April 2014

Spectrum

The Lifeblood of Mobile Connectivity

QUALCOMM®

Spectrum is the lifeblood of mobile connectivity

1

3G/4G

Licensed spectrum is the foundation for mobile broadband, ensuring predictable performance and seamless mobility

2

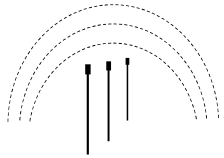
Wi-Fi

Unlicensed spectrum is the foundation for local area broadband, enabling simple deployment to provide local coverage

3

Solving the 1000x mobile data challenge will require the best use of all spectrum, licensed and unlicensed

4



Solving 1000x will also require innovative solutions to make use of under-utilized bands and aggregate all spectrum resources

5

QUALCOMM

Qualcomm is a leader in technologies for licensed and unlicensed spectrum, with solutions to make the best use of all spectrum

Connectivity is the foundation of a great mobile experience

Connect Reliably
Talk and browse without interruption with more bars in more places

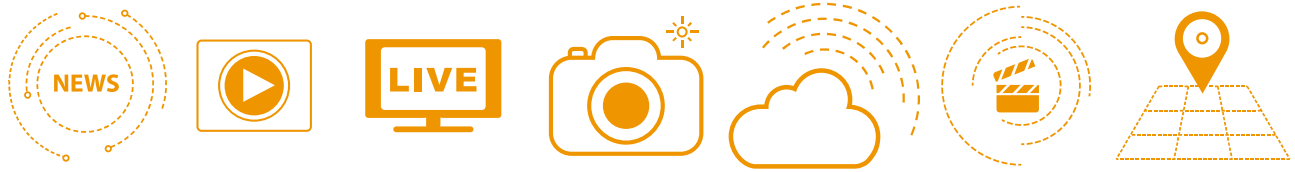
Connect Real-Time
Get instant access to content with less delay for “always-on” experience

Connect On-the-Go
Talk and browse with seamless mobility anywhere you get a signal

Connect Fast
Stream, surf, upload, and download with fast, predictable data rates

Connect Longer
Go longer without plugging in with improved battery efficiency

Delivering rich mobile broadband experiences



Spectrum is the lifeblood of mobile connectivity

More
Spectrum

→ **More**
Capacity

→ **Faster**
Data Rates

Richer content

Bestseller example (more video):

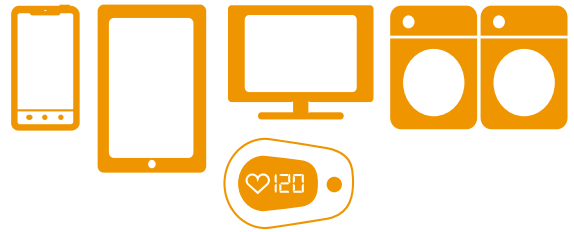
5.93 GB
Movie (High Definition)

2.49 GB
Movie (Standard Definition)

0.0014 GB
Homepage

1.8 GB
Game for Android

0.14 GB
Soundtrack



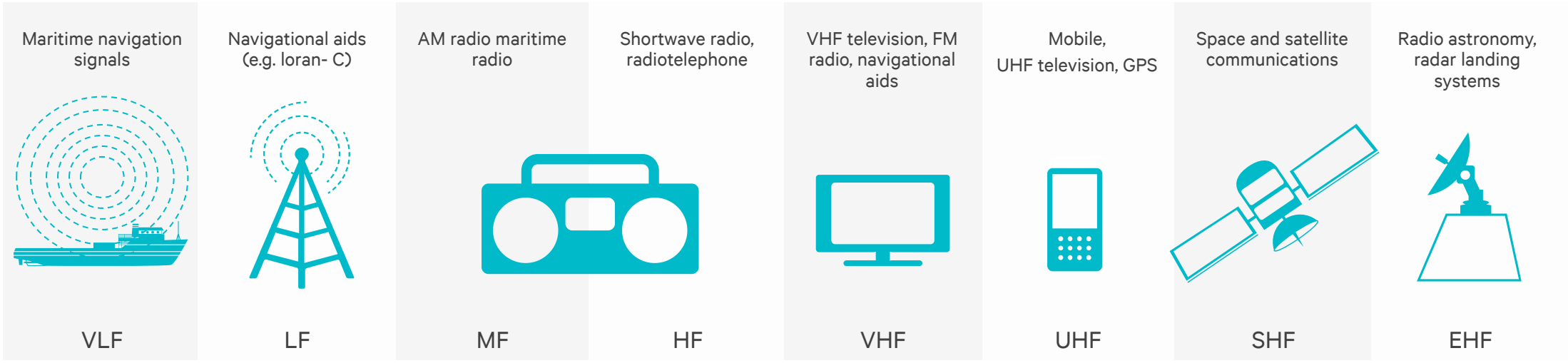
More connections

~25 Billion
Interconnected device forecast in 2020[1]

~7 Billion
Cumulative smartphone forecast between 2013-2017[2]

[1] Machina Research, Oct. '12; [2] Gartner, Sep. '13

Spectrum is the airwaves that all wireless communications travel



Spectrum is allocated by local governments

Spectrum is divided into frequency ranges (bands) for different types of wireless communication (e.g., 87.5 to 108.0 MHz for FM radio)

Spectrum is a finite resource

UHF spectrum is best suited for macro mobile communications; must be shared with other government and commercial uses

Mobile uses different spectrum for different types of access

Unlicensed Spectrum

Spectrum shared by multiple technologies

(Wi-Fi, LTE, BT & others)

Licensed Spectrum

Cleared spectrum or Authorized Shared Access (ASA) for exclusive use

(Mobile 3G/4G technologies)

Foundation of Local Area Broadband

Simple Deployment

Short Range, Local Coverage

Residential, Enterprise, Connected Home

Foundation of Mobile Broadband

Predictable Performance, Subscription-based

Ubiquitous Coverage

Seamless Mobility

Unlicensed spectrum is the foundation of local area broadband

Wi-Fi delivers portable, high-speed internet access for enterprise and the connected home

Simple Deployment

User-deployed

Access Point + Backhaul = Local Area Access

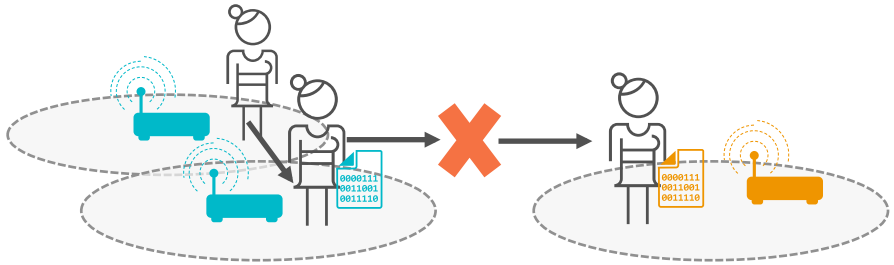
Local Coverage

Short Range, Portability

1 Watt Max Transmit Power

Higher Spectrum Bands
E.g. 2.4 GHz and 5 GHz

Short range, ideal for local access



Portability within local network
Access may need to be reestablished in new networks[1]

High Throughput

Wide Spectrum Bands

Wider spectrum bands available especially around 5 GHz

Excellent throughput in ideal conditions

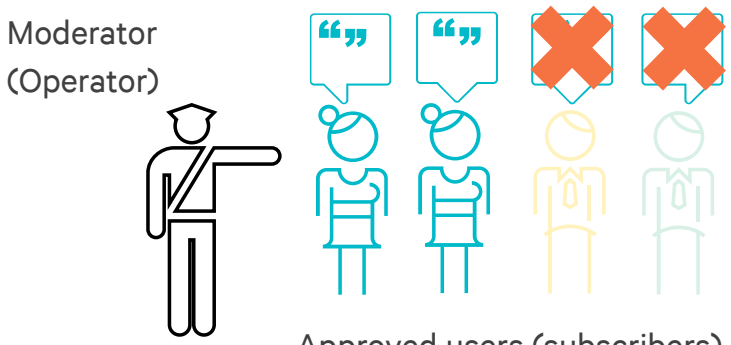
[1] New Passpoint™ / Hotspot 2.0 Wi-Fi technologies are providing solutions to streamline network access in hotspots and eliminate need for users to find and authenticate each time they connect

Licensed spectrum is the foundation of mobile broadband

Mobile 3G/4G delivers reliable, high-speed internet access while on-the-go

Predictable Performance

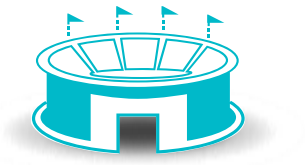
Exclusive Use



Approved users (subscribers) only

Coordinate before/while transmitting data

Demanding applications



Hyper-dense environments

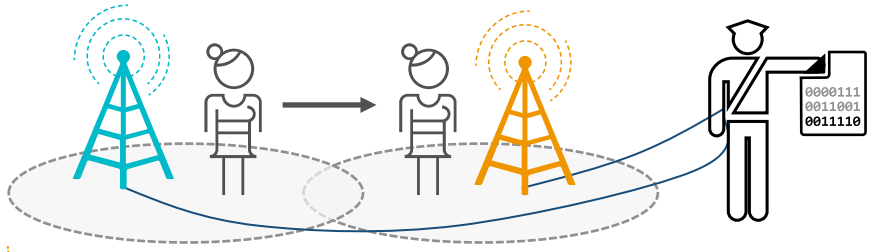
Seamless Mobility

Coordinated Network

60 Watt Max Transmit Power

Low and High Spectrum Bands
700MHz to 3800 MHz

Short to very long ranges, from small to macro cells

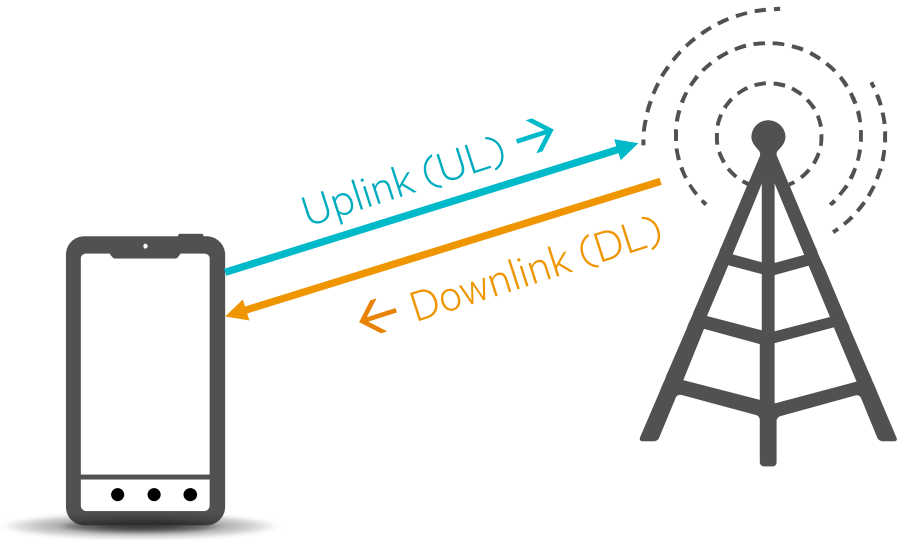


Seamless access and seamless handoffs

Anywhere you get a signal

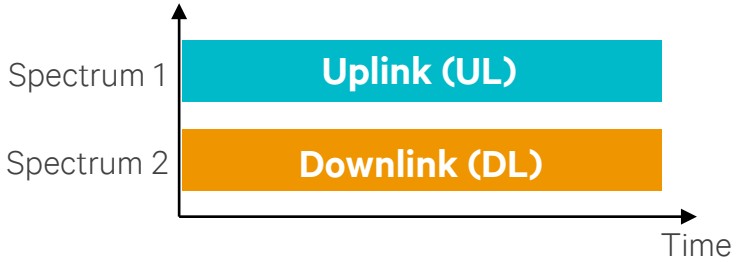
While on-the-go

Mobile licensed spectrum may be paired or unpaired



Frequency Division Duplex (FDD)

Paired spectrum



Time Division Duplex (TDD)

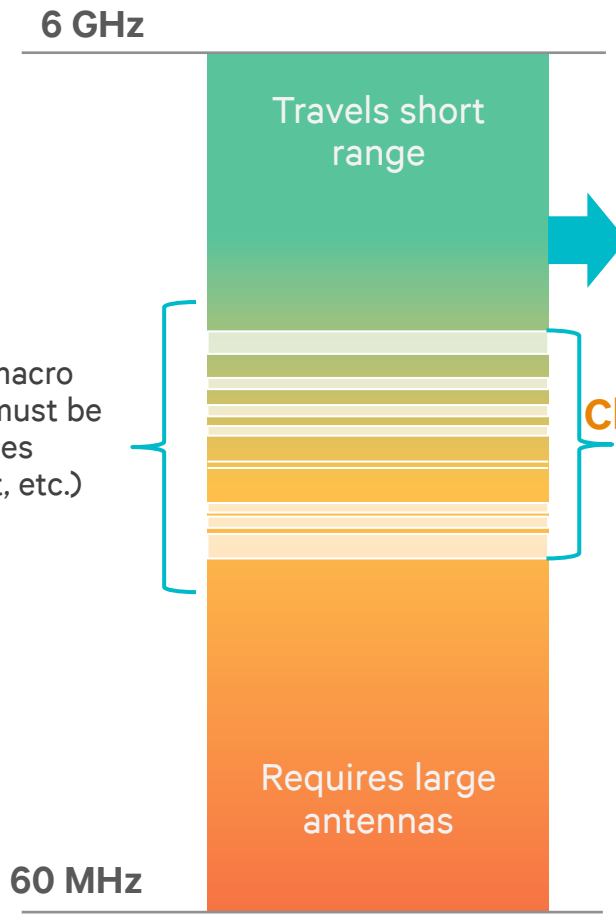
Unpaired spectrum

LTE is one global standard for paired and unpaired spectrum

Common LTE FDD and LTE TDD technology ecosystem, common products

The same 3GPP specifications for LTE FDD and LTE TDD

Mobile licensed spectrum is a finite resource – A crucial ingredient for 1000x



Exploring higher spectrum bands suitable for small cell coverage (e.g., 3.4 to 3.8 GHz)

Spectrum suitable for macro mobile communications must be shared with other uses (government, broadcast, etc.)

Cleared Spectrum for Mobile 3G/4G

Industry preparing for

1000x

data traffic growth[1]

Richer content

more video

More devices

everything connected

[1] 1000x would be e.g. reached if mobile data traffic doubled ten times, but Qualcomm does not make predictions when 1000x will happen, Qualcomm works on the solutions to enable 1000x

Rising to meet the 1000x mobile data challenge

3 **Use spectrum more efficiently** (bps/Hz)

Continue to evolve 3G, 4G LTE, and LTE Advanced, plus technology enhancements like LTE Direct and LTE Broadcast

2 **Use more spectrum** (Hz)

More licensed spectrum is industry's top priority, but also leveraging unlicensed spectrum opportunistically

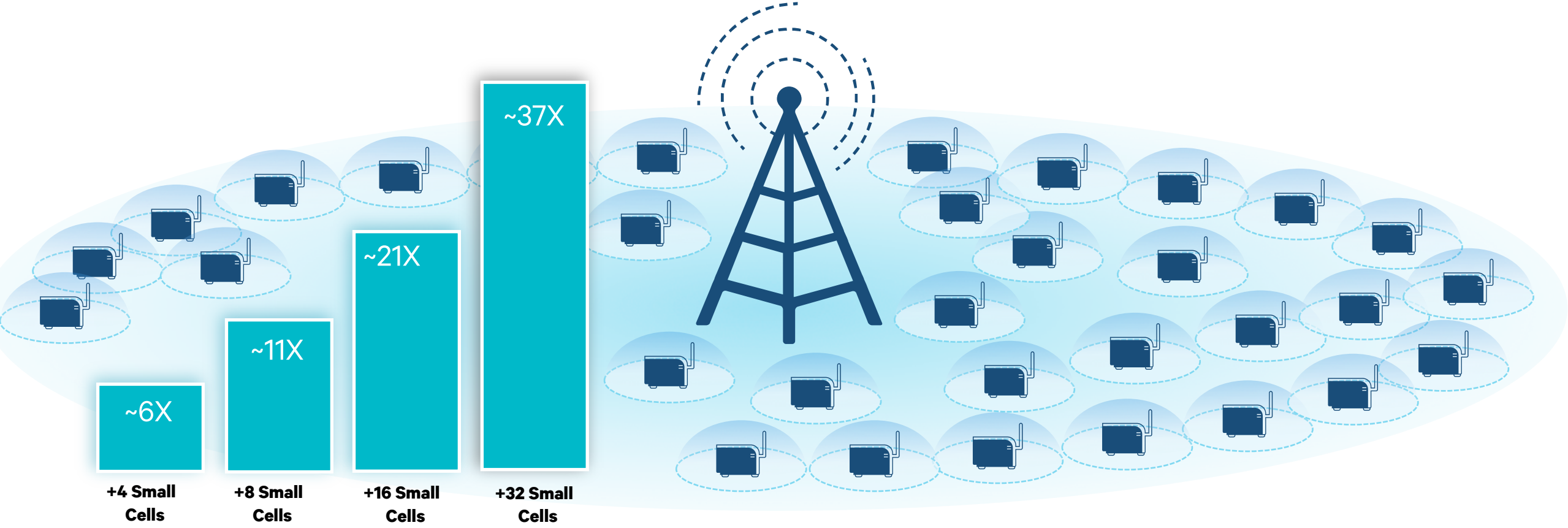
1 **Re-use spectrum** (bps/Hz/km^2)

Deploy hyper-dense heterogeneous networks with small cells everywhere

More Small Cells is Key to 1000x

Small cells everywhere are the foundation of 1000x

Re-use spectrum with hyper-dense heterogeneous networks anchored in licensed spectrum

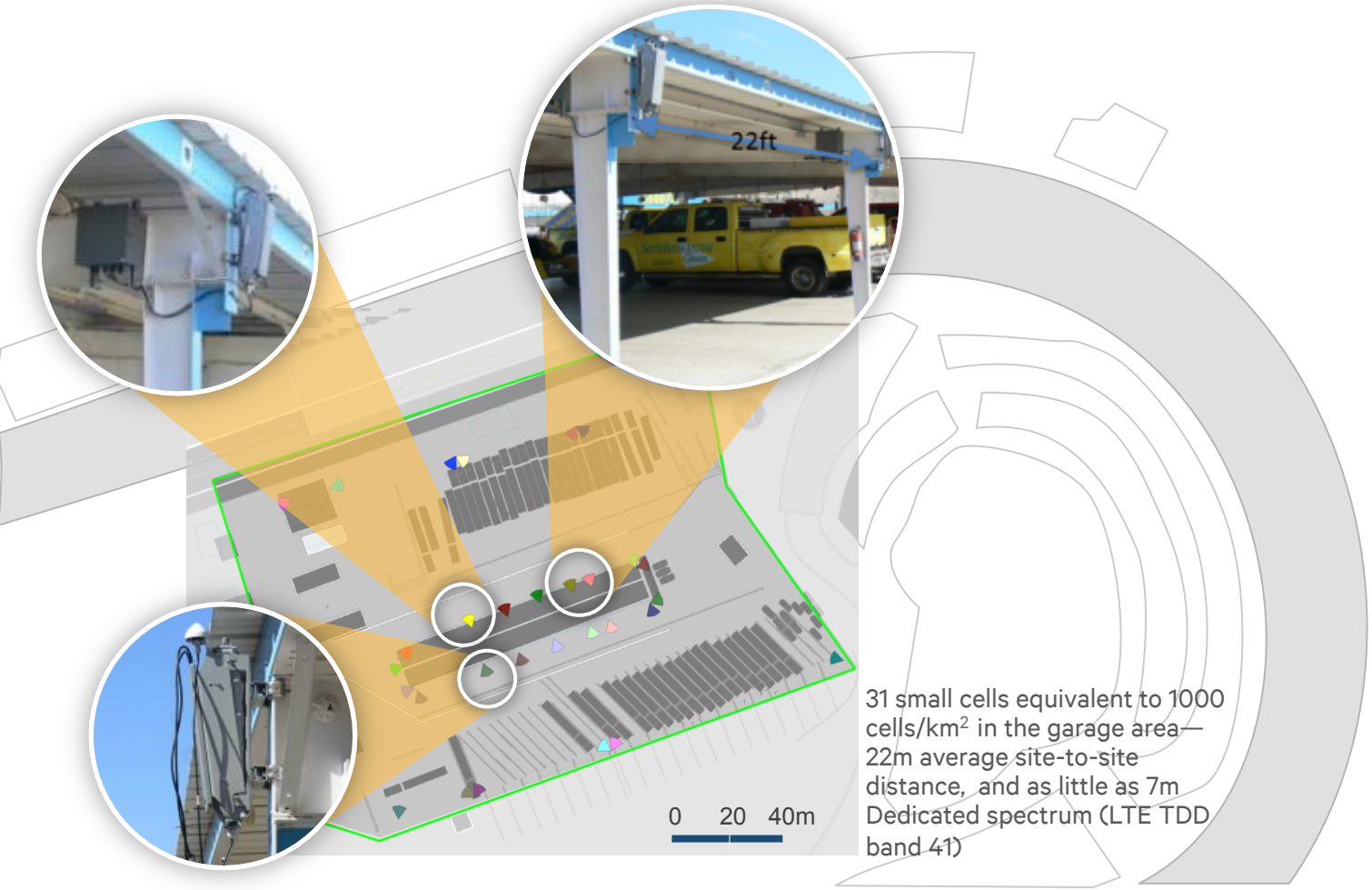


Capacity scales with small cells added[1]

Thanks to exclusive use of licensed spectrum enabling interference management

[1] Assumptions: LTE Advanced with 2x Spectrum added. Pico type of small cell, 10MHz@2GHz + 10MHz@3.6GHz,D1 scenario macro 500m ISD, uniform user distribution scenario. Gain is median throughput improvement, from baseline with macro only on 10MHz@2GH, part of gain is addition of 10MHz spectrum. Users uniformly distributed—a hotspot scenario could provide higher gains. Macro and outdoor small cells sharing spectrum (co-channel)

Bringing 1000x closer to reality: Hyper-dense small cell deployments



31 small cells equivalent to 1000 cells/km^2 in the garage area—22m average site-to-site distance, and as little as 7m Dedicated spectrum (LTE TDD band 41)

World's densest LTE outdoor network[1]

Extreme localized data demand, challenging RF conditions

40x more capacity than alt. solutions

Compared to traditional portable macro solution[2]

Enabled by UltraSON™

Unplanned deployment, robust mobility, reliable user experience

UltraSON is a product of Qualcomm Technologies, Inc.

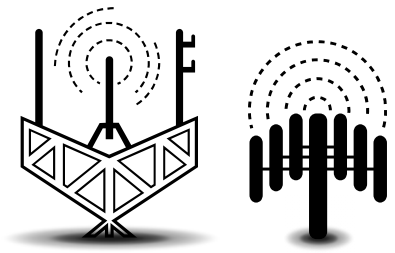
[1]World's densest outdoor LTE small cell network to Qualcomm technologies knowledge. [2]Compared to a Portable 'Capacity on Wheels' site. Sprint/Nascar/Airspan/Qualcomm small cell demo took place March 2nd 2014 at the Phoenix international raceway

We need to make best use of all available spectrum for 1000x

Use more spectrum (Hz) with more licensed spectrum as industry's top priority

Licensed Spectrum

Auctions of cleared spectrum for Mobile 3G/4G

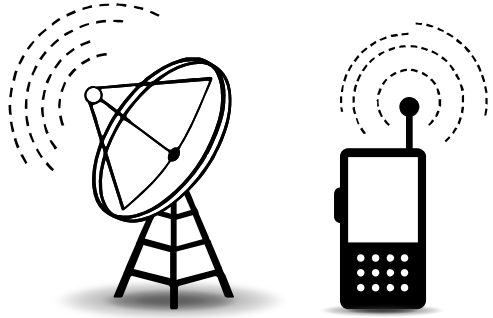


Exclusive use

Industry's top priority, ensures quality of service (QoS), mobility and control

Shared Licensed Spectrum

Complementary licensing for 3G/4G: Authorized Shared Access (ASA)

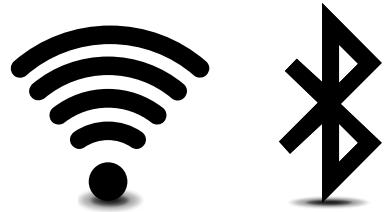


Shared exclusive use

ASA required when government spectrum cannot be cleared within a reasonable timeframe, or at all locations

Unlicensed Spectrum

Multiple technologies (Wi-Fi, LTE, BT & others)



Shared use

Unpredictable QoS, good for local area access and opportunistic use for mobile broadband

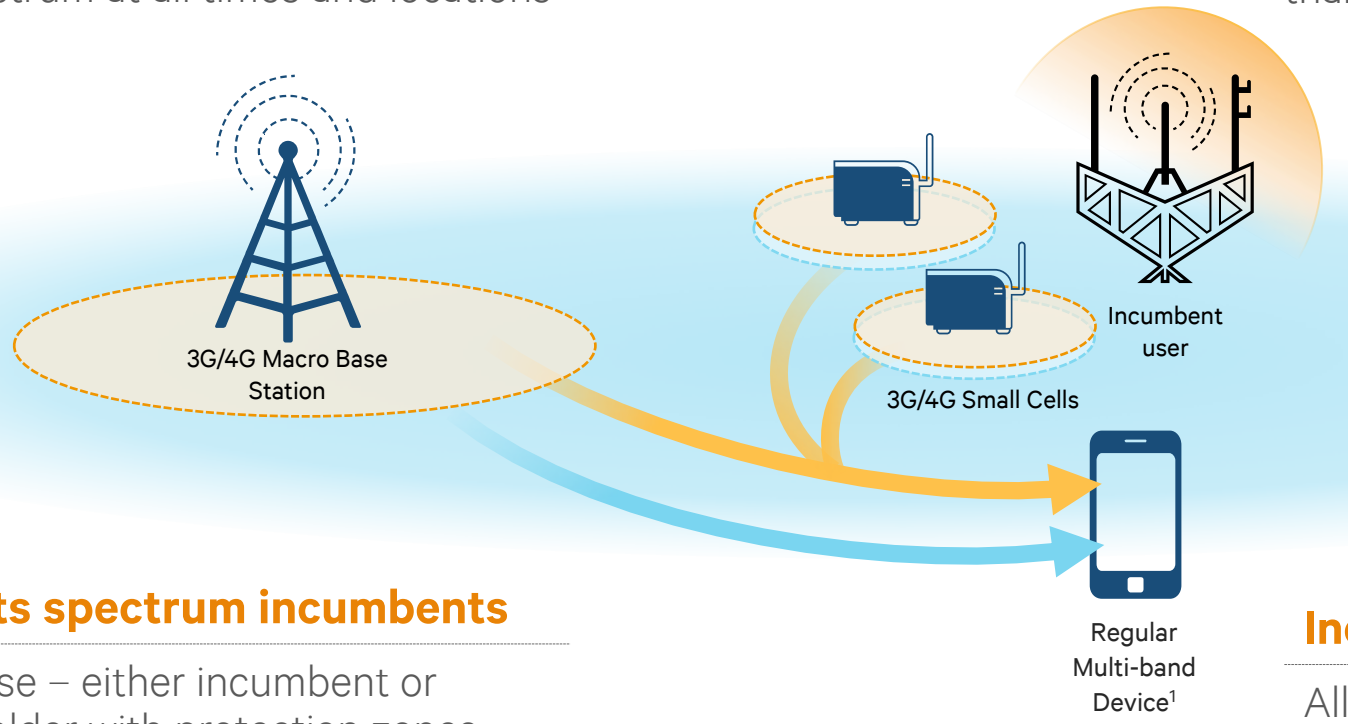
ASA leverages underutilized spectrum for exclusive use

Exclusive Use

Incumbents (i.e., government) may not use spectrum at all times and locations

Used in both macros and small cells

Small cells can be closer to incumbent than macros



Protects spectrum incumbents

Binary use – either incumbent or rights holder with protection zones

Incentive-based cooperation model

Allows incumbents to monetize unused spectrum

[1] No device impact due to ASA, just a regular 3G/4G device supporting global harmonized bands targeted for ASA. Carrier aggregation would be beneficial to aggregate new ASA spectrum with existing spectrum, but is not required.

Bringing 1000x closer to reality
Implementing ASA/LSA[1] in Europe and United States

POLICY

Endorsed
by 28 EU member states Nov '13

Evaluation by NTIA

Endorsed by 28 EU member states Nov '13

REGULATORY

Defined by CEPT
in report published in Feb '14[2] for harmonizing 2.3 GHz[3]

CEPT ECC
Electronic Communications Committee

Proposed by FCC

To make 3.5GHz[4] band dedicated to licensed shared access for mobile broadband

FCC

STANDARDS

Specified by ETSI
Currently working on requirements

ETSI
World Class Standards

PROOF OF CONCEPT

Demonstrated
by many infra/device vendors; 2.3 GHz and 3.5 GHz demos at MWC Feb '14

GSMA MOBILE WORLD CONGRESS

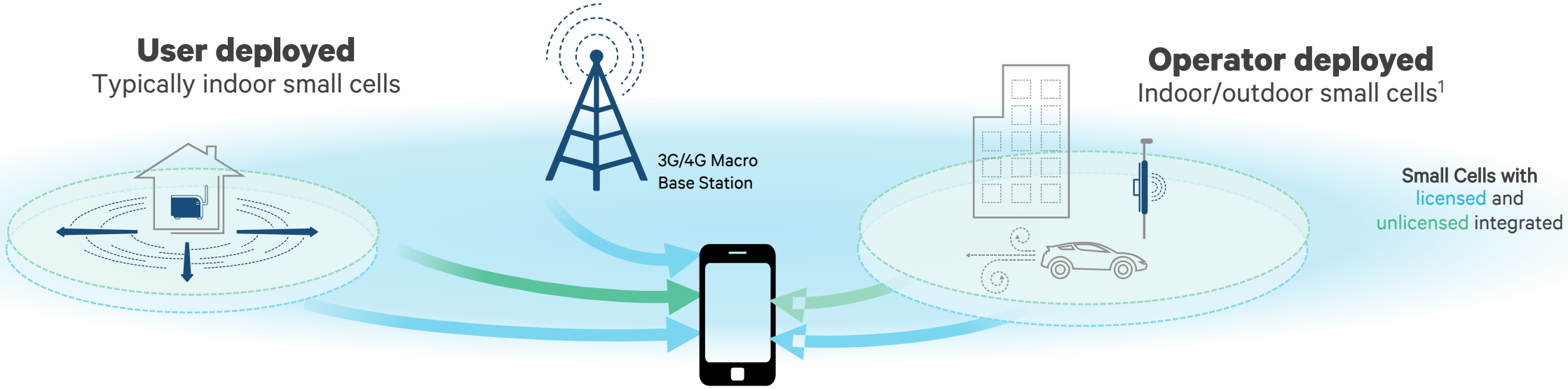
OPERATOR INTEREST

Trialed
Live in Finland in Sep'13

[1] ASA has been named LSA (Licensed Shared Access) in the EU by the Radio Spectrum Policy Group;
[2] 3GPP Band 40, 2.3-2.4 GHz; [3] Target 3.5 GHz in the US is 3550-3650 MHz

Unlicensed spectrum is ideal for opportunistic use in small cells

Complementing licensed spectrum – the foundation of mobile broadband



Low cost, non-exclusive

Unpredictable performance

Use opportunistically when possible

>500 MHz spectrum available

(mostly around 5 GHz)

Untapped capacity for opportunistic use

Higher spectrum bands

(and lower transmit power levels)

Shorter range – ideal for small cells

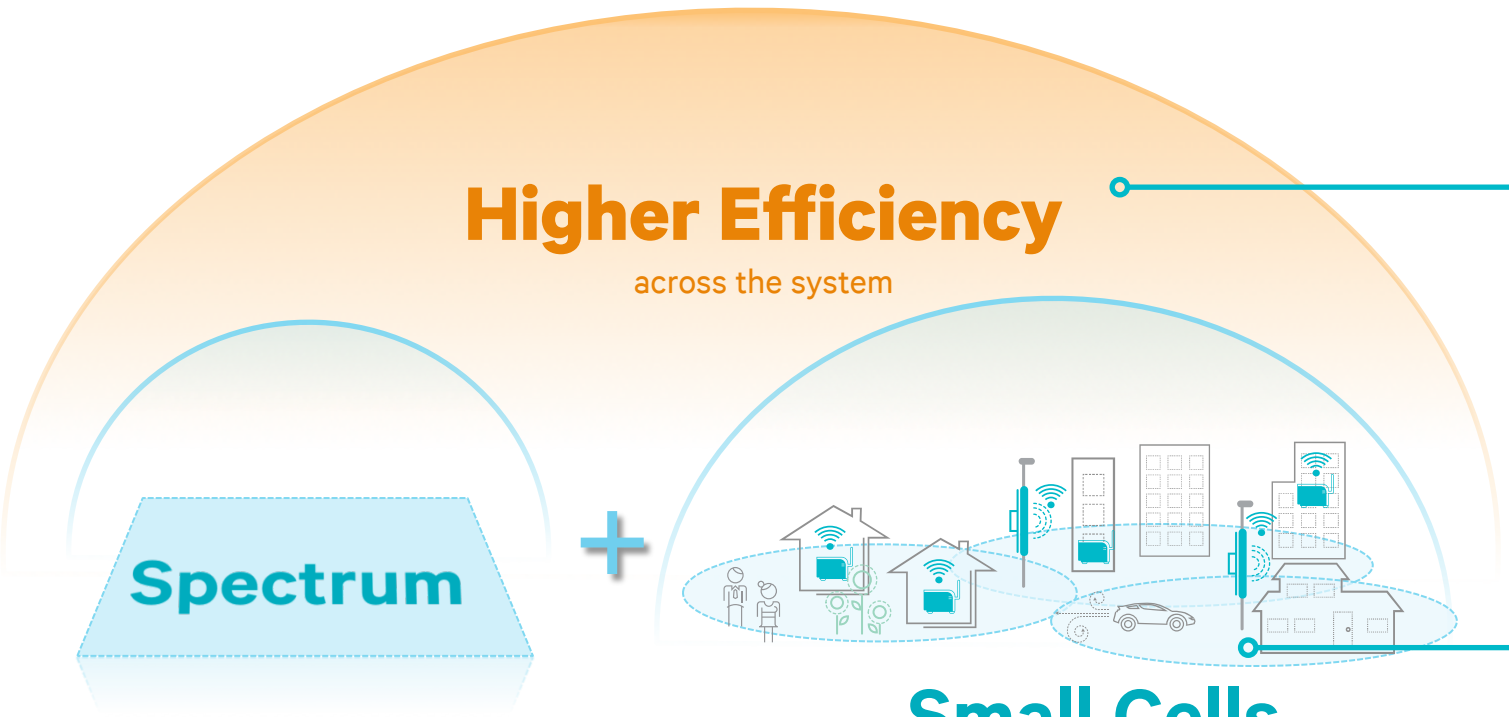
Wider spectrum bands

(especially around 5 GHz)

Efficiently share amongst multiple users

[1] Such as relay and Pico/Metro/RRH small cells for hotspots. RRH= Remote Radio Heads, in addition Distributed Antenna Systems are used in HetNets

Bringing 1000x closer to reality: Opportunistic use of Carrier Wi-Fi in small cells



11ac

Next-Gen Wi-Fi with 3x more throughput (per stream)

Evolving for tighter interworking with 3G/4G

Wi-Fi integrated into 3G/4G small cells

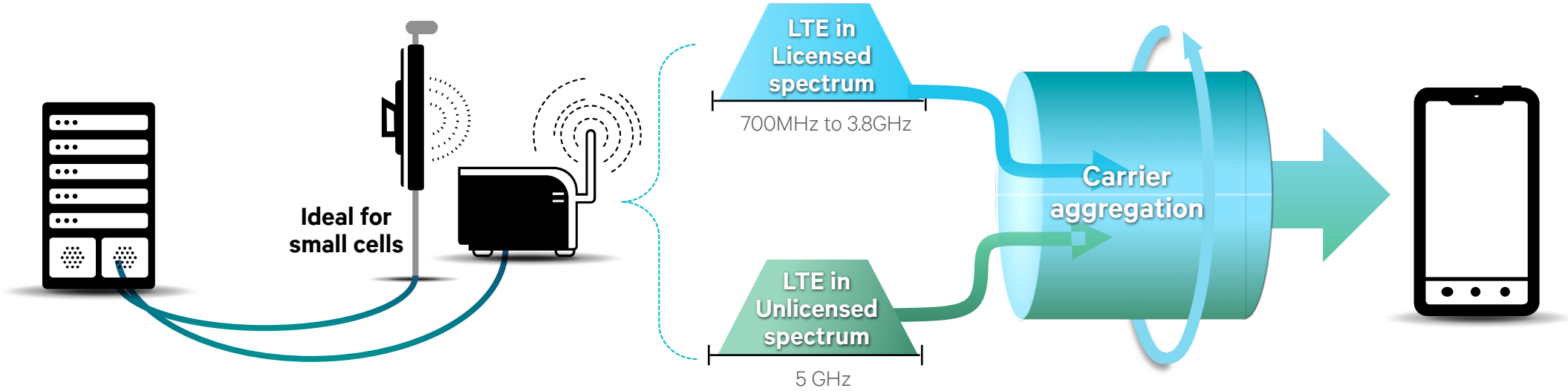
Bringing 1000x closer to reality:
Extending the benefits of LTE Advanced to unlicensed spectrum

Better performance

Longer range and increased capacity

Enhanced user experience

Thanks to LTE Advanced anchor in licensed spectrum with robust mobility



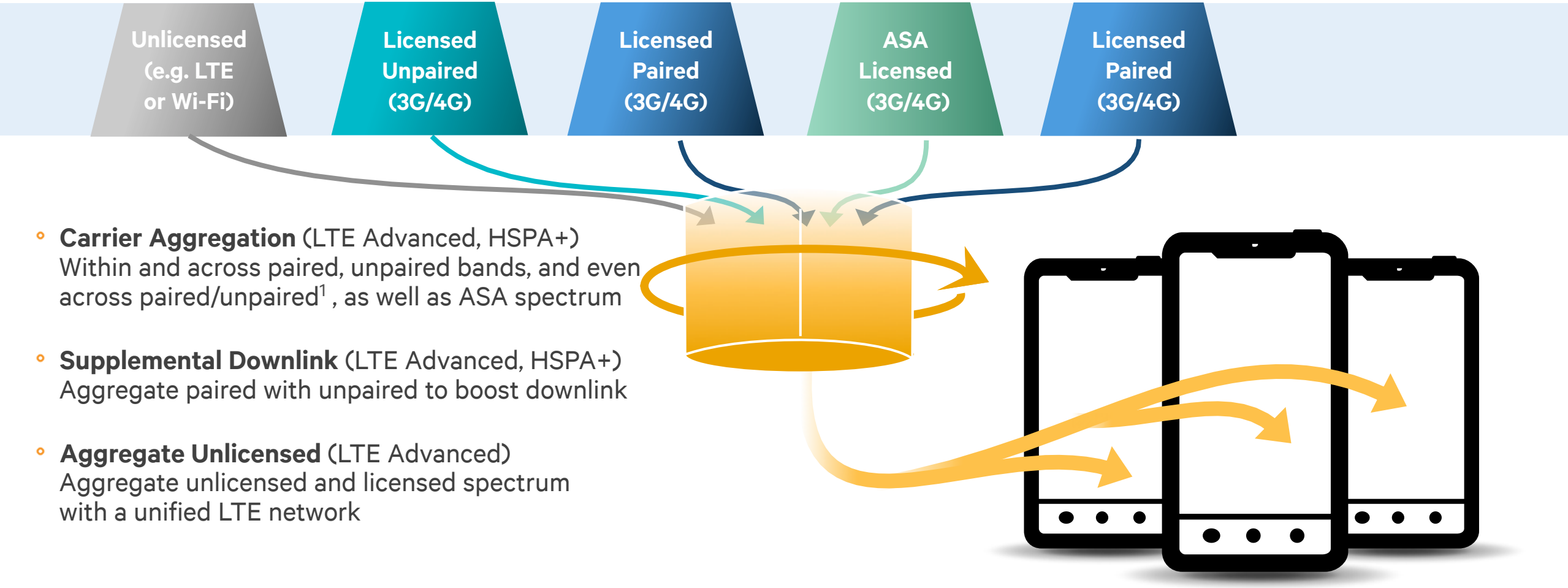
Unified LTE Network

Common LTE network with common authentication, security and management.

Coexists with Wi-Fi

Features to protect Wi-Fi neighbors

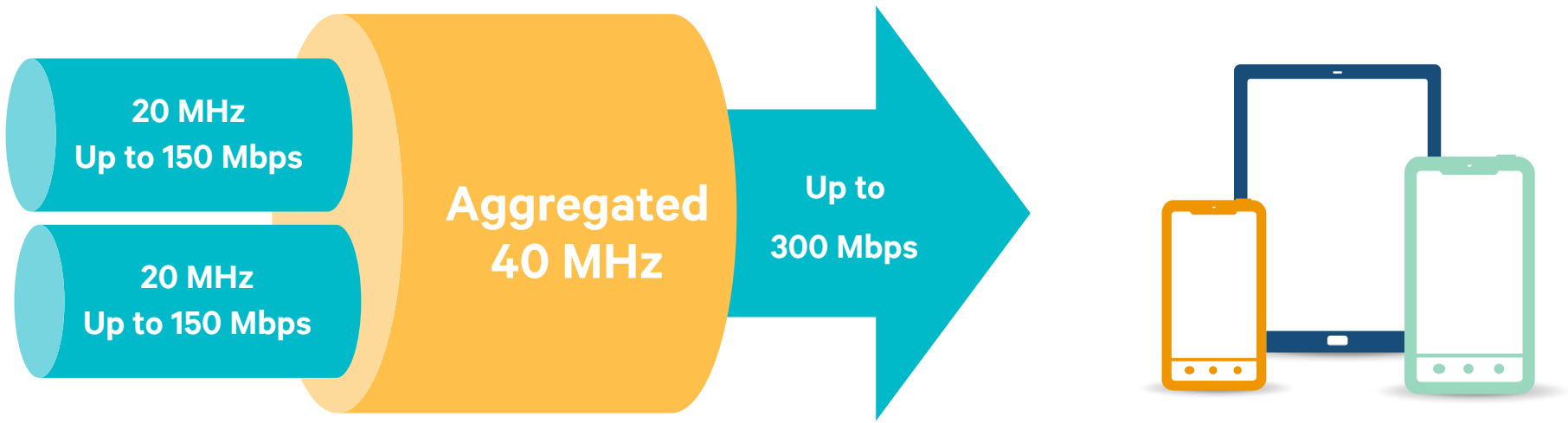
Spectrum aggregation makes best use of all spectrum assets



- **Carrier Aggregation** (LTE Advanced, HSPA+)
  Within and across paired, unpaired bands, and even across paired/unpaired[1] , as well as ASA spectrum
- **Supplemental Downlink** (LTE Advanced, HSPA+)
  Aggregate paired with unpaired to boost downlink
- **Aggregate Unlicensed** (LTE Advanced)
  Aggregate unlicensed and licensed spectrum with a unified LTE network

[1]LTE Advanced supports FDD or TDD aggregation, but FDD and TDD aggregation is a candidate for future revisions of the standard

Bringing 1000x closer to reality:
Aggregating spectrum with LTE Advanced Carrier Aggregation



Higher peak data rates

Higher user data rates and lower latencies for all users

More capacity for typical 'bursty' usage[1]

Leverages all spectrum assets

[1]The typical bursty nature of usage, such as web browsing, means that aggregated carriers can support more users at the same response (user experience) compared to two individual carriers, given that the for carriers are partially loaded which is typical in real networks. The gain depends on the load and can exceed 100% for fewer users (less loaded carrier) but less for many users. For completely loaded carrier, there is limited capacity gain between individual carriers and aggregated carriers,

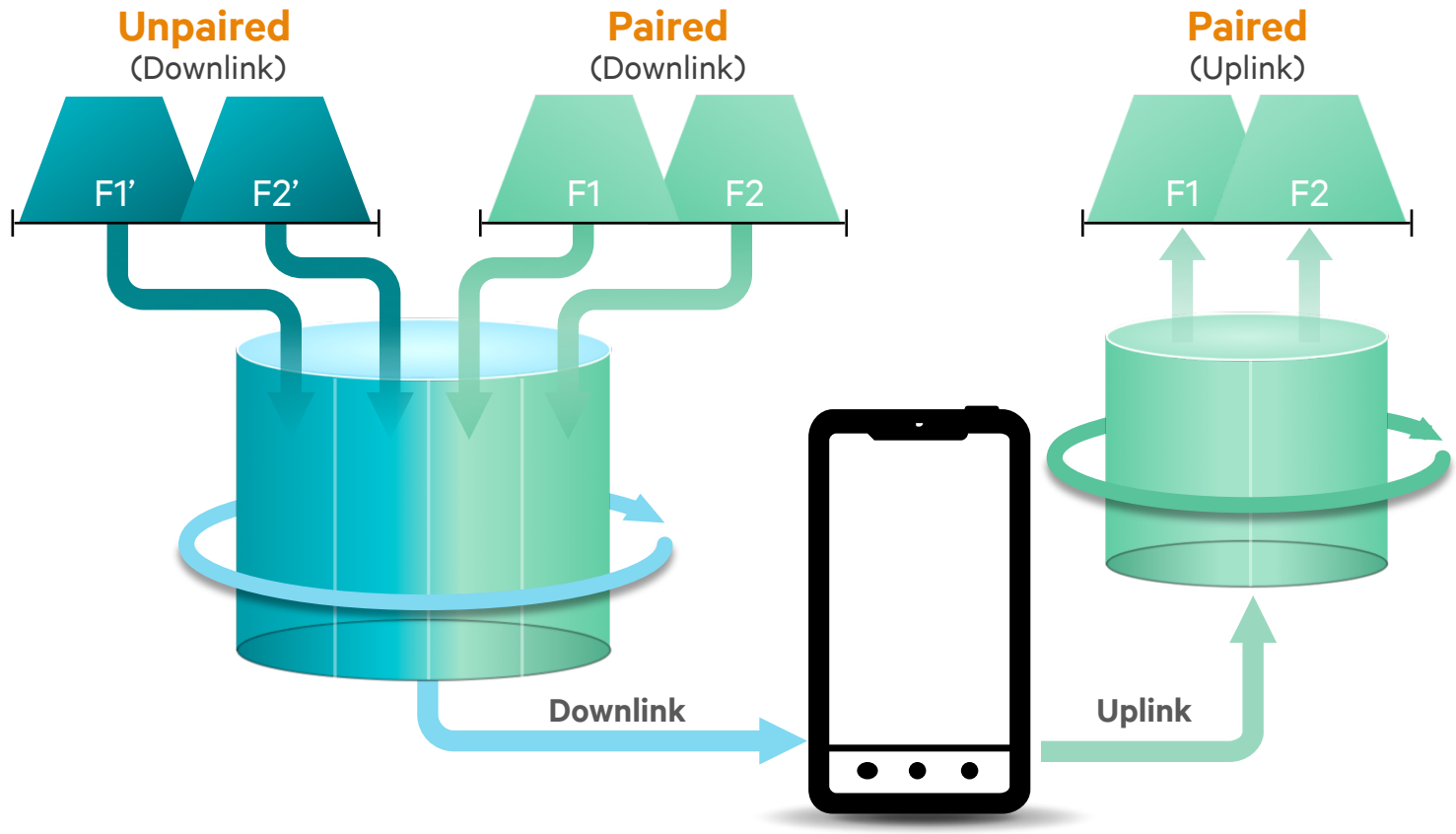
Bringing 1000x closer to reality: Implementing supplemental downlink

L-Band 1.4GHz harmonized in Europe[1]

- L-Band has 40 MHz of idle unpaired spectrum available[2]
- Commercial launch 2014/2015
- Now standardized as band XXXII in 3GPP

700 MHz to launch in the US

- AT&T[3] planning to launch 12 MHz of unpaired spectrum for SDL



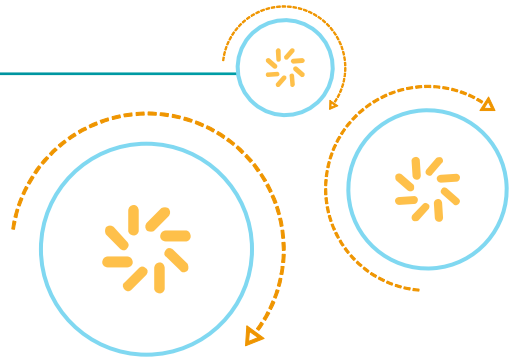
USES HSPA+ MULTICARRIER ACROSS BANDS[2], OR LTE ADVANCED CARRIER AGGREGATION[2]

1 L-Band in Europe: 1452 MHz to 1492 MHz, sometimes referred to as 1.4GHz or 1.5GHz spectrum.

2 Aggregation across bands is supported in HSPA+ R9 for two downlink carriers, but each specific band combination, e.g. combination of band 1 and L-band, has to be defined in 3GPP.

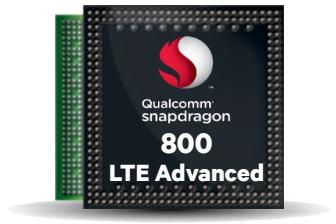
3 AT&T is planning to deploy supplemental downlink in lower 700 MHz (12 MHz of unpaired spectrum)

Qualcomm is a leader in technologies for licensed and unlicensed spectrum, with solutions to make the best use of all spectrum

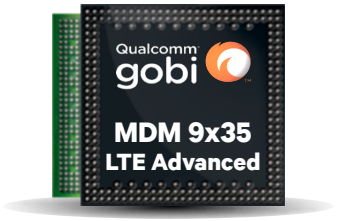


Qualcomm is a leader in Mobile 3G/4G for mobile broadband

Technology leadership in making the best use of available licensed spectrum



World's 1st LTE Advanced solution



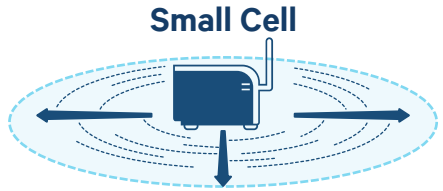
300Mpbs (Cat 6) solution

Leverage wider bandwidth

Aggregation across multiple carriers and multiple bands to enable higher data rates and leverage use of all spectrum assets

Leverage advanced receivers

Advanced interference cancellation techniques enables hyper-dense small cell deployment

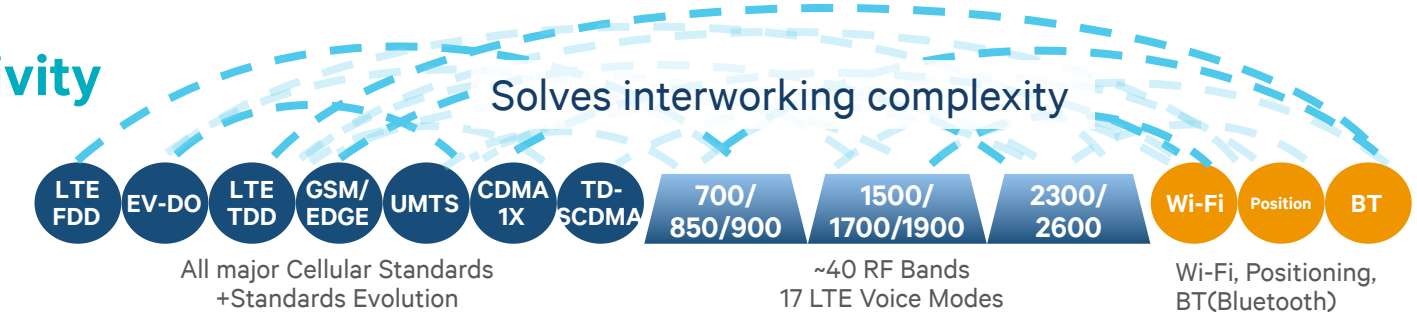


Advanced Antenna Techniques

Advanced multiple antenna techniques for more capacity with MIMO and receive diversity

Seamless Mobile Connectivity

Solving the complexity to support seamless mobile connectivity across all spectrum assets



Supports all technologies, bands, modes, ...

Qualcomm Atheros, Inc. is a leader in Wi-Fi solutions

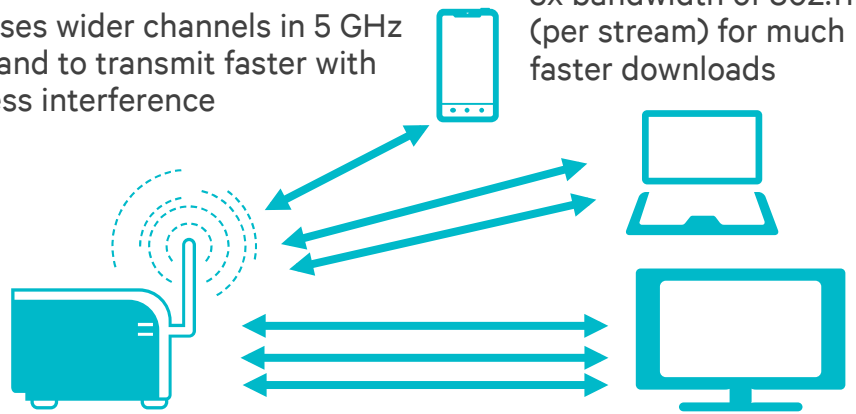
Technology leadership leveraging unlicensed spectrum for wireless broadband access

Local Area Broadband Access

Qualcomm VIVE™ brings content and devices to life
Enabling robust end-to-end 11ac ecosystem

Uses wider channels in 5 GHz band to transmit faster with less interference

3x bandwidth of 802.11n (per stream) for much faster downloads



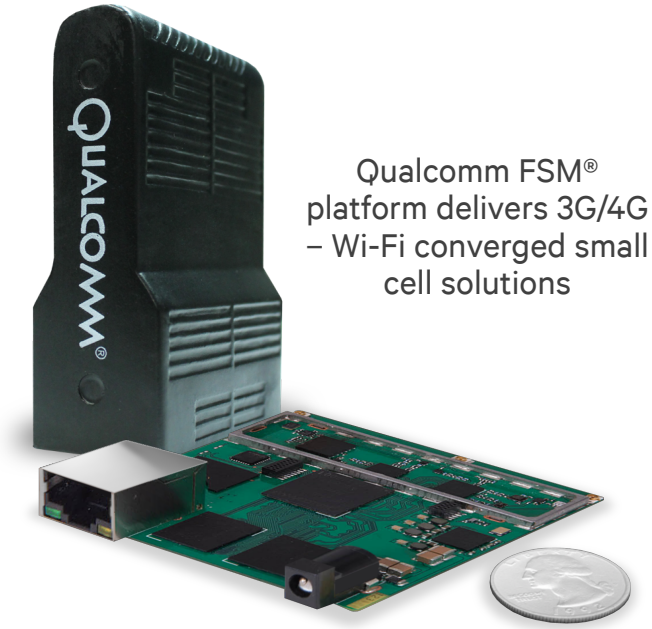
The first 4-stream 802.11ac solutions with multi-user MIMO (MIMO) to support more simultaneous clients

11ac

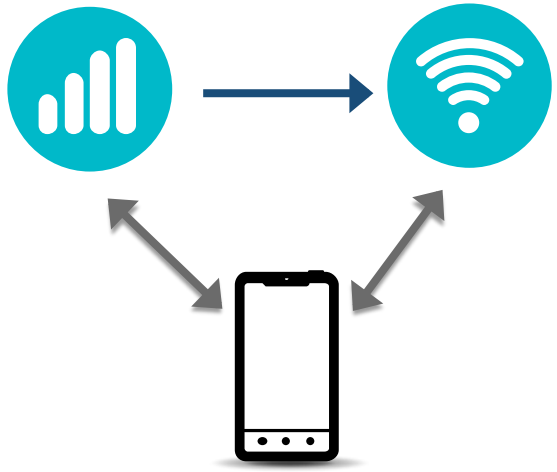
The center of the connected home

Mobile Broadband Opportunistic Use

Carrier Wi-Fi integrated with 3G/4G in small cells



Qualcomm FSM® platform delivers 3G/4G – Wi-Fi converged small cell solutions



Qualcomm is pioneering tighter integration of 3G/4G and Wi-Fi

Helping solve 1000x with mobile data offload

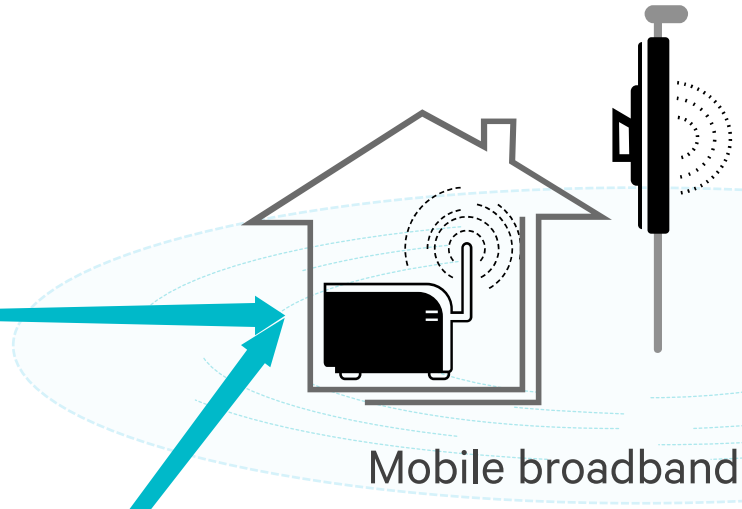
Qualcomm VIVE is a product of Qualcomm Atheros, Inc.; Qualcomm StreamBoost and FSM are products of Qualcomm Technologies, Inc.

A leader in all solutions to best leverage unlicensed spectrum

Committed to continued leadership in both Mobile 3G/4G and Wi-Fi

Licensed Spectrum
Cleared spectrum for 3G/4G, ASA for 3G/4G
Exclusive use

Unlicensed Spectrum
Multiple technologies (Wi-Fi, LTE in unlicensed)
Shared use



Common LTE Advanced for licensed and unlicensed spectrum

Mobile operator managed service that aggregates licensed and unlicensed spectrum[1]

3G/4G for licensed and carrier Wi-Fi for unlicensed spectrum

Mobile operator managed service with tighter Wi-Fi integration for better offload and services

Wi-Fi in unlicensed spectrum

Local area access for private/residential and enterprise users

[1] With Wi-Fi for backward compatibility

Spectrum is the lifeblood of mobile connectivity

1

3G/4G

Licensed spectrum is the foundation for mobile broadband, ensuring predictable performance and seamless mobility

2

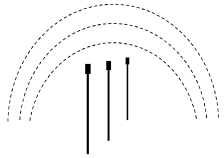
Wi-Fi

Unlicensed spectrum is the foundation for local area broadband, enabling simple deployment to provide local coverage

3

Solving the 1000x mobile data challenge will require the best use of all spectrum, licensed and unlicensed

4



Solving 1000x will also require innovative solutions to make use of under-utilized bands and aggregate all spectrum resources

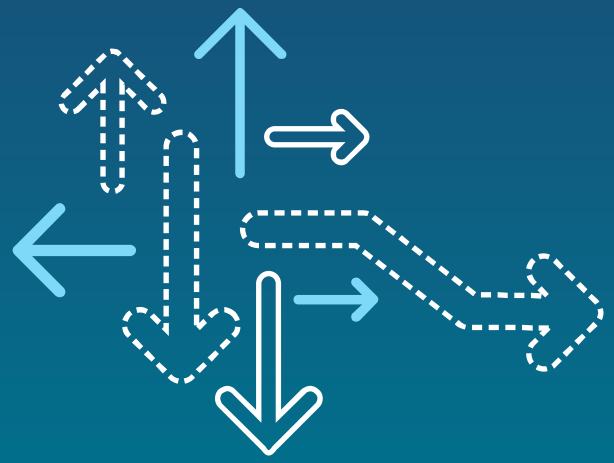
5

QUALCOMM

Qualcomm is a leader in technologies for licensed and unlicensed spectrum, with solutions to make the best use of all spectrum

to learn more, go to: www.qualcomm.com/spectrum

Questions? - Connect with Us



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Thank you

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