Leading the world to 5G

February 2016

Qualcomm Technologies, Inc.

Our 5G vision: a unifying connectivity fabric

5G

Enhanced mobile broadband

- Multi-Gbps data rates
- Extreme capacity
- Uniformity
- Deep awareness

Mobile devices

Networking

Mission-critical services

- Ultra-low latency
- High reliability
- High availability
- Strong security

Automotive

Robotics

Health

Massive Internet of Things

- Low cost
- Ultra-low energy
- Deep coverage
- High density

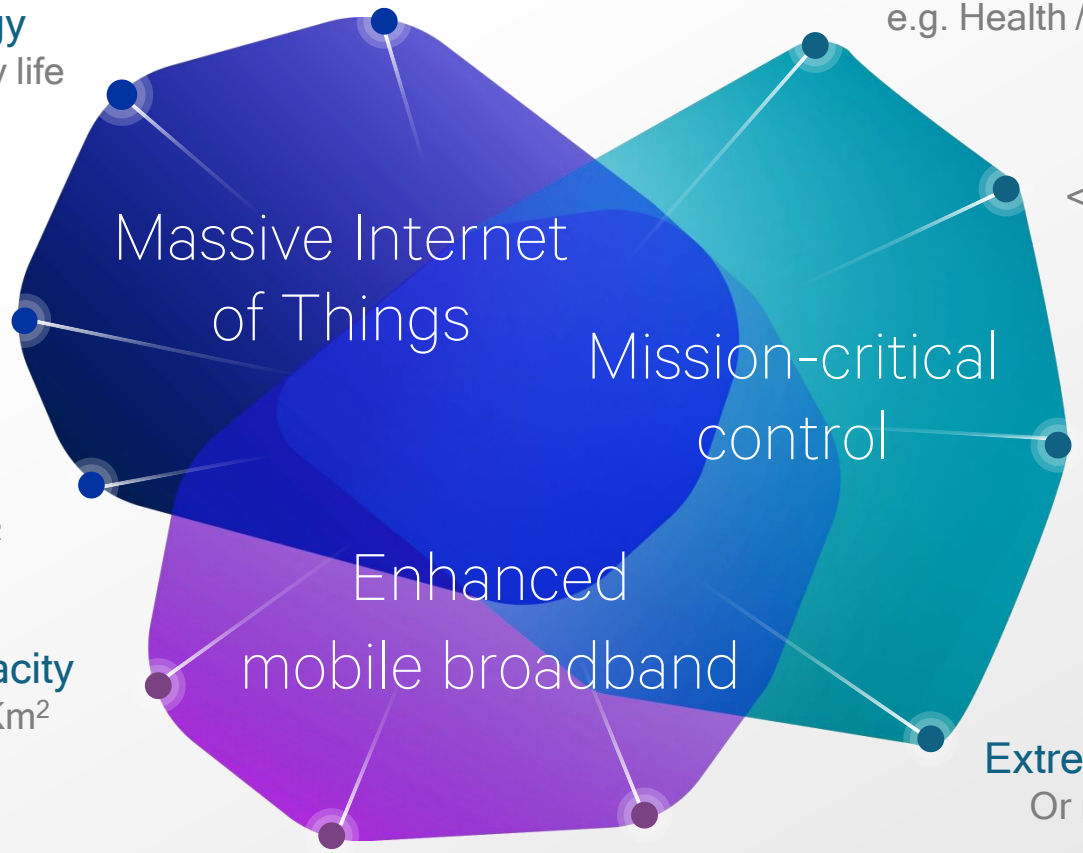
Wearables

Smart cities

Smart homes

Unified design for all spectrum types and bands from below 1GHz to mmWave

Scalable to an extreme variation of requirements



Deep coverage
To reach challenging locations

Strong security
e.g. Health / government / financial trusted

Ultra-low energy
10+ years of battery life

Ultra-high reliability
<1 out of 100 million packets lost

Ultra-low complexity
10s of bits per second

Ultra-low latency
As low as 1 millisecond

Ultra-high density
1 million nodes per Km^2

Extreme capacity
10 Tbps per Km^2

Extreme user mobility
Or no mobility at all

Extreme data rates
Multi-Gigabits per second

Deep awareness
Discovery and optimization

Based on target requirements for the envisioned 5G use cases

Enhancing mobile broadband

Ushering in the next era of immersive experiences and hyper-connectivity

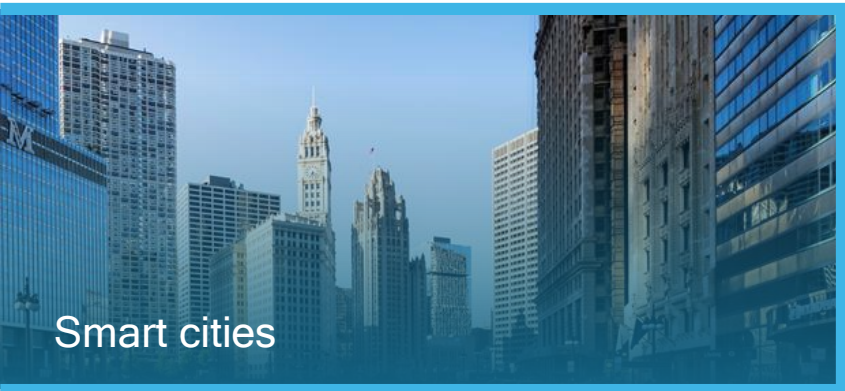
Extreme throughput
multi-gigabits per second

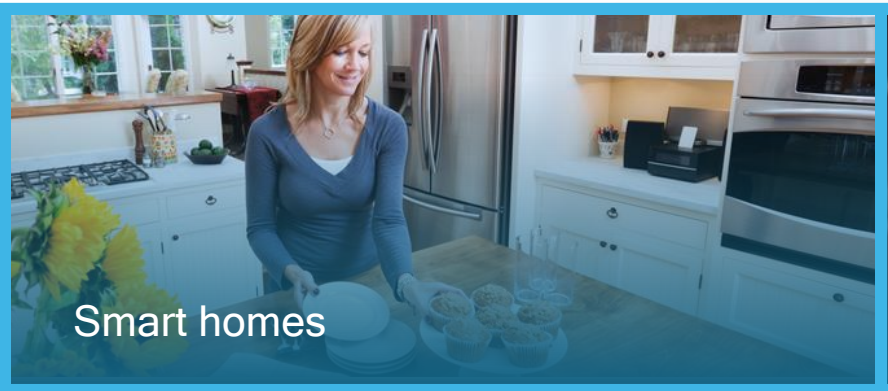
Ultra-low latency
down to 1ms e2e latency

Uniform experience
with much more capacity

Connecting the massive Internet of Things

Optimizing to connect anything, anywhere with efficient, low cost communications





Power efficient
Multi-year battery life

Low complexity
Low device and network cost

Long range
Deep coverage

Enabling new mission-critical control services

With ultra-reliable, ultra-low latency communication links

High reliability
Extremely low loss rate

Ultra-low latency
Down to 1ms e2e latency

High availability
Multiple links for failure tolerance & mobility

A unified 5G design for all spectrum types/bands

Addressing a wide range of use cases and deployment scenarios

Licensed Spectrum
Cleared spectrum
EXCLUSIVE USE

Shared Licensed Spectrum
Complementary licensing
SHARED EXCLUSIVE USE

Unlicensed Spectrum
Multiple technologies
SHARED USE

Below 1 GHz: longer range for massive Internet of Things

1 GHz to 6 GHz: wider bandwidths for enhanced mobile broadband and mission critical

Above 6 GHz, e.g. mmWave: extreme bandwidths, shorter range for extreme mobile broadband

From wide area macro to local hotspot deployments

Also support diverse network topologies (e.g. D2D, mesh)

Qualcomm, leading the world to 5G

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

Wireless/OFDM technology and chipset leadership

Pioneering 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

Pioneering 5G technologies today with LTE

We are driving 4G and 5G in parallel to their fullest potential

Advanced MIMO
Unlicensed spectrum
256QAM
Enhanced CA
FeICIC
Internet of Things
Carrier aggregation
FDD-TDD CA
Massive/FD-MIMO
CoMP
Device-to-device
Shared broadcast
SON+
Dual connectivity
V2X
Low latency

5G

Rel-15 and beyond

Further backwards-compatible 4G enhancements

Rel-10/11/12
LTE Advanced

Rel-13 and beyond
LTE Advanced Pro

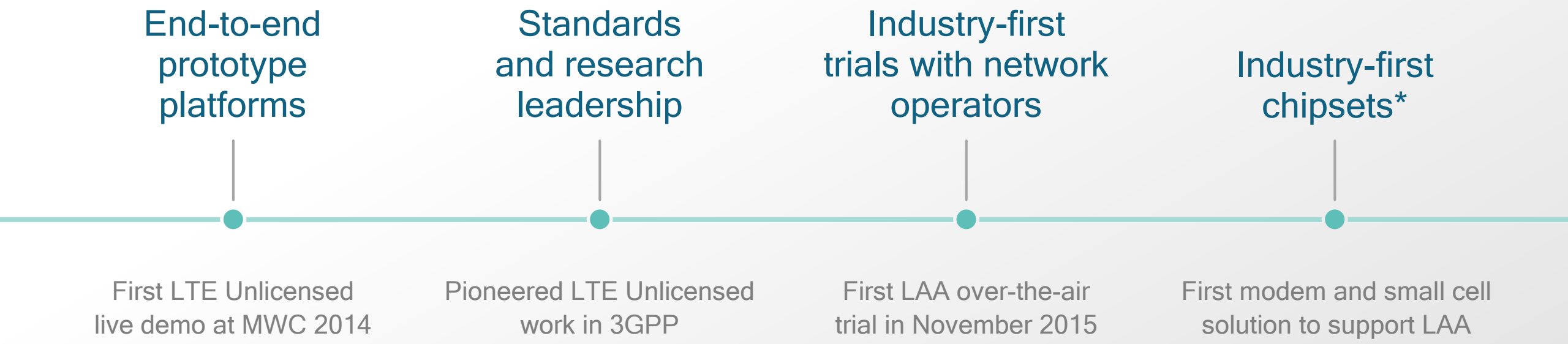
2015

2020+

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

Driving new LTE technologies to commercialization

Pushing LTE towards 5G with our unique end-to-end system approach



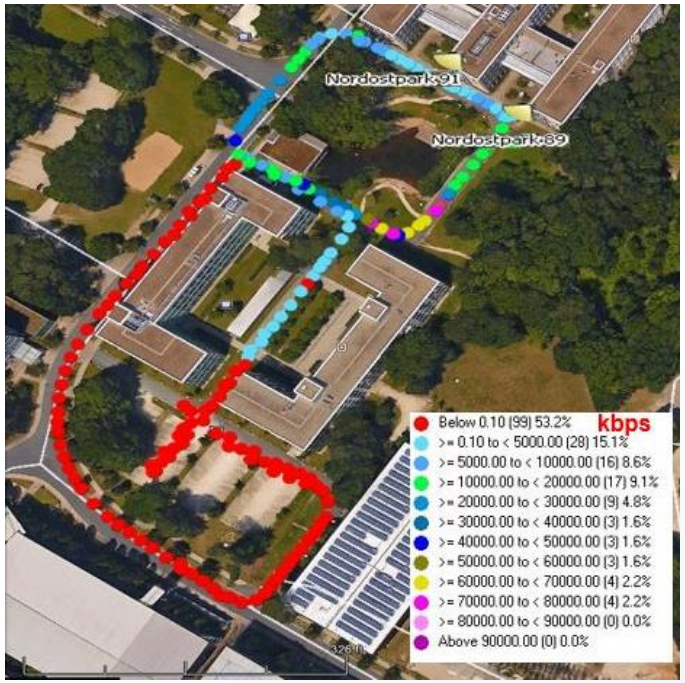
Example: Driving LTE Unlicensed to commercialization

* Chipsets are products of Qualcomm Technologies, Inc.; firsts with respect to public announcement of a commercial LTE modem chipset

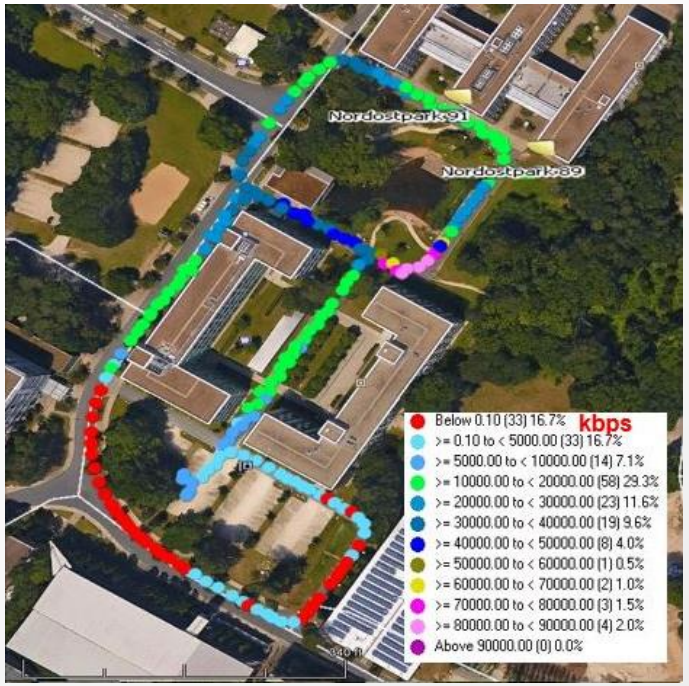
World's first over-the-air LAA trial during November 2015

Joint effort by Qualcomm Technologies with Deutsche Telekom AG

LWA (Wi-Fi) test route*



LAA test route*



Coverage^ in unlicensed

Mbps	Wi-Fi	LAA
		x2.5
>10	24% of route	60% of route
		x1.8
>1	39% of route	71% of route
		x1.7
>0	47% of route	82% of route

Wide range of indoor and outdoor test cases

Demonstrated coverage and capacity benefits of LAA

Demonstrated fair co-existence with Wi-Fi

* 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; ^ Based on geo-binned measurements over test route

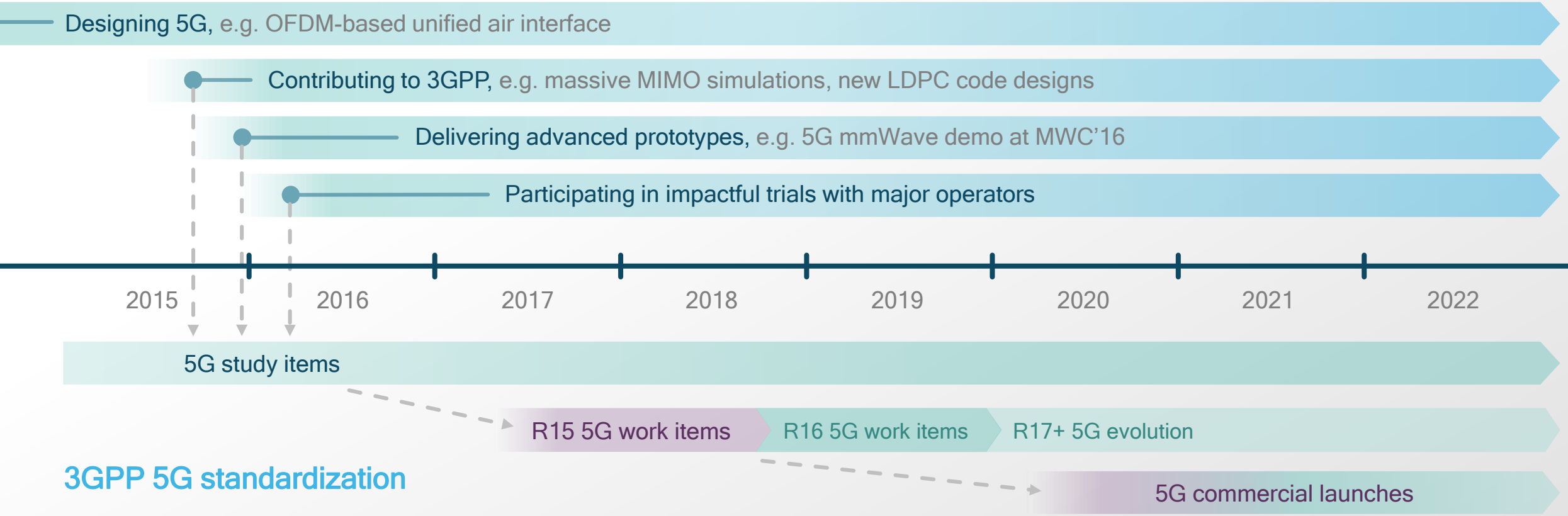
Multi-mode/multi-connectivity essential to 5G success

Simultaneous connectivity across
5G, 4G and Wi-Fi

Leading the world to 5G

From standardization to commercialization

Qualcomm 5G activities

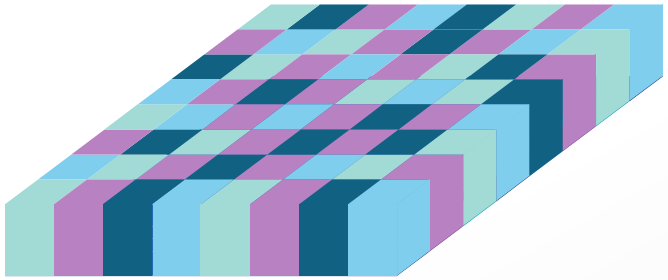


3GPP 5G standardization

Note: Estimated commercial dates;

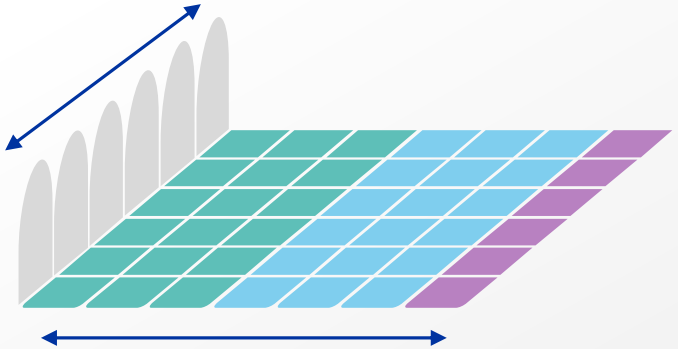
Designing a unified, more capable 5G air interface

Building on our strong OFDM/wireless foundation



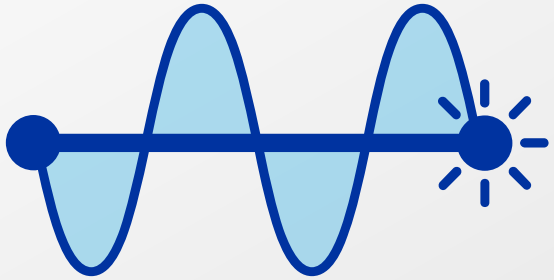
Optimized OFDM-based waveforms

OFDM adapted to extremes



A common, flexible framework

Designed for forward compatibility

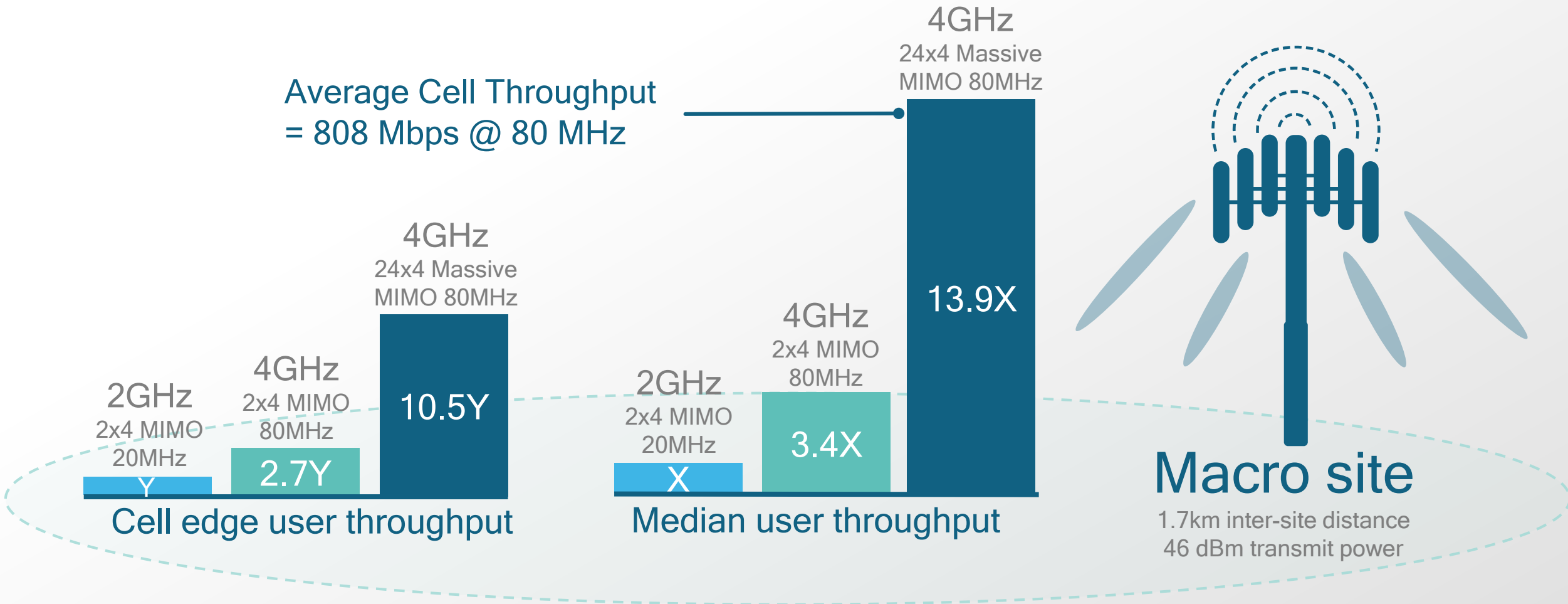


Advanced wireless technologies

Such as massive MIMO, mmWave

Massive MIMO at 4 GHz allows reuse of existing sites

Leverage higher spectrum band using same sites and same 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, 2.4x Massive MIMO

Realizing the mmWave opportunity for mobile broadband

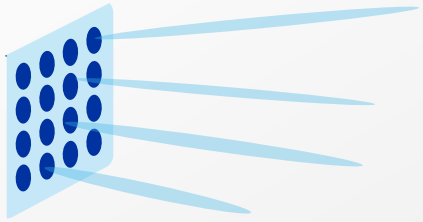
The extreme mobile broadband opportunity

- Large bandwidths, e.g. 100s of MHz
- Multi-Gpbs data rates
- Flexible deployments (integrated access/backhaul)
- High capacity with dense spatial reuse

The challenge–'mobilizing' mmWave

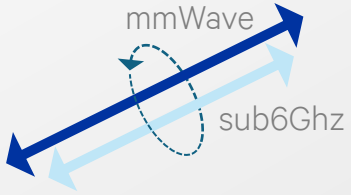
- Robustness due to high path loss and susceptibility to blockage
- Device cost/power and RF challenges at mmWave frequencies

5G Solutions



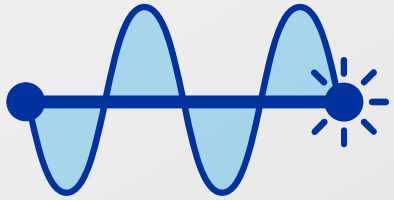
Intelligent directional beam forming & beam tracking

Increase coverage & provide continuous connectivity



Tight interworking with sub 6 GHz

Increase robustness and faster system acquisition



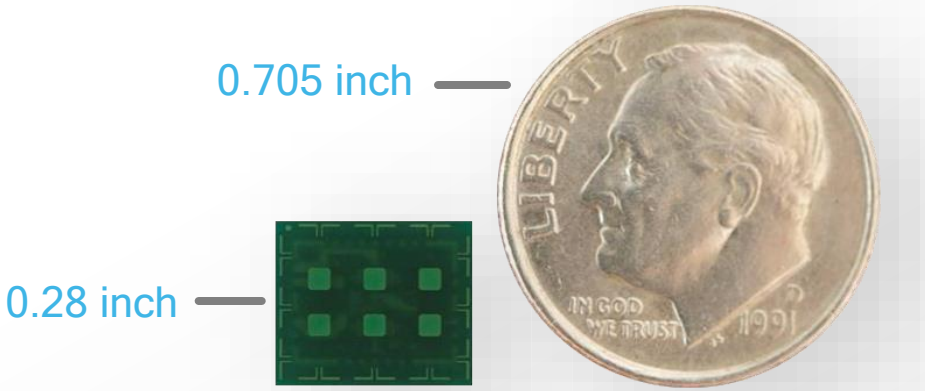
Optimized mmWave design for mobile

To meet cost, power & thermal constraints

Making mmWave a reality for mobile

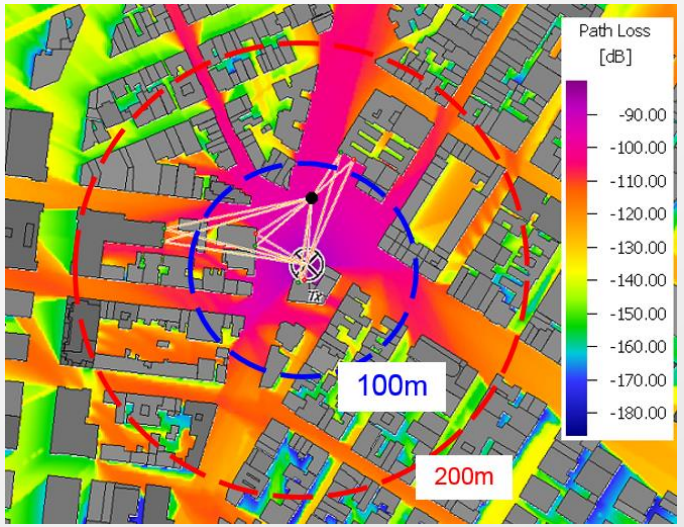
Qualcomm is driving 5G mmWave

60 GHz chipset commercial today for mobile devices



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

Developing robust 5G mmWave for extreme mobile broadband



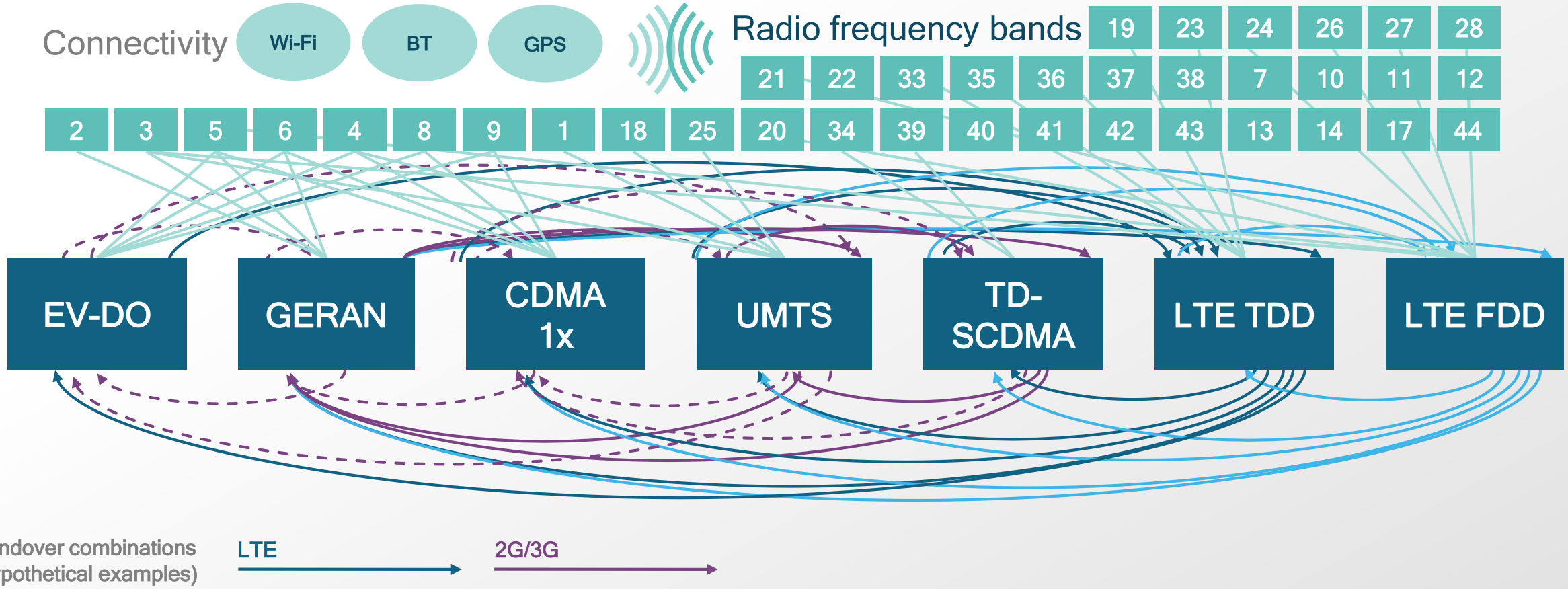
Manhattan 3D map
Results from ray-tracing^

28 GHz outdoor example with ~150m dense urban LOS and NLOS coverage using directional beamforming^

Qualcomm VIVE is a product of Qualcomm Atheros, Inc.;
^ Based on Qualcomm Technologies Inc. simulations

Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving



Source: Qualcomm Technologies Inc.

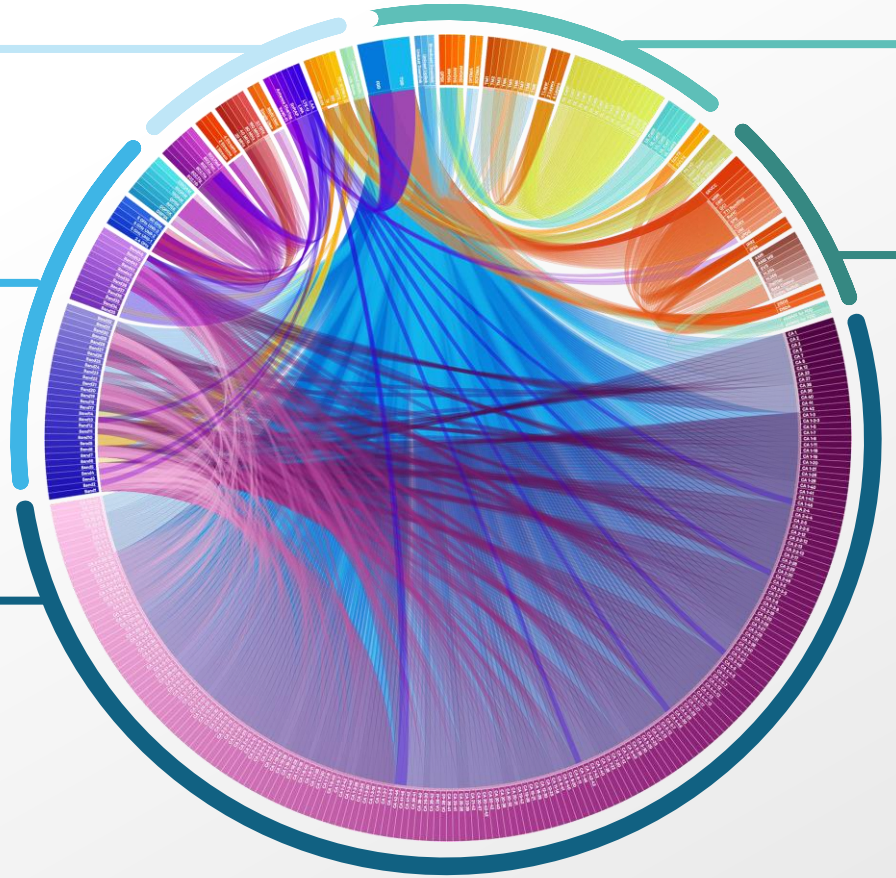
Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving

Wi-Fi, 3G, 2G technologies

50+ spectrum bands 450 MHz-5.8 GHz (licensed and unlicensed)

~200 Carrier Aggregation combinations



4G LTE OFDM-based waveforms, transmission modes, and UE categories

New LTE services, e.g. LTE Broadcast, VoLTE

2000+

modem features to-date and counting

Source: Qualcomm Technologies Inc.

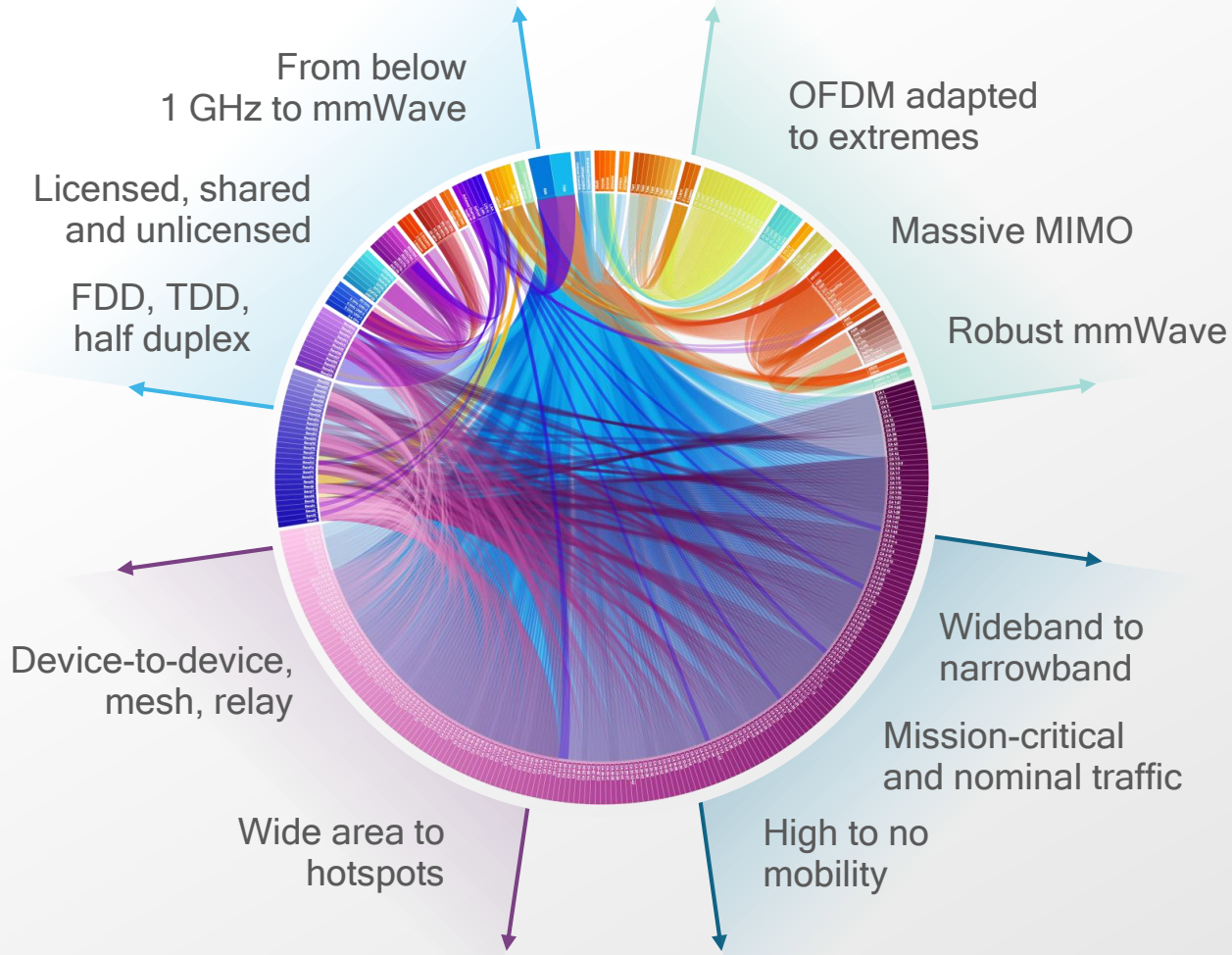
2012 LTE Multimode | Today–LTE evolution | Tomorrow–5G and LTE evolution

Modem and RFFE leadership critical

Roadmap to 5G is significantly more complex and faster moving

Many more spectrum bands/types

More diverse deployment scenarios



Advanced wireless technologies

A much wider variation of use cases

Source: Qualcomm Technologies Inc.

2012 LTE Multimode | Today–LTE evolution | Tomorrow–5G and LTE evolution

Leading the world to 5G

A unifying connectivity fabric for the next decade and beyond

Connecting new industries and devices

Empowering new user experiences

Enabling new services

Delivering new levels of efficiency

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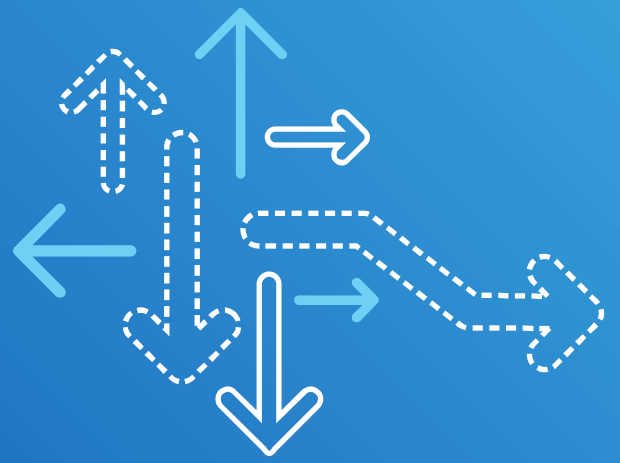

Thank you

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