Making 5G NR a reality
Leading the technology innovations for a unified, more capable 5G air interface

CTIA Super Mobility 2016 - 5G Technical Workshop
Qualcomm Technologies, Inc.
September 8th, 2016
#whywait @Qualcomm
5G Vision & 5G NR
Introduction

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SVP, Engineering
Qualcomm Technologies, Inc.
Transforming our world
through intelligent connected platforms

Last 30 years
Interconnecting people

Next 30 years
Interconnecting their worlds

Utilizing unparalleled systems leadership in connectivity and compute
Mobile fueled the last 30 years—interconnecting people

1980s
Analog voice
AMPS, NMT, TACS

1990s
Digital voice
D-AMPS, GSM, IS-95 (CDMA)

2000s
Mobile broadband
WCDMA/HSPA+, CDMA2000/EV-DO

2010s
Mobile Internet
LTE, LTE Advanced
A unifying connectivity fabric

Always-available, secure cloud access

Enhanced mobile broadband
Mission-critical services
Massive Internet of Things

Unifying connectivity platform for future innovation

Convergence of spectrum types/bands, diverse services, and deployments, with new technologies to enable a robust, future-proof 5G platform
5G will redefine a wide range of industries
A platform for new connected services - existing, emerging and unforeseen
Designing 5G New Radio (NR)

An OFDM-based unified, more capable air interface
Pioneering new technologies to meet 5G NR requirements

Based on ITU vision for IMT-2020 compared to IMT-advanced

- 10x experienced throughput
- 10x decrease in end-to-end latency
- 10x connection density
- 3x spectrum efficiency
- 100x traffic capacity
- 100x network efficiency
Simplifying 5G deployments with multi-connectivity

Fully leveraging 4G LTE and Wi-Fi investments for a seamless user experience

5G NR radio access designed to utilize LTE anchor for mobility management (non-standalone) or operate stand-alone with new multi-access 5G NextGen Core Network (NGCN)
The path to 5G includes a strong LTE foundation

Advanced MIMO
256QAM
Carrier aggregation
Gigabit-class LTE
NB-IoT
Device-to-device

Shared spectrum
Massive MIMO
Low Latency
Enhanced broadcast
C-V2X

Significantly improve performance, cost and energy efficiency

Further backwards-compatible enhancement

Rel-10/11/12
LTE Advanced

Rel-13 and beyond
LTE Advanced Pro

Rel-15 and beyond
5G NR

Note: Estimated commercial dates. Not all features commercialized at the same time
Qualcomm and AT&T announce UAS trial
Preparing for wide-scale deployment of 5G mission critical services

Optimize LTE Networks
Inform Regulations
Drive 5G Specifications
Advancing safe and secure UAS operations
We are driving technology innovations to mobilize mmWave

Working with operators on trials & early deployments starting late 2017/early 2018

802.11ad 60 GHz chipset commercial for mobile devices

5G mmWave prototype system and trial platform

28 GHz mmWave RFIC development

Qualcomm® VIVE™ 802.11ad 60 GHz technology with a 32-antenna array

End-to-end system operating at 28 GHz demonstrating NLOS operation and robust mobility

With integrated PA, LNA, phase shifter, power splitters for beamforming

Qualcomm VIVE is a product of Qualcomm Atheros, Inc.

1 For limited regional fixed wireless deployments (e.g. Korea and US) operating at 28 and 39 GHz; also will be utilized for mobile wireless access trials to drive 5G NR standardization
Bringing new level of performance for sub-6 GHz
5G NR sub-6 GHz prototype system and trial platform

Operating in sub-6 GHz spectrum bands
Allows for flexible deployments with ubiquitous network coverage and a wide range of use cases

Achieving multi-Gbps at low latency
Showcases innovative Qualcomm 5G designs to efficiently achieve multi-gigabit per second data rates and low latency

Driving standardization on 5G NR
OFDM-based designs implemented on the prototype system are being utilized to drive 3GPP standardization

Will enable impactful 5G NR trials
Designed to flexibly track 3GPP standardization and be utilized as a trial platform for impactful and timely 5G NR trials

Watch the demo video at: https://www.qualcomm.com/videos/5g-nr-sub-6ghz-prototype-system
We are accelerating the path to 5G NR

Best-in-class 5G prototype systems and testbeds
5G standards, technology and research leadership
Impactful trials and early deployments with network operators
Modem and RFFE leadership to solve 5G complexity

Test, demonstrate and verify our innovative 5G designs to contribute to and drive standardization
Such as advanced channel coding, self-contained subframe, mobilizing mmWave, ...
Over-the-air interoperability testing leveraging prototype systems and our leading global network experience
Roadmap to 5G significantly more complex and faster moving—builds upon our rich history of industry firsts

Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.
5G NR standardization progressing for 2019 launches

Continue to evolve LTE in parallel to become a critical part of the 5G Platform

3GPP 5G NR R14 Study Item

R15 5G Work Items

R16 5G Work Items

R17 + 5G evolution

Accelerating 5G NR\(^1\) with trials & early deployments

5G NR R15 launches\(^2\)

5G NR R16 launches

Gigabit LTE & LTE IoT deployments

Note: Estimated commercial dates. 1 The latest plenary meeting of the 3GPP Technical Specifications Groups (TSG#72) has agreed on a detailed workplan for Release-15; 2 Forward compatibility with R16 and beyond
Anyone can talk about 5G. We are creating it.
5G NR Design & Technology Innovation

John Smee
VP, Engineering
Qualcomm Technologies, Inc.
Designing 5G New Radio (NR)

An OFDM-based unified, more capable air interface

Diverse deployments
Diverse spectrum
Diverse services and devices
Scalability to address diverse service and devices

Based on target requirements for the envisioned 5G use cases

**Massive Internet of Things**

- **Ultra-low energy**
  - 10+ years of battery life
- **Ultra-low complexity**
  - 10s of bits per second
- **Ultra-high density**
  - 1 million nodes per Km²

**Enhanced mobile broadband**

- **Extreme capacity**
  - 10 Tbps per Km²
- **Extreme data rates**
  - Multi-Gbps peak rates; 100+ Mbps user experienced rates

**Deep coverage**

- To reach challenging locations

**Mission-critical control**

- **Strong security**
  - e.g. Health / government / financial trusted
- **Ultra-high reliability**
  - <1 out of 100 million packets lost
- **Ultra-low latency**
  - As low as 1 millisecond
- **Extreme user mobility**
  - Or no mobility at all

**Deep awareness**

- Discovery and optimization
Getting the most out of every bit of diverse spectrum

Low bands below 1 GHz: longer range for e.g. mobile broadband and massive IoT
  e.g. 600 MHz, 700 MHz, 850/900 MHz

Mid bands 1 GHz to 6 GHz: wider bandwidths for e.g. eMBB and mission-critical
  e.g. 3.4-3.8 GHz, 3.8-4.2 GHz, 4.4-4.9 GHz

High bands above 24 GHz (mmWave): extreme bandwidths
  e.g. 24.25-27.5 GHz, 27.5-29.5, 37-40, 64-71 GHz

Licensed Spectrum
  Exclusive use

Shared Spectrum
  New shared spectrum paradigms

Unlicensed Spectrum
  Shared use
Adaptable to diverse deployments and topologies

5G will be deployed and managed by a variety of entities. Mobile operator networks provide ubiquitous coverage—the backbone of 5G.
5G NR R15\(^1\) will establish the 5G foundation

For enhanced mobile broadband and beyond

**Optimized OFDM-based waveforms**

With scalable numerology and TTI, plus optimized multiple access for different use cases

**A common, flexible framework**

To efficiently multiplex services and features with a dynamic, low-latency TDD/FDD design

**Advanced wireless technologies**

Such as massive MIMO, robust mmWave, advanced channel coding, and device-centric mobility

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Unified design across spectrum types and bands

For licensed and shared/unlicensed spectrum bands both below 6 GHz and above 6 GHz\(^2\)

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\(^1\) 3GPP R16+ will bring continued eMBB evolution, plus new features for massive IoT and mission-critical; \(^2\) 3GPP R15 focused on spectrum bands up to ~40 GHz; R16+ will bring support for bands up to ~100 GHz
Designing 5G NR

Leading the technology innovations for a unified, more capable 5G air interface
OFDM family is the right choice for 5G mobile broadband and beyond

Adapted for scaling to an extreme variations of 5G requirements

- **Spectral efficiency**: Efficient framework for MIMO spatial multiplexing
- **Low complexity**: Low complexity receivers even when scaling to wide bandwidths
- **Frequency localization**: Windowing can effectively minimizes in-band and out-of-band emissions
- **Lower power consumption**: Single-carrier OFDM well suited for efficient uplink transmissions
- **Asynchronous multiplexing**: Co-exist with optimized waveforms and multiple access for wide area IoT

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1 Weighted Overlap Add. 2 Such as Resource Spread Multiple Access (RSMA) - more details later in presentation
Efficient service multiplexing with windowed OFDM

OFDM with WOLA\(^1\) windowing
Substantially increases frequency localization

Key for 5G service multiplexing
Mitigate interference between flexible sub-carriers

OFDM with WOLA windowing
Effectively reduces in-band and out-of-band emissions

Windowed OFDM proven in LTE system today
Alternative OFDM-approaches, such as FBMC and UFMC, add complexity with marginal benefits

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1 Weighted Overlap Add

Source: Qualcomm Research, assuming 12 contiguous data tones, 60 symbols per run, 1000 runs. CP length is set to be roughly 10% of the OFDM symbol length. For Tx-WOLA, raised-cosine edge with rolloff \(\alpha=0.078\) is used.
Optimizing for diverse services and deployments

5G NR Downlink
Unified downlink design

- Mobile Broadband
- Massive IoT
- Mission-critical

CP-OFDM\(^1\) + OFDMA
Also recommended for D2D and inter-cell communications to maximize Tx/Rx design reuse

5G NR Uplink
Optimized for different deployments

- Macro cell
  - SC-OFDM\(^1\) + SC-FDMA
  - To maximize device energy efficiency
- Small cell
  - CP-OFDM\(^1\) + OFDMA
  - To maximize spectral efficiency

Optimized for different services

- Massive IoT
  - Low energy single-carrier\(^2\)
- Mission-critical
  - CP-OFDM / SC-OFDM\(^1\)

Resource Spread Multiple Access (RSMA)\(^3\)
Grant-free transmissions efficient for sporadic transfer of small data bursts with asynchronous, non-orthogonal, contention-based access

Download Qualcomm Research whitepaper for detailed analysis:
https://www.qualcomm.com/documents/5g-research-waveform-and-multiple-access-techniques

1 With time domain windowing as common in LTE systems today; 2 Such as SC-FDE and GMSK; 3 Mission-critical service may also use OFDMA/SC-FDMA for applications that may be scheduled
A flexible framework with forward compatibility

Efficiently multiplex envisioned and future 5G services on the same frequency

1 Blank resources may still be utilized, but are designed in a way to not limit future feature introductions; 2 Nominal 5G access to be designed such that it is capable to sustain puncturing from mission-critical transmission or bursty interference.
Scalable numerology with scaling of subcarrier spacing

Efficiently address diverse spectrum, deployments and services

Outdoor and macro coverage
FDD/TDD <3 GHz
Subcarrier spacing e.g. 15 kHz
- e.g. 1, 5, 10 and 20 MHz

Outdoor and small cell
TDD > 3 GHz
Subcarrier spacing e.g. 30 kHz
- e.g. 80/100 MHz

Indoor wideband
TDD e.g. 5 GHz (Unlicensed)
Subcarrier spacing e.g. 60 kHz
- e.g. 160 MHz

mmWave
TDD e.g. 28 GHz
Subcarrier spacing, e.g. 120 kHz
- e.g. 500 MHz

Example usage models and channel bandwidths
Self-contained integrated subframe design
UL/DL scheduling info, data and acknowledgement in the same sub-frame

Unlicensed spectrum
Listen-before-talk headers e.g. Clear Channel Assessment (CCA) and hidden node discovery

D2D, mesh and relay
Headers for e.g. direction of the link for dynamic distributed scheduling

Add'l headers
Ctrl (Tx)
Data (Tx)
Example: TDD downlink
Guard Period

Adaptive UL/DL
Flexible configuration for capacity allocation; also dynamic on a per-cell basis

Massive MIMO
Leveraging channel reciprocity in UL transmission for DL beamforming training

Faster, more flexible TDD switching and turn around, plus support for new deployment scenarios and forward compatibility
5G NR design innovations across diverse services

**Massive IoT**
- Low complexity narrowband
- Low power modes for deep sleep
- Efficient signaling
- Grant-free uplink transmissions
- Optimized link budget
- Managed multi-hop mesh

**Enhanced Mobile Broadband**
- Wider bandwidths
- Mobilizing mmWave
- Shared spectrum
- Device-centric mobility

**Mission-Critical Control**
- Low-latency with bounded delay
- Efficient multiplexing with nominal traffic
- Grant-free uplink transmissions
- Simultaneous redundant links
- Reliable device-to-device links
- Optimized PHY/pilot/HARQ

- Dynamic, low-latency TDD/FDD
- Massive MIMO
- Advanced channel coding
- Native HetNet and multicast support
Enhancing mobile broadband

Extreme throughput
Ultra-low latency
Uniform experience
Massive MIMO is a key enabler for higher spectrum bands

Allows reuse of existing sites and same transmit power at e.g. 4 GHz

- 1.7 km inter-site distance
- 46 dBm transmit power

Source: Qualcomm Technologies, Inc. simulations; Macro-cell with 1.7km inter-site distance, 10 users per cell, 46 dBm Tx power at base station, 20MHz@2GHz and 80MHz@4GHz BW TDD, 2x4 Massive MIMO
Realizing the mmWave opportunity for mobile broadband

**Extreme bandwidth opportunity**
- Extreme bandwidths capable of Multi-Gbps data rates
- Flexible deployments (integrated access/backhaul)
- High capacity with dense spatial reuse

**Mobilizing mmWave challenge**
- Robustness due to high path loss and susceptibility to blockage
- Device cost/power and RF challenges at mmWave frequencies

5G NR

- Smart beamforming and beam tracking
  - Increase coverage and minimize interference

- Tight interworking with sub 6 GHz
  - Increase robustness, faster system acquisition

- Optimized mmWave design for mobile
  - To meet cost, power and thermal constraints

Learn more at: [www.qualcomm.com/documents/promise-5g-mmwave-how-do-we-make-it-mobile](http://www.qualcomm.com/documents/promise-5g-mmwave-how-do-we-make-it-mobile)
Mobilizing mmWave—live demonstration of our prototype

Millimeter Wave UE

Millimeter wave base station

Beamforming and scanning

Non-line-of-sight through reflection

Handover

Outdoor

Learn more at: www.qualcomm.com/videos/mobilizing-mmwave-5g
Delivering advanced 5G NR channel coding

ME-LDPC\(^1\) codes more efficient than today’s LTE Turbo codes at higher data rates

Example ME-LDPC Basegraph

- **High Efficiency**: Significant gains over LTE Turbo - particularly for large block sizes suitable for MBB
- **Low Complexity**: Easily parallelizable decoder scales to achieve high throughput at low complexity
- **Low Latency**: Efficient encoding/decoding enables shorter TTI

Also exploring alternative channel coding for mission-critical and massive IoT traffic\(^2\)

\(^1\) Multi-Edge Low-Density Parity-Check; \(^2\) such as Polar or TBCC
Device-centric mobility management in 5G NR
Control plane improvements to improve energy and overhead efficiency

**Edgeless mobility zone**
(area of tightly coordinated cells)

**Lightweight mobility**
for device energy savings

- Apply COMP-like\(^1\) concepts to the control plane
- Intra-zone mobility transparent to the device

**Less broadcast for network energy savings**

- Low periodic beacon for initial discovery of device(s)
- On-demand system info (SIB) when devices present\(^2\)

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\(^1\) Coordinated MultiPoint is an LTE Advanced feature to send and receive data to and from a UE from several access nodes to ensure the optimum performance is achieved even at cell edges;

\(^2\) Minimum system information is broadcast periodically, other system information available on demand; may dynamically revert to broadcast system info when needed, e.g. system info changes
Connecting massive Internet of Things

- Power efficient
- Low complexity
- Long range
5G NR will bring new capabilities for the massive IoT

NB-IoT continuing to evolve beyond Release 13—foundation of Narrowband 5G

- **eMTC**: Scales down LTE to address the broadest range of IoT use cases
- **NB-IoT**: Optimizes to lowest cost/power for delay-tolerant, low-throughput IoT use cases; evolving with new features such as VoLTE and positioning support
- **NB-5G**: 3GPP 5G NR further enhances massive IoT with new capabilities such as RSMA\(^1\) & multi-hop mesh

\(^1\) Resource Spread Multiple Access
Non-orthogonal RSMA for efficient IoT communications

Characterized by small data bursts in uplink where signaling overhead is a key issue

Grant-free transmission of small data exchanges

- Eliminates signaling overhead for assigning dedicated resources
- Allows devices to transmit data asynchronously
- Capable of supporting full mobility

Increased battery life

Scalability to massive # of things

Better link budget

Downlink remains OFDM-based for coexistence with other services
Support for multi-hop mesh with WAN management

Problem: Uplink coverage
Due to low power devices and challenging placements, in e.g. basement

Solution: Managed uplink mesh
Uplink data relayed via nearby devices—uplink mesh but direct downlink.

1 Greater range and efficiency when using licensed spectrum, e.g. protected reference signals. Network time synchronization improves peer-to-peer efficiency
5G Enabling mission-critical services

High reliability
Ultra-low latency
High availability
5G NR will enable new mission-critical control services
A platform for tomorrow’s more autonomous world

1ms e2e latency
Faster, more flexible frame structure; also new non-orthogonal uplink access

Ultra-high reliability
Ultra-reliable transmissions that can be time multiplexed with nominal traffic through puncturing

Ultra-high availability
Simultaneous links to both 5G and LTE for failure tolerance and extreme mobility

Strong e2e security
Security enhancements to air interface, core network, & service layer across verticals

1 Also exploring alternative roots of trust beyond the SIM card
Efficient mission-critical multiplexing with other services

A more flexible design as compared to dedicated mission-critical resources (e.g. FDM)

Mission-critical transmission may occur at any time and cannot wait for scheduling

Nominal traffic (with new FEC and HARQ design)

Opportunity for uplink RSMA non-orthogonal access using OFDM waveforms

Design such that other traffic can sustain puncturing from mission-critical transmission
New 5G design allows for optimal trade-offs

E.g. leveraging wider bandwidths to offset mission-critical capacity reductions

Latency vs. capacity...

Reliability vs. capacity...

But wider bandwidth can offset reductions

Mission-critical capacity

Mission-critical capacity

Mission-critical capacity

Example: 2X bandwidth for 3x capacity gain

1 Low BLER Block Error Rate, required to achieve high-reliability with a hard delay bound. 2 All data based on Qualcomm simulations with approximate graphs and linear scales. 3x gain when increasing from 10Mhz to 20Mhz for 1e-4 BLER.
As we did in 3G and 4G, Qualcomm is leading the world to 5G

Making 5G NR a reality
Qualcomm Research 5G NR prototype systems
Testbed for 5G designs to drive standardization and timely commercialization

Sub-6 GHz for flexible deployments across a wide range of use cases

End-to-end system operating sub-6 GHz and showcasing innovations to efficiently achieve large bandwidths capable of multi-Gbps rates at low latency

Robust mmWave for extreme mobile broadband

End-to-end system operating at 28 GHz, demonstrating beam forming and scanning to address non-line-of-sight scenarios, improve indoor/outdoor range, and provide robust mobility
Anyone can talk about 5G. We are creating it.

Investing in 5G for many years—building upon our leadership foundation

Wireless/OFDM technology and chipset leadership
Pioneering new 5G technologies to meet extreme requirements

End-to-end system approach with advanced prototypes
Driving 5G from standardization to commercialization

Leading global network experience and scale
Providing the experience and scale that 5G demands

Learn more at www.qualcomm.com/5G
5G Shared Spectrum

Mingxi Fan
VP, Engineering
Qualcomm Technologies, Inc.
New spectrum sharing paradigms—opportunity to innovate
Can enable more efficient utilization of, and access to, scarce resources

**Licensed spectrum**
Exclusive use
Example: 2.1 GHz

**Shared spectrum**
New shared spectrum paradigms
Example: 2.3 GHz Europe / 3.5 GHz USA

**Unlicensed spectrum**
Shared use
Example: 2.4 GHz global / 5 GHz global
Shared/unlicensed spectrum is important for 5G

Unlocking more spectrum

Shared spectrum can unlock spectrum that is lightly used by incumbents

High spectrum utilization

Spectrum sharing has the potential to increase spectrum utilization

A lot of spectrum may be shared/unlicensed

FCC recent decision on high-band spectrum included a significant portion of shared/unlicensed spectrum

1) FCC ruling FCC 16-89 on 7/14/2016 allocated 3.25 MHz of licensed spectrum and 7.6 MHz of shared/unlicensed spectrum.
Leading the way with Wi-Fi in the mobile industry

- **11ad**: 2GHz / SISO
- **11ay**: 8 GHz, MU-MIMO

Led the way for multi-band Wi-Fi ecosystem with 802.11ad

- 11bg: 2.4GHz / 5GHz
- 11n: 20 MHz / SISO
- 11ac: 40 MHz / MIMO 4x4
- 11ac Wave-2: 160 MHz / 5 GHz support
- 11ax: Downlink MU-MIMO / OFDMA / Uplink MU-MIMO

Introduced industry’s first 802.11ac Wave 2 SOC

Qualcomm Wi-Fi chipsets are products of Qualcomm Technologies, Inc.
Pioneered shared/unlicensed spectrum in 4G LTE

1. Licensed Shared Access (LSA)
2. Licensed-Assisted Access (LAA)
3. Citizen Broadband Radio Service (CBRS), Priority Access Licenses (PAL), General Authorized Access (GAA)

Technically extensive pilot in France with Ericsson and Red in Jan 2016
We designed the original proposal, commercialized by the LTE-U forum
Performed world’s first over-the-air LAA trial with Deutsche Telekom Nov 2015
A founder of the MulteFire Alliance and a key contributor to its specification
A founder of the CBRS Alliance and a key contributor to coexistence

1) Licensed Shared Access (LSA); 2) Licensed-Assisted Access (LAA); 3) Citizen Broadband Radio Service (CBRS), Priority Access Licenses (PAL), General Authorized Access (GAA)
LTE is the high performance option in unlicensed spectrum

LAA ~2X coverage outdoors compared to Wi-Fi\(^1\)

<table>
<thead>
<tr>
<th></th>
<th>Wi-Fi</th>
<th>LAA</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;10</td>
<td>24% of route</td>
<td>60% of route</td>
</tr>
<tr>
<td>&gt;1</td>
<td>39% of route</td>
<td>71% of route</td>
</tr>
<tr>
<td>&gt;0</td>
<td>47% of route</td>
<td>82% of route</td>
</tr>
</tbody>
</table>

World’s first over-the-air LAA trial in Nov. 2015 together with Deutsche Telekom

MulteFire by itself offers >2X capacity over Wi-Fi\(^2\)

1) Single small cell, LAA based on 3GPP release 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, same 20 MHz channel in 5 GHz unlicensed spectrum with 1W transmit power; terminal transmit power 0.2W; mobility speed 6-8 mph; 2) Indoor, single 20 MHz channel in 5 GHz, 80%-20% traffic split between down- and uplink, bursty traffic generated with 4 Mb files arriving with exponential inter arrival times, high traffic load with buffer occupancy at 50% in downlink and 20% in uplink for Wi-Fi only baseline, 4 APs per operator, 2 operators, office building size 120m x 50m, propagation model 3GPP indoor hotspot (InH), Wi-Fi is 802.11ac, MIMO 2x2; no MU-MIMO

©2009 GeoBasis-DE/BKG, ©2016 Google
CBRS introduces a 3-tiered shared spectrum

Enables to open up 150 MHz spectrum while incumbents are still using it

Tier 1
Incumbents

Tier 2
Priority Access Licenses (PAL)

Tier 3
General Authorized Access (GAA)

Incumbents are protected from interference from PAL and GAA

PAL has priority over GAA, licensed via auction, 10 MHz blocks, up to 7 licenses

GAA can use any spectrum not used, yields to PAL and incumbents

1) Wireless ISP transitioning from incumbent to PAL/GAA after 5 years; 2) Fixed satellite service - receiving only; 3) Citizen Broadband Radio Service (CBRS)
Multiple high performance LTE options can coexist in GAA\(^1\)

Possible to launch with LTE-TDD and introduce LBT later

1. General Authorized Access (GAA) is tier 3 in the CBRS 3-tier licensing model for shared 3.5 GHz in USA; 2. Licensed-Assisted Access, also includes enhanced LAA (eLAA); 3. Listen before talk; 4. Channels can be reused with sufficient RF isolation
MulteFire helps GAA scale to multiple deployments

Multiple deployments share a wide channel—better spectrum utilization & peak-rate

1) Example with one deployment (#1) with a high traffic load and two deployments (#2 and #3) with medium traffic loads; 2) Spectrum cannot always be evenly split; 3) Trunking benefits depend on relative traffic loads.

Highest spectrum efficiency with one LTE-TDD deployment

Multiple LTE-TDD deployments with reduced channel size, spectrum may become underutilized

MulteFire brings trunking efficiency from sharing a wide channel to improve spectrum utilization

1) Example with one deployment (#1) with a high traffic load and two deployments (#2 and #3) with medium traffic loads; 2) Spectrum cannot always be evenly split; 3) Trunking benefits depend on relative traffic loads.
Potential of high gains from spectrum sharing

1) These are examples, the gains from LTE OTA sharing is dependent on scenario; 2) Two operators use OTA sharing over the available spectrum; 3) Two operators divide the available spectrum between themselves.

- LTE over-the-air (OTA) sharing performs better at low to moderate loads
- Gains mainly from trunking efficiency with bursty traffic and more flexible TDD
- Room for improvement in the future, e.g., OTA sharing at higher loads
We are pioneering 5G shared spectrum today

Building on LTE-U/LAA, LWA, CBRS/LSA and MulteFire

1) Licensed-Assisted Access (LAA), LTE Wi-Fi Link Aggregation (LWA), Citizen Broadband Radio Service (CBRS), Licensed Shared Access (LSA)
Shared spectrum—valuable for wide range of deployments

**Extreme bandwidth by aggregating spectrum**
Mobile operators provide extreme bandwidths by aggregating shared/unlicensed spectrum with licensed spectrum.

**Enhanced local broadband**
Shared/unlicensed spectrum enables entities without licensed spectrum to offer enhanced mobile broadband.

**Internet of Things verticals**
Shared/unlicensed spectrum opens up opportunity to service different IoT verticals, e.g., a private IoT network.
Flexible radio
- Scalable numerology: narrow-to-wideband
- Spectrum from sub-6GHz to mmWave
- Self-contained integrated sub-frames

Flexible unlicensed operation
- Unlicensed aggregation with licensed anchor
- Multi-connectivity: NR, LTE and/or Wi-Fi
- Stand-alone in unlicensed

Flexible spectrum sharing
- Dynamic sharing between deployments, technologies, priority tiers, etc.
- Enhanced spatial separation with mmWave
- Solutions for new spectrum sharing paradigms
Designed for sharing: Self-contained integrated sub-frame

Faster, more flexible TDD switching, plus support for new deployment scenarios

Unlicensed spectrum
Listen-before-talk headers e.g.
clear Channel Assessment (CCA)
and hidden node discovery

D2D, mesh and relay
Headers for e.g. direction
of the link for dynamic
distributed scheduling

Add’l headers
Ctrl (Tx)
Data (Tx)

Adaptive UL/DL
Flexible configuration for
capacity allocation; also
dynamic on a per-cell basis

Guard Period

Massive MIMO
Leveraging channel
reciprocity in UL transmission
for DL beamforming training

Example: TDD downlink
Opportunity to enhance spectrum sharing further
Leveraging 4G leadership to provide new solutions for NR shared spectrum

Licensed spectrum
Full control, partially loaded

LAA/MulteFire
Higher peak rate and utilization

Synchronized access
Increased spectral efficiency

Operator 1

Operator 2

Licensed spectrum diagram
LAA/MulteFire diagram
Synchronized access diagram
5G NR will natively support all different spectrum types

NR shared spectrum will support new shared spectrum paradigms

- **Licensed Spectrum**: Exclusive use
- **Shared Spectrum**: New shared spectrum paradigms
- **Unlicensed Spectrum**: Shared use

- **High bands above 24 GHz** (mmWave): Extreme bandwidths
- **Mid bands 1GHz to 6 GHz**: Wider bandwidths for e.g. eMBB and mission-critical
- **Low bands below 1 GHz**: Longer range for e.g. mobile broadband and massive IoT
5G Spectrum for US

Dean Brenner
SVP, Government Affairs
Qualcomm Incorporated
5G will support low, mid, and high band spectrum and all regulatory paradigms

- **Licensed Spectrum**: EXCLUSIVE USE
- **Shared Spectrum**: NEW SHARED SPECTRUM PARADIGMS
- **Unlicensed Spectrum**: SHARED USE

**Low bands** below 1 GHz: longer range for e.g. mobile broadband and massive Internet of Things

**Mid bands** 1 GHz to 6 GHz: wider bandwidths for e.g. enhanced mobile broadband and mission critical

**High bands** above 6 GHz, e.g. mmWave: extreme bandwidths
The FCC is driving key spectrum initiatives to enable 5G
Across low-band, mid-band, and high-band including mmWave

### 5G Spectrum

- **Low-band**
  - Broadcast Incentive Auction
  - First stage auction opened up 126 MHz in 600 MHz band, auction failed to close with clearing cost set at $88.4B
  - Second stage auction opens up 114 MHz, auction will begin on 9/13
  - Spectrum availability timing aligns with 5G

- **Mid-band**
  - Citizens Broadband Radio Service
  - Opening up 150 MHz in 3.5 GHz band
  - 3-tier spectrum sharing with incumbents, PAL\(^1\), and GAA\(^2\)
  - CBRS Alliance formally launched to drive an LTE-based ecosystem

- **High-band**
  - Spectrum Frontiers Ruling\(^3\)
  - Opening up 11 GHz in multiple mmWave bands
  - 70% of newly opened spectrum is shared or unlicensed
  - Unanimously approved by FCC with additional candidate bands identified for IMT-2020

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1 Priority Access Licenses to be auctioned; 2 General Authorized Access; 3 FCC ruling FCC 16-89 on 7/14/2016 allocated 3.25 MHz of licensed spectrum and 7.6 MHz of shared/unlicensed spectrum.
Spectrum Frontiers ruling for 5G mmWave

Shared and unlicensed spectrum is key for more bandwidths

**Licensed access**
- 27.5 - 28.35 GHz: 850 MHz (2x425 MHz)
- 37.6 - 38.6 GHz: 1 GHz (5x200 MHz)
- 38.6 - 40 GHz: 1.4 GHz (7x200 MHz)

**Shared and unlicensed access**
- 37 - 37.6 GHz: 600 MHz (3x200 MHz)
- 64 - 71 GHz: 7 GHz expansion of existing 60 GHz band

Total spectrum = ~11 GHz

FCC also identified additional candidate bands for IMT-2020
Including 24.25-24.35, 24.75-25.25, 31.8-33.4, 42-42.5, 47.2-50.2, 50.4-52.6, 71-76 GHz
The FCC’s July 14th Spectrum Frontiers ruling is “the final piece in the spectrum trifecta of low-band, mid-band, and high-band airwaves that will open up unprecedented amounts of spectrum, speed the rollout of next-generation wireless networks and re-define network connectivity for years to come.”

- FCC Chairman Tom Wheeler, June 20, 2016
Anyone can talk about 5G. We are creating it.
Thank you

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