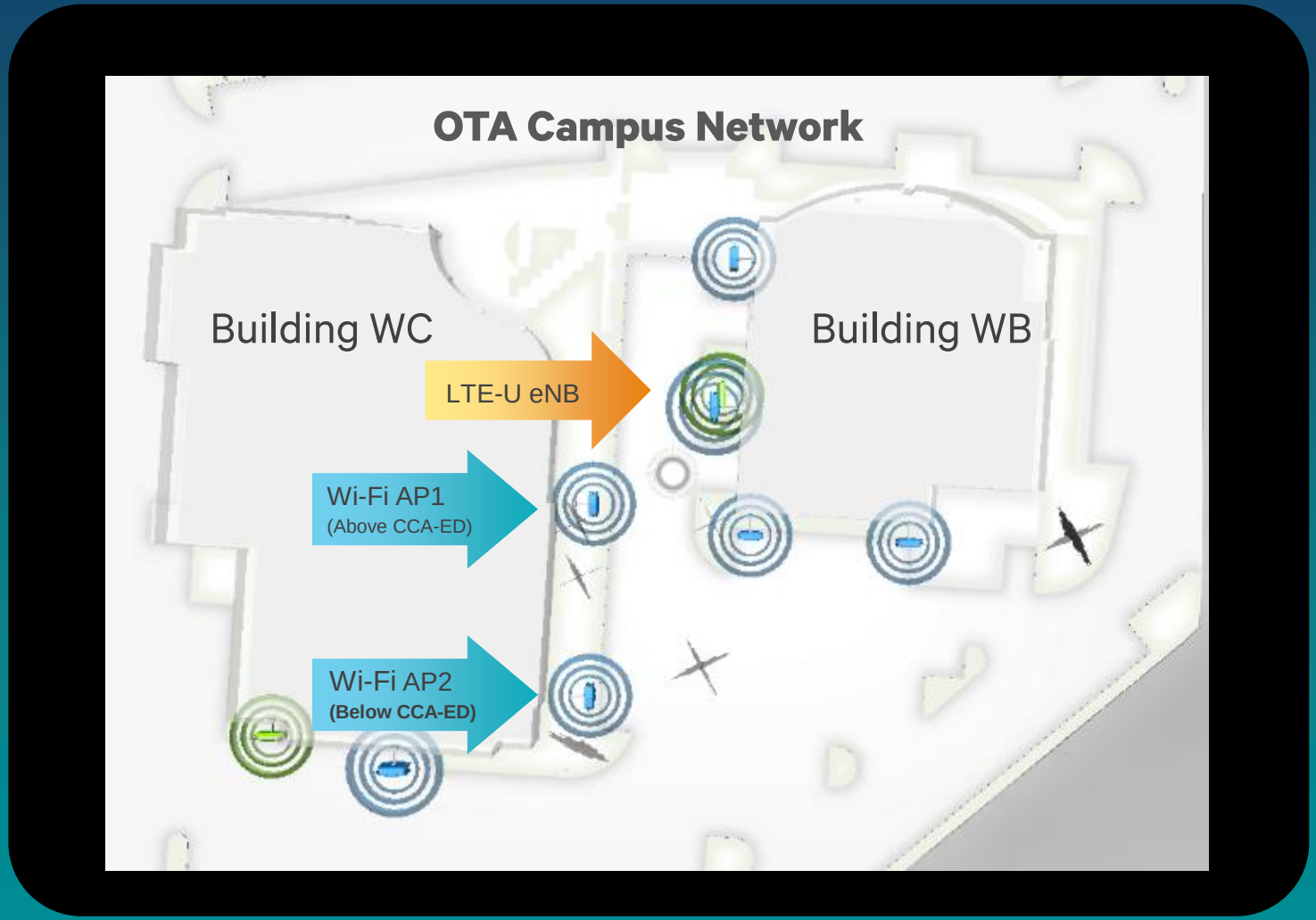
Duty cycle distribution



- Wide variation in Wi-Fi to Wi-Fi sharing
- LTE-U ensures a fair ~50% sharing
- Anomaly due to one Wi-Fi not following spec

Testing pair-wise airtime sharing across 4 Wi-Fi AP models and between Wi-Fi/LTE-U Points corresponding to all 4 Wi-Fi AP models

Over-the-air campus network for testing LTE-U



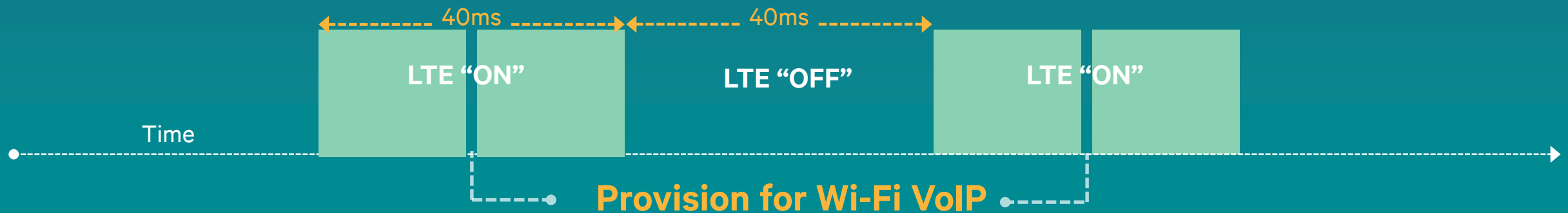
Note: Wi-Fi AP 1 is above CCA-ED (CCA energy detect level at -62dBm where Wi-Fi backs off for other non-Wi0Di users). and Wi-Fi AP 2 is below CCA-ED,, which is used for some of the following test to show that LTE-U CSAT works well below Wi-Fi's ED

Over-the-air Wi-Fi VoIP coexistence and quality ensured

Using Qualcomm Technologies' over-the-air outdoor campus network

			Probability of Jitter > 50ms	Packet loss rate
Downlink (Max one-way delay)	Wi-Fi + Wi-Wi	48ms	No change 0%	No change 0%
	Wi-Fi + LTE-U	42ms		
Uplink (Max one-way delay)	Wi-Fi + Wi-Wi	40ms	Increased to 0.76%	Increased to 0.08%
	Wi-Fi + LTE-U	50ms		

Compliant with WFA's requirements[1]

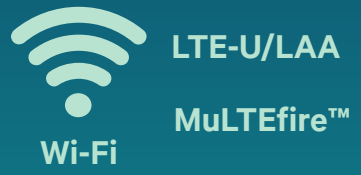


2ms puncturing introduces gaps to help Wi-Fi flush delay-sensitive data that may be queued due to LTE-U

1 Compliant with Wi-Fi Alliance's VoIP Enterprise specification: One way Delay < 50 ms maximum, maximum Jitter < 50ms maximum, Packet loss < 1%, Consecutive lost packets, no more than 3. Overall statics from 5 pairs of WiFi VoIP with LTE-U Presence.

LTE Unlicensed is a good neighbor to Wi-Fi

1



Fair coexistence with Wi-Fi a key principle in the design of LTE unlicensed

2

Extensive LTE-U over-the-air testing in lab/field proves fair coexistence with Wi-Fi

3

LTE-U Forum

3GPP

Extensive collaboration on coexistence across mobile and Wi-Fi industries.

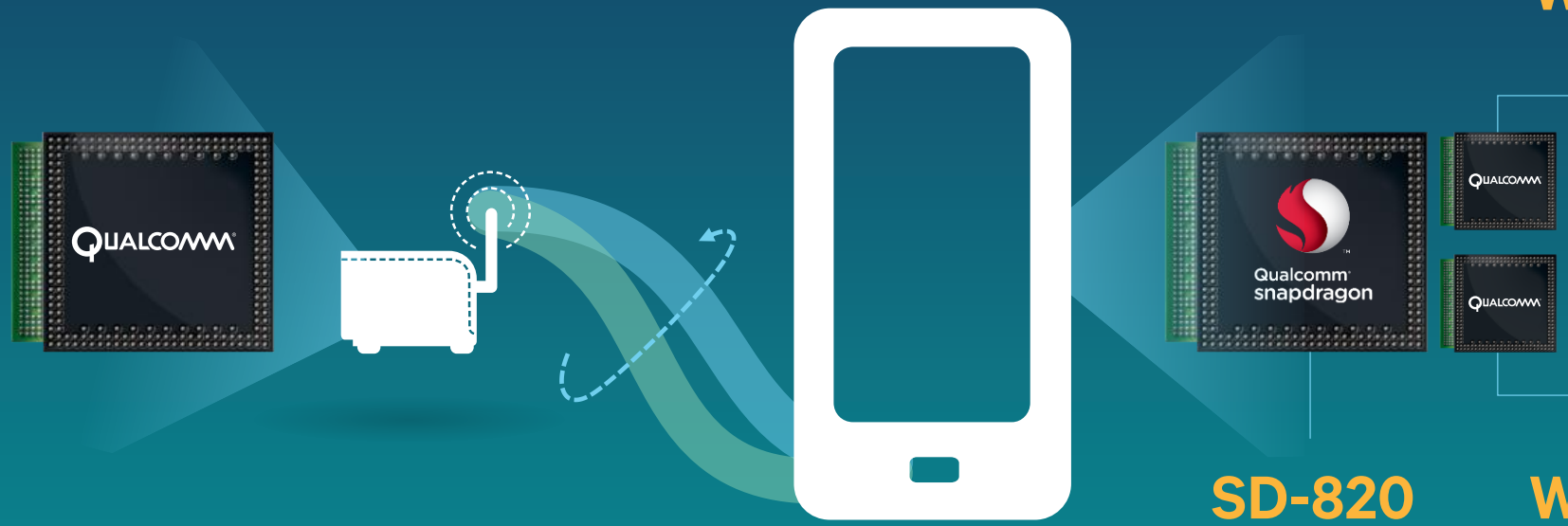
4

Committed to LTE Unlicensed, the Wi-Fi evolution, and LTE – Wi-Fi convergence solutions

FSM99xx and X12 LTE spearheading LTE-U commercialization

Industry's first LTE-U small cell and LTE-U mobile device solutions

FSM99xx
Converged LTE/LTE-U
Small Cell SoC



WTR3925

SD-820
X12 LTE

WTR3950
LTE Transceiver with
5 GHz support

More network capacity for all users

Enhanced user experience

Single unified network

A good neighbor to Wi-Fi

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