Challenges and Design Aspects for 5G Wireless Networks

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Challenges and Design Aspects for 5G Wireless Networks

Talk Outline

- Background on evolution of cellular wireless networks
- Technical goals and timeline for 5G
- 5G design aspects
  - Air interface overall
  - Mobile broadband
  - Mission critical
  - Massive IOT
  - Shared Spectrum
- Q & A and perspectives on research challenges

Mobile fueled the last 30 years—interconnecting people

1G
1980s
Analog voice
AMPS, NMT, TACS

2G
1990s
Digital voice
D-AMPS, GSM, IS-95 (CDMA)

3G
2000s
Mobile broadband
WCDMA/HSPA+, CDMA2000/EV-DO

4G
2010s
Mobile Internet
LTE, LTE Advanced

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

A unifying connectivity fabric

Always-available, secure cloud access

Enhanced mobile broadband

Mission-critical services

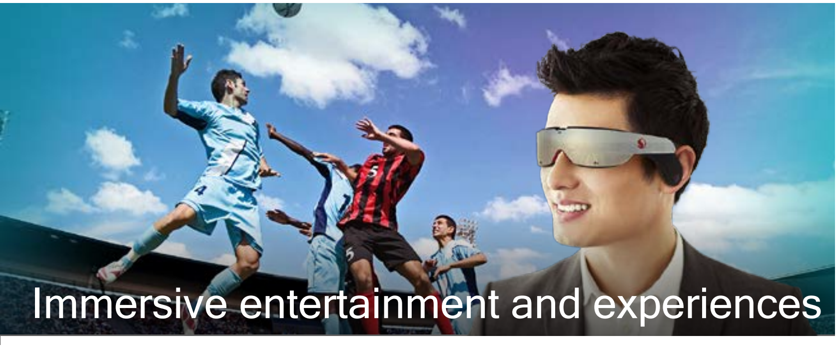
Massive Internet of Things

Unifying connectivity platform for future innovation

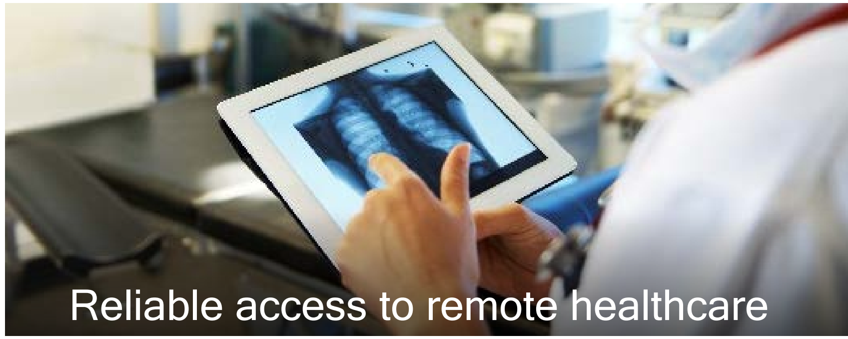
Convergence of spectrum types/bands, diverse services, and deployments, with new technologies to enable a robust, future-proof 5G platform

5G will redefine a wide range of industries

A platform for new connected services - existing, emerging and unforeseen


Immersive entertainment and experiences


Safer, more autonomous transportation

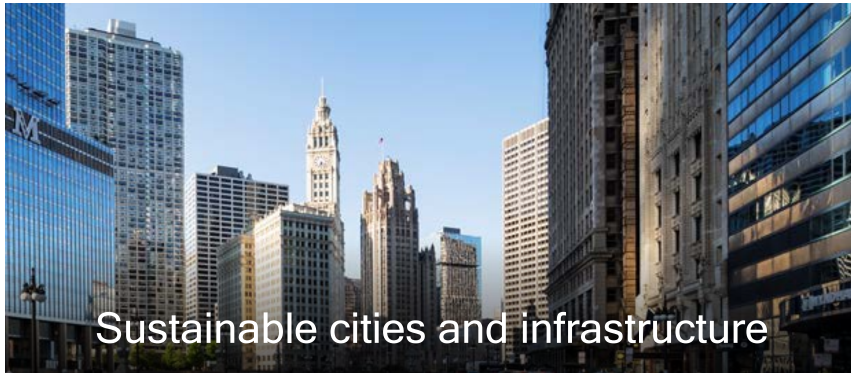

Reliable access to remote healthcare


Improved public safety and security


Smarter agriculture

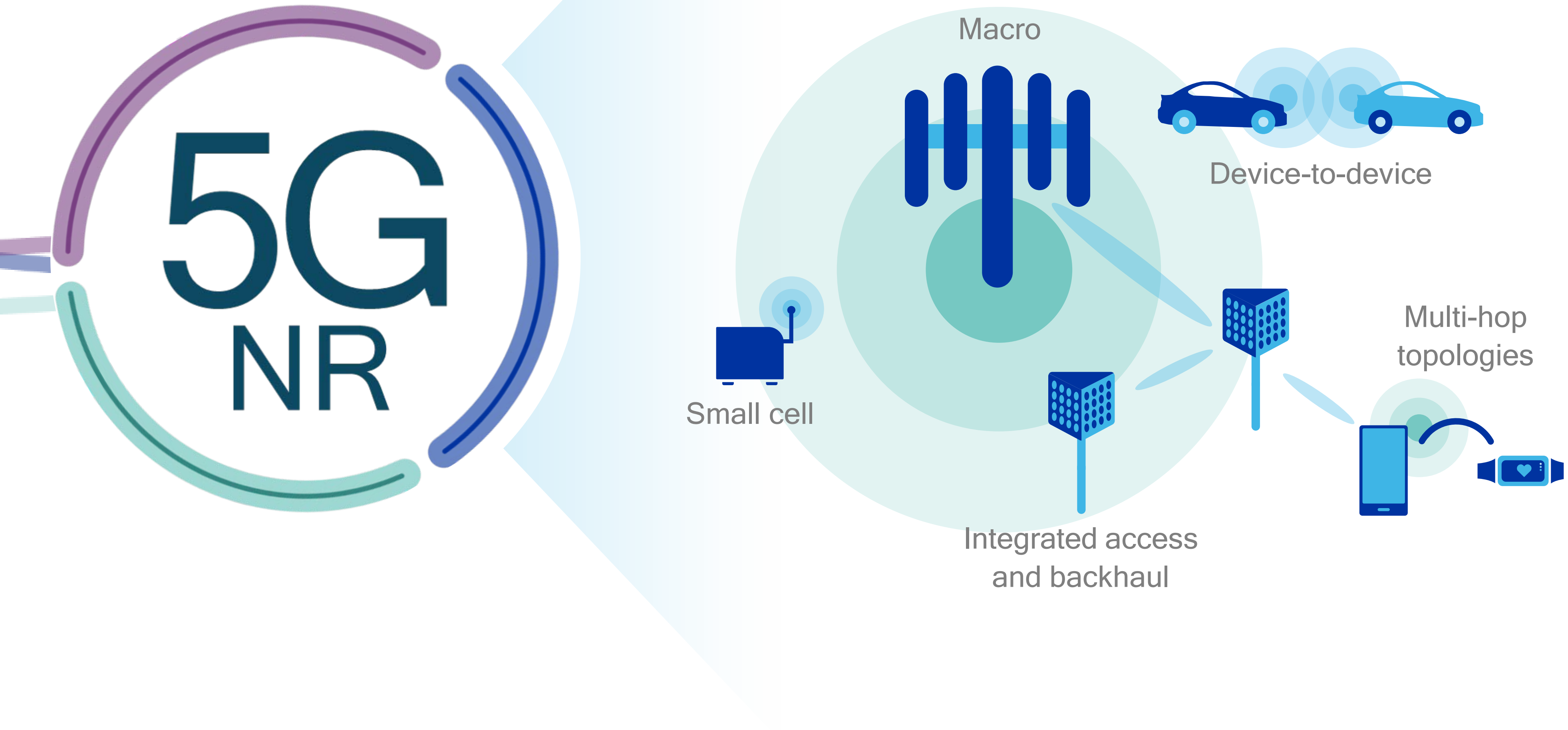

More efficient use of energy/utilities


More autonomous manufacturing


Sustainable cities and infrastructure


Digitized logistics and retail

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

Getting the most out of every bit of diverse spectrum

5G NR

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

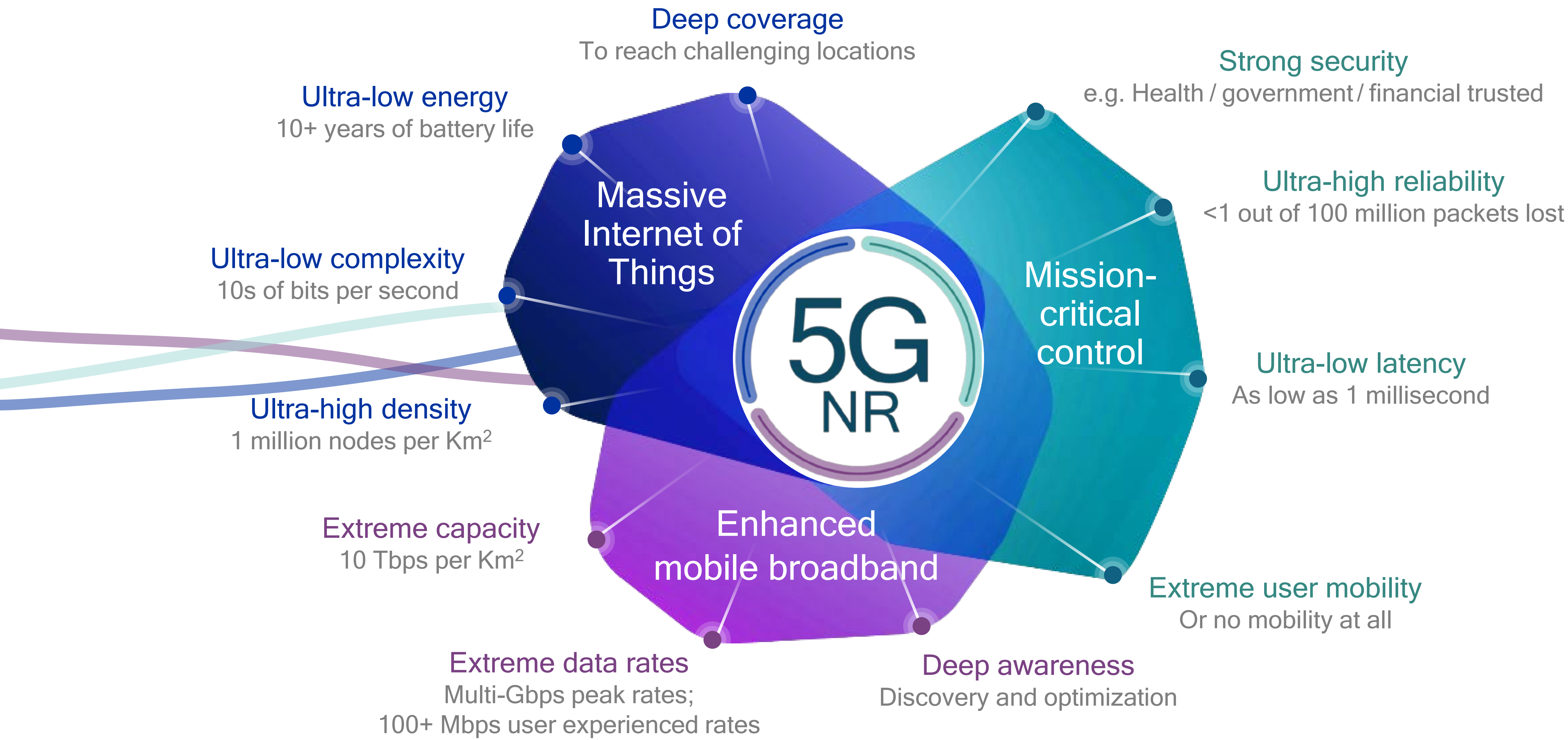
High bands above 24 GHz (mmWave): extreme bandwidths
e.g. 24.25-27.5 GHz, 27.5-29.5, 37-40, 64-71 GHz

Licensed Spectrum
Exclusive use

Shared Spectrum
New shared spectrum paradigms

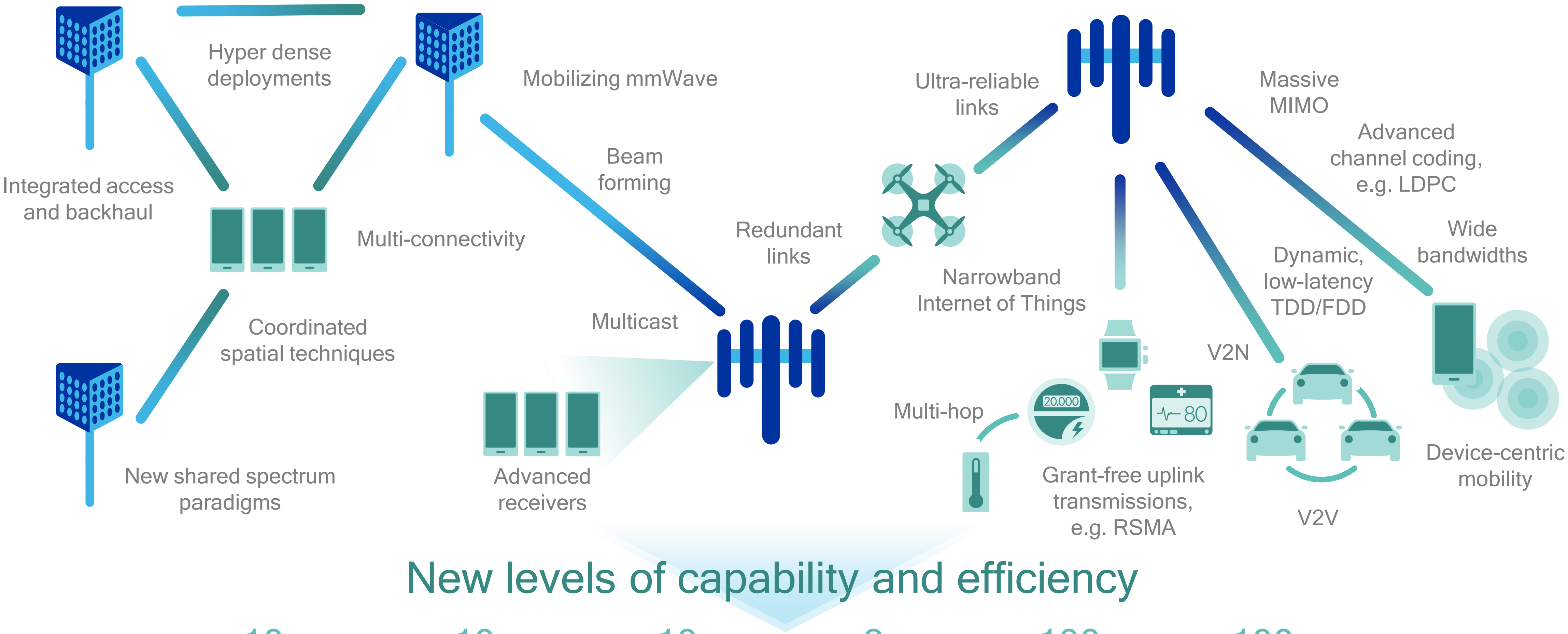
Unlicensed Spectrum
Shared use

Scalability to address diverse service and devices



Based on target requirements for the envisioned 5G use cases

Pioneering new technologies to meet 5G NR requirements



New levels of capability and efficiency

10x experienced throughput

10x decrease in end-to-end latency

10x connection density

3x spectrum efficiency

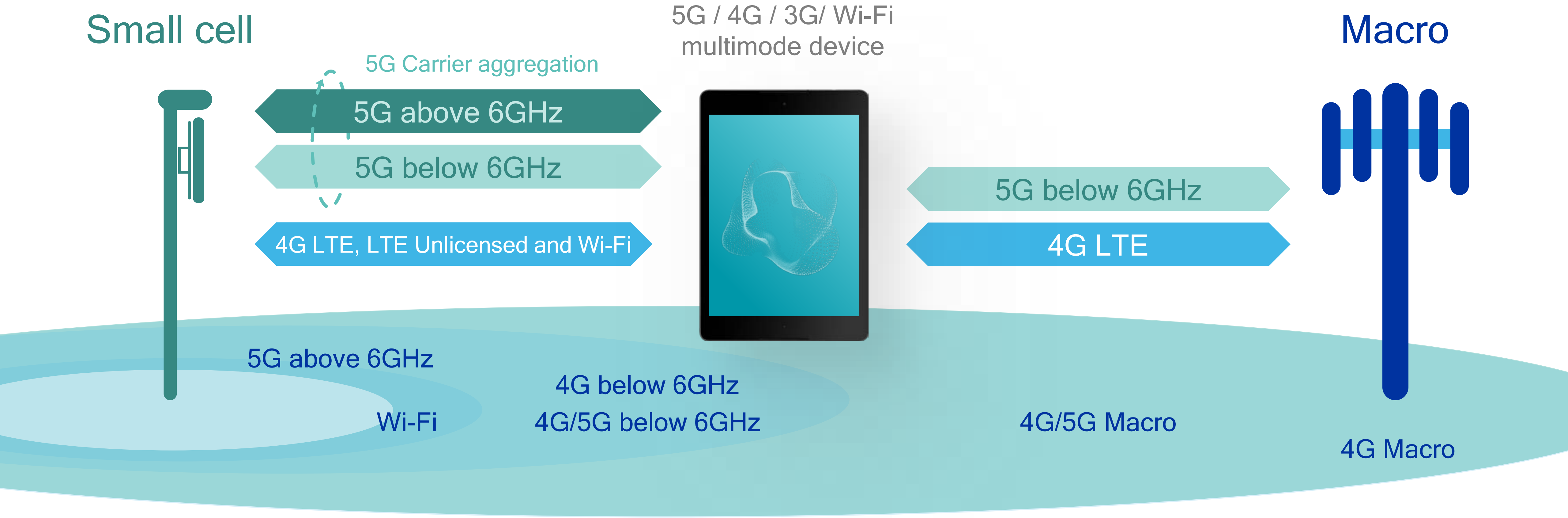
100x traffic capacity

100x network efficiency

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

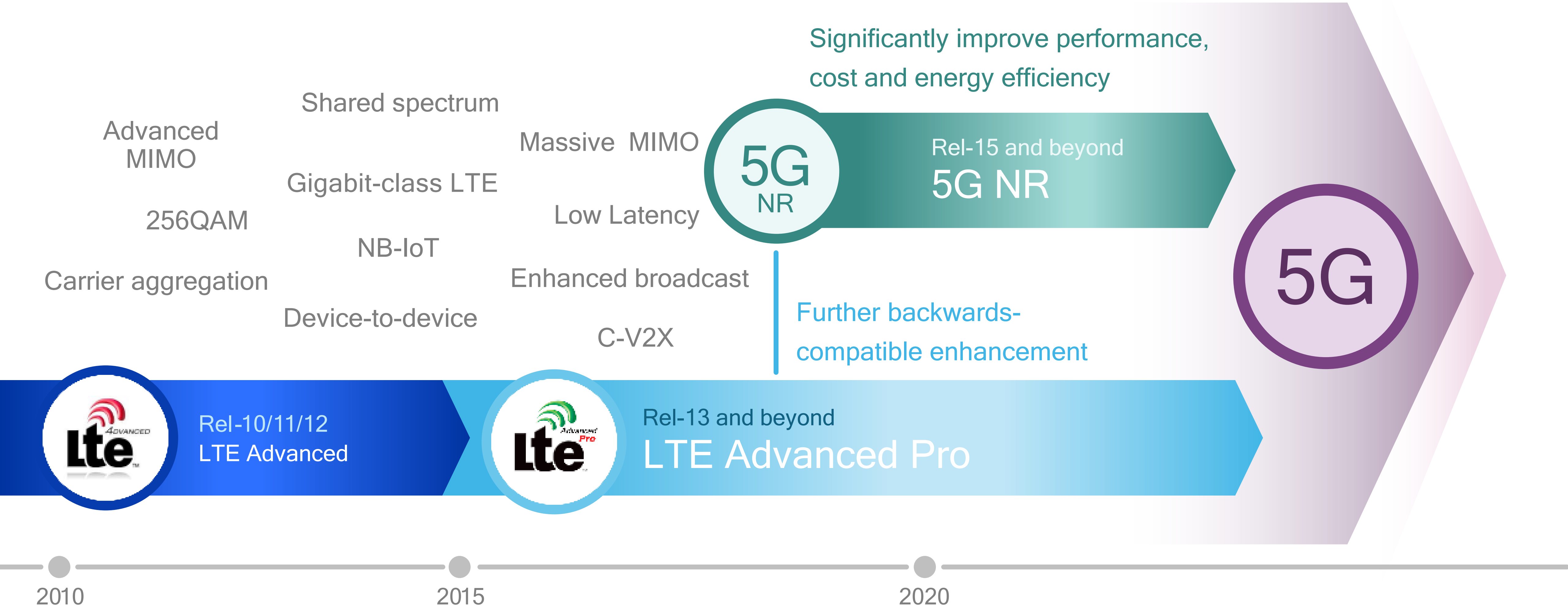
Simplifying 5G deployments with multi-connectivity

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



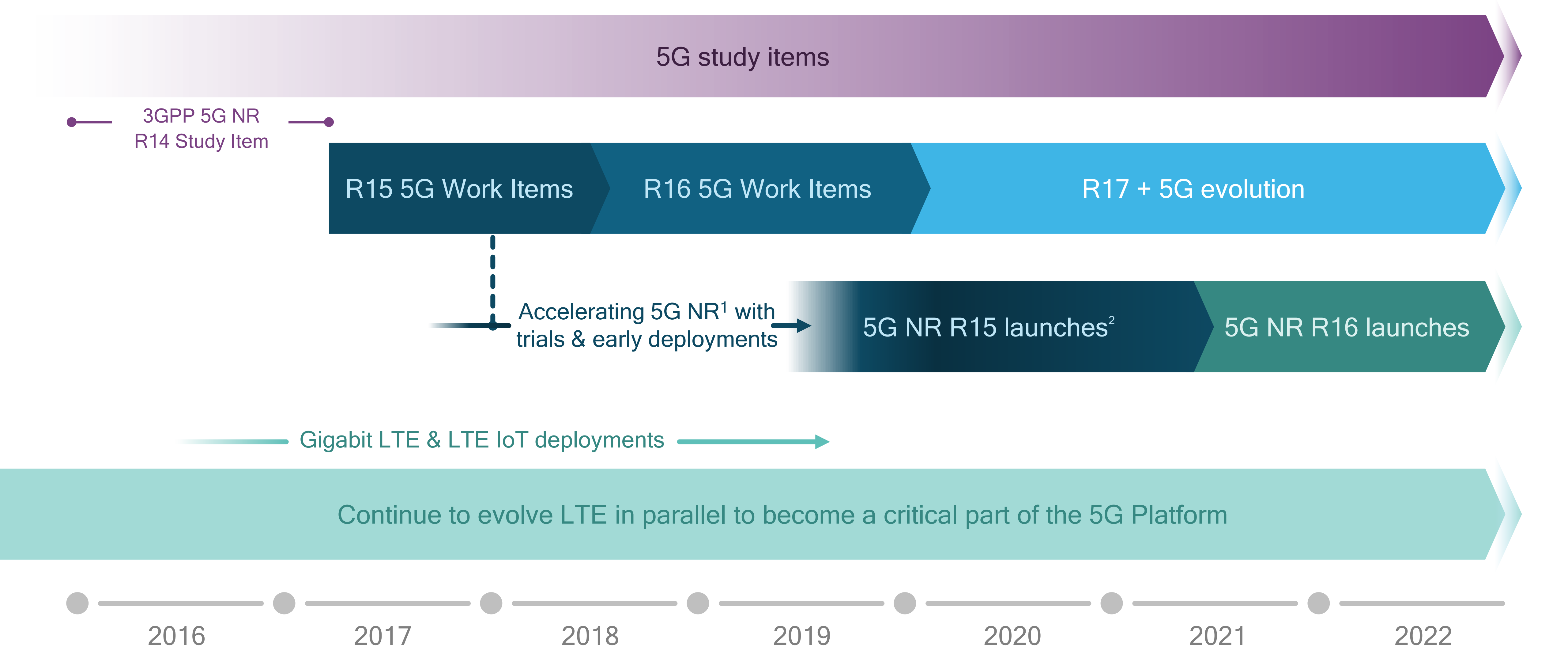
5G NR radio access designed to utilize LTE anchor for mobility management (non-standalone) or operate stand-alone with new multi-access 5G NextGen Core Network (NGCN)

The path to 5G includes a strong LTE foundation



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

5G NR standardization progressing for 2019 launches



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

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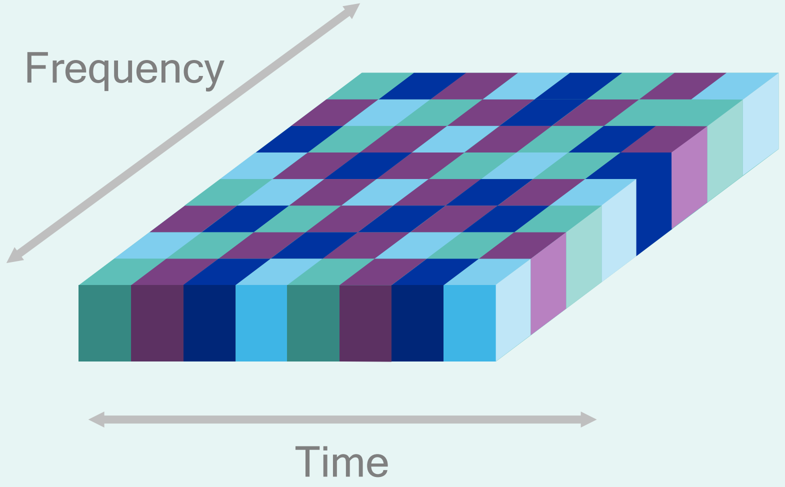
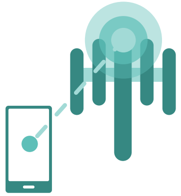
OFDM family is the right choice for 5G mobile broadband and beyond

Adapted for scaling to an extreme variations of 5G requirements



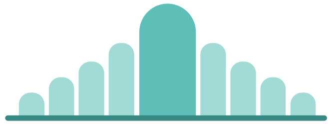
Spectral efficiency

Efficient framework for MIMO spatial multiplexing



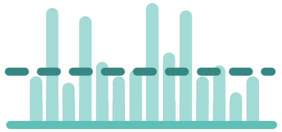
Low complexity

Low complexity receivers even when scaling to wide bandwidths



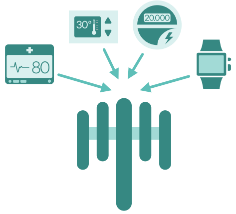
Frequency localization

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

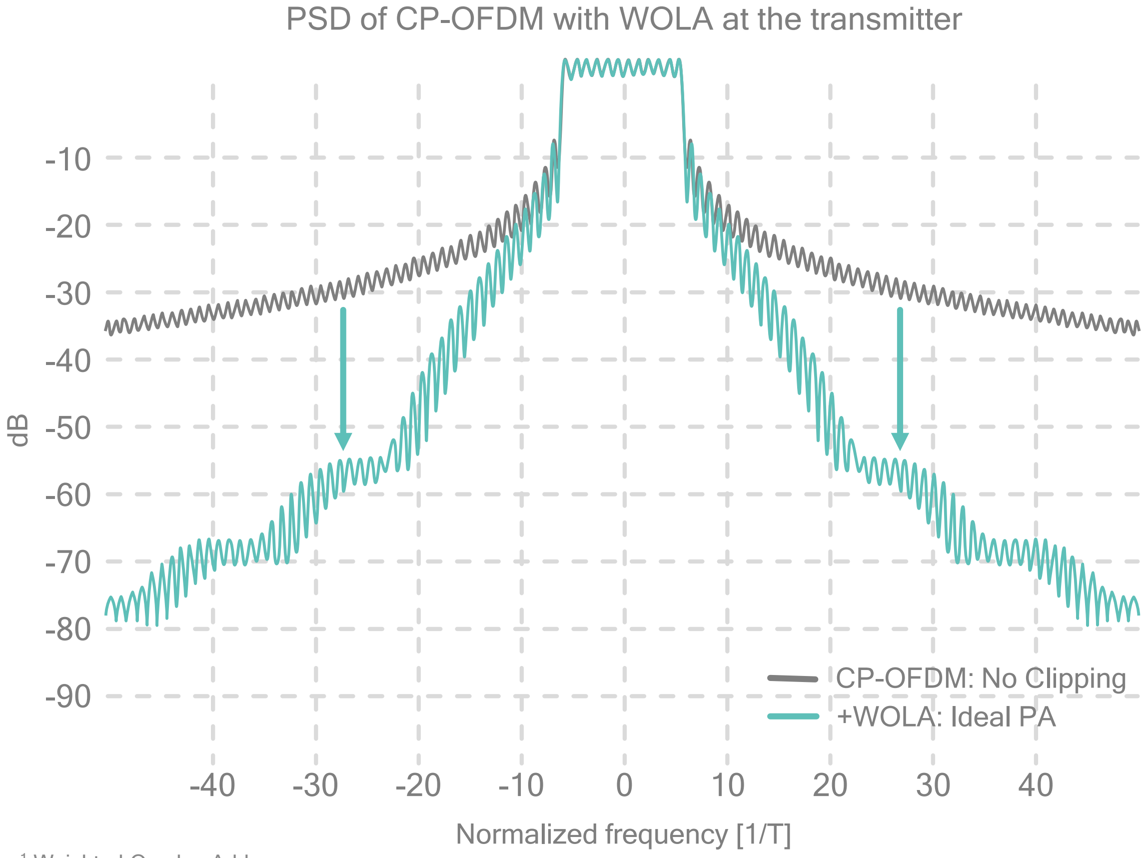
Co-exist with optimized waveforms and multiple access for wide area IoT

[1] Weighted Overlap Add; [2] Such as Resource Spread Multiple Access (RSMA) - more details later in presentation

Efficient service multiplexing with windowed OFDM

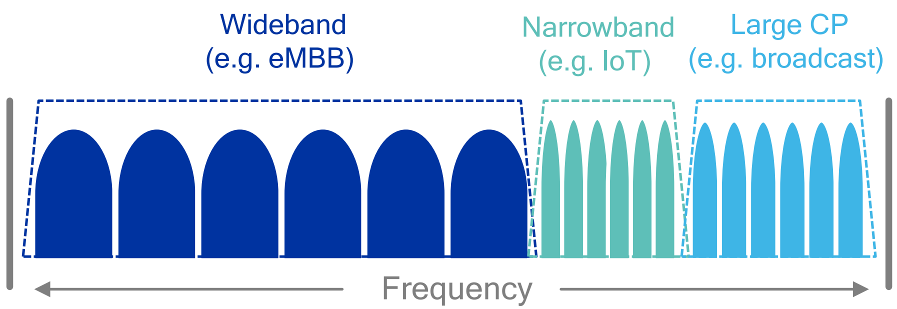
OFDM with WOLA[1] windowing

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

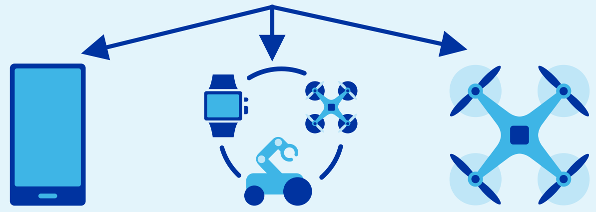
[1] Weighted Overlap Add

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 α≈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

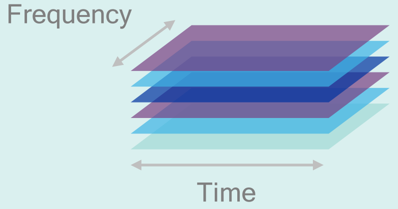
Massive IoT

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

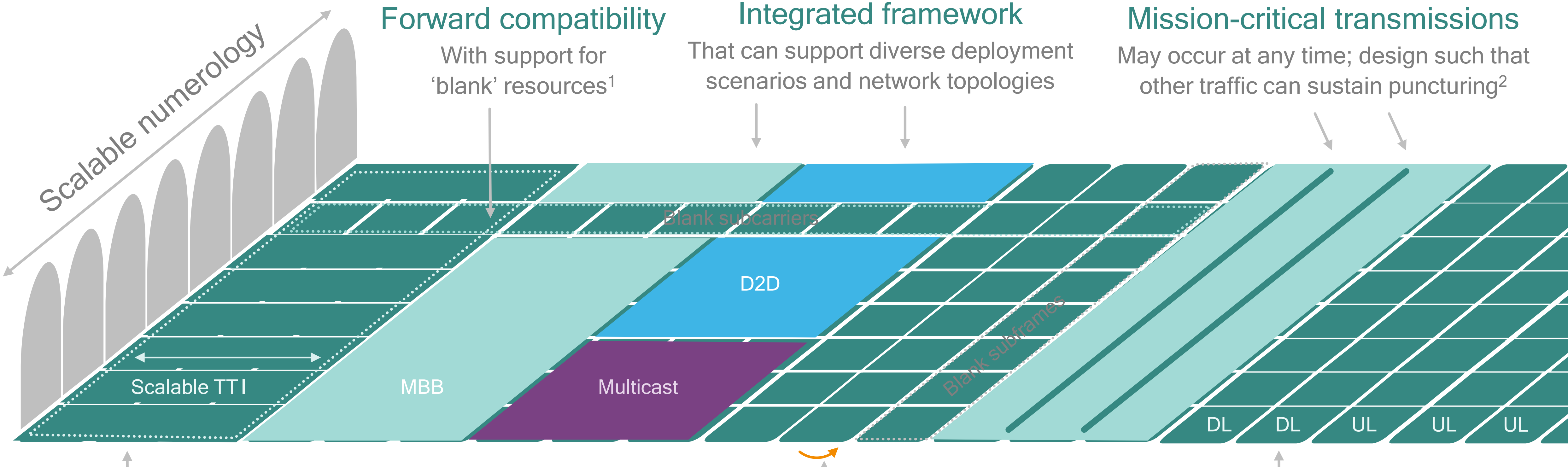
A flexible framework with forward compatibility

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

Forward compatibility
With support for 'blank' resources[1]

Integrated framework
That can support diverse deployment scenarios and network topologies

Mission-critical transmissions
May occur at any time; design such that other traffic can sustain puncturing[2]



Scalable transmission time interval (TTI)
For diverse latency requirements–capable of latencies an order of magnitude lower than LTE

Self-contained integrated subframe
UL/DL scheduling info, data and acknowledgement in the same sub-frame

Dynamic uplink/downlink
Faster switching for more flexible capacity based on traffic conditions

[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

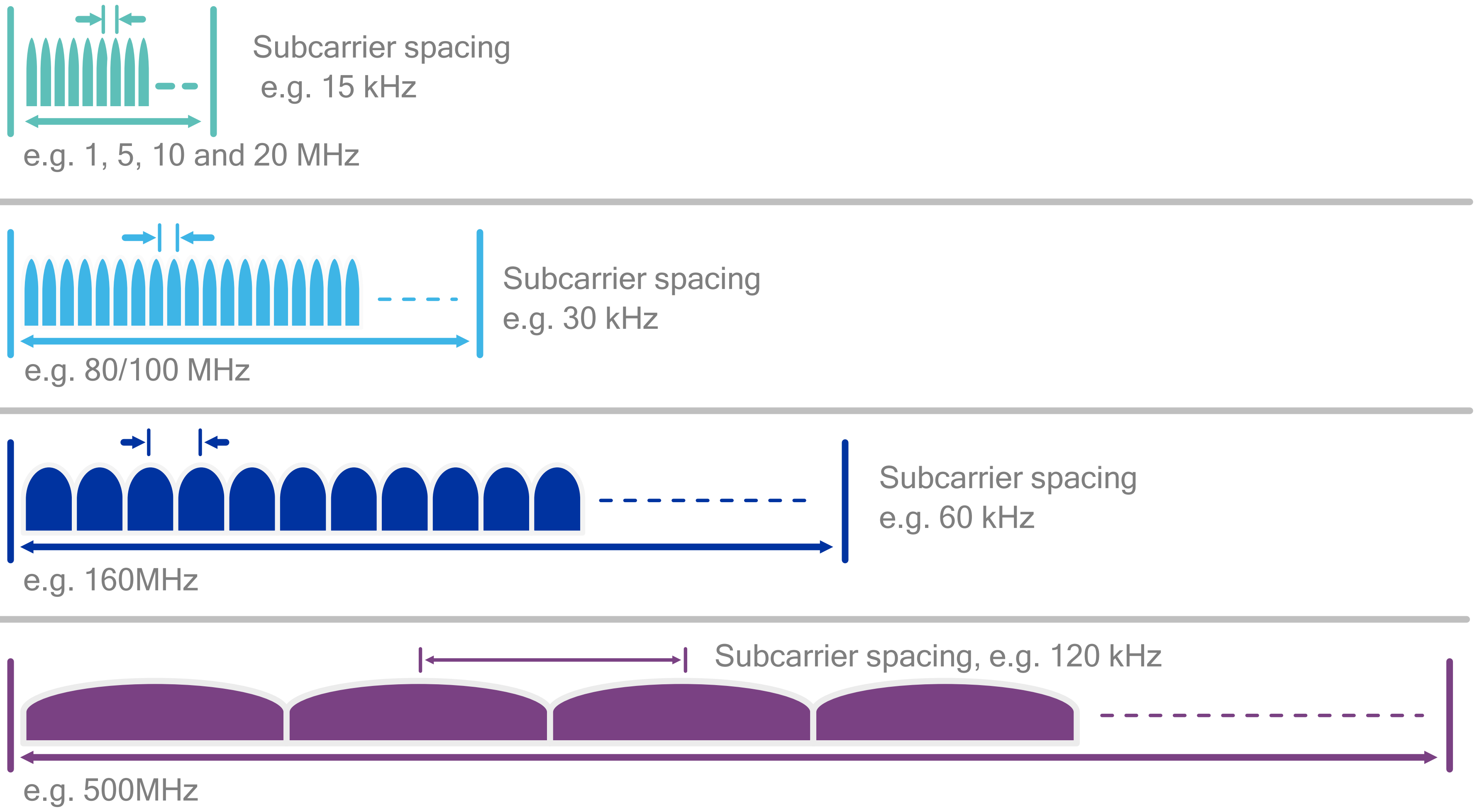
Efficiently address diverse spectrum, deployments and services

Outdoor and macro coverage
FDD/TDD <3 GHz

Outdoor and small cell
TDD > 3 GHz

Indoor wideband
TDD e.g. 5 GHz (Unlicensed)

mmWave
TDD e.g. 28 GHz



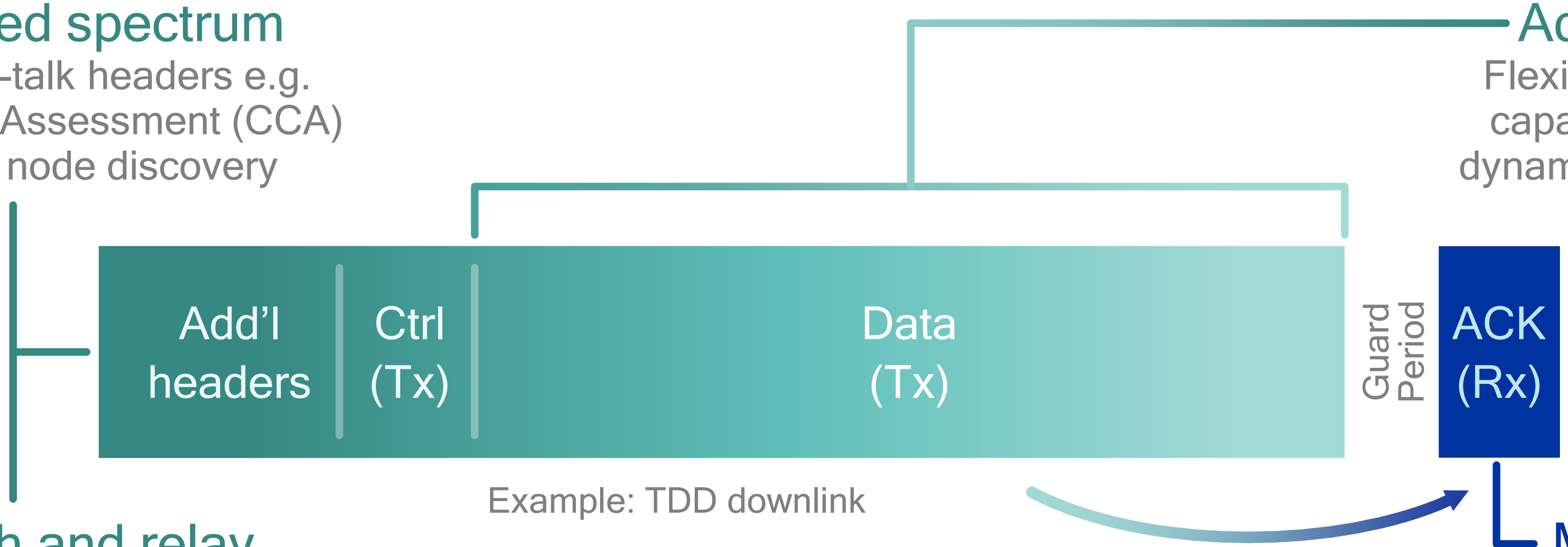
Example usage models and channel bandwidths

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

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



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

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

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

Enhanced Mobile Broadband

- Wider bandwidths
- Mobilizing mmWave
- Shared spectrum
- Device-centric mobility
- Dynamic, low-latency TDD/FDD
- Massive MIMO
- Advanced channel coding
- Native HetNet and multicast support

5G

Enhancing mobile broadband

Extreme throughput

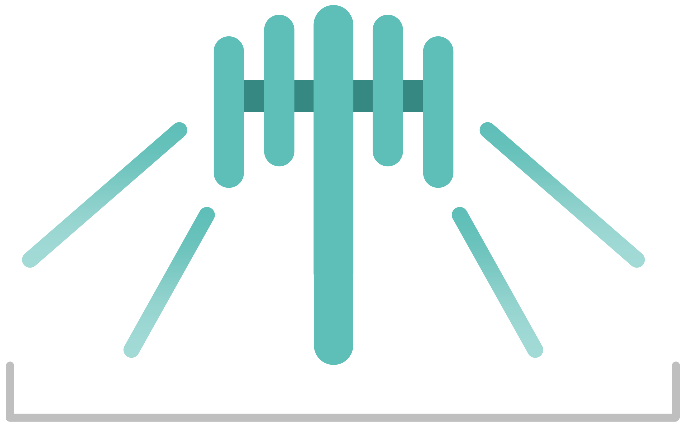
Ultra-low latency

Uniform experience

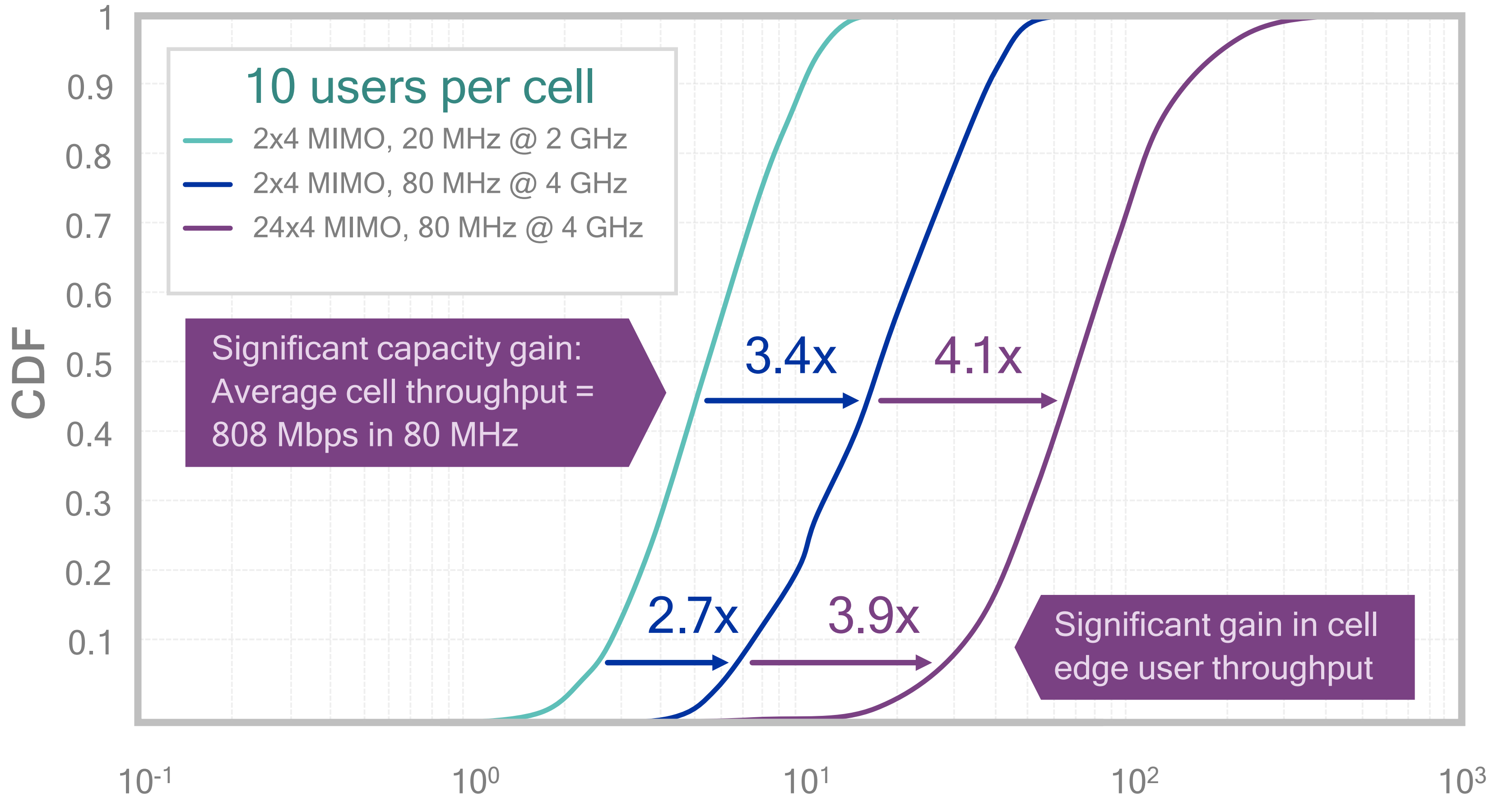
Massive MIMO is a key enabler for higher spectrum bands

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

Macro site



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



Realizing the mmWave opportunity for mobile broadband

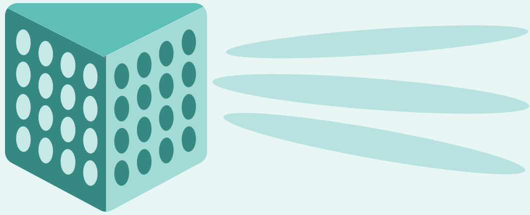
Extreme bandwidth opportunity

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

Mobilizing mmWave challenge

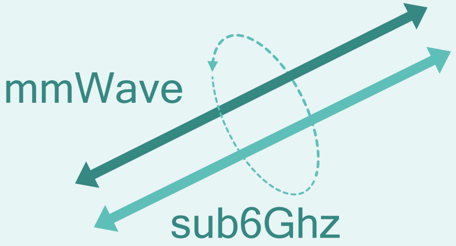
- Robustness due to high path loss and susceptibility to blockage
- Device cost/power and RF challenges at mmWave frequencies

5G NR



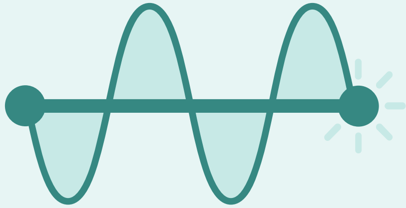
Smart beamforming and beam tracking

Increase coverage and minimize interference



Tight interworking with sub 6 GHz

Increase robustness, faster system acquisition



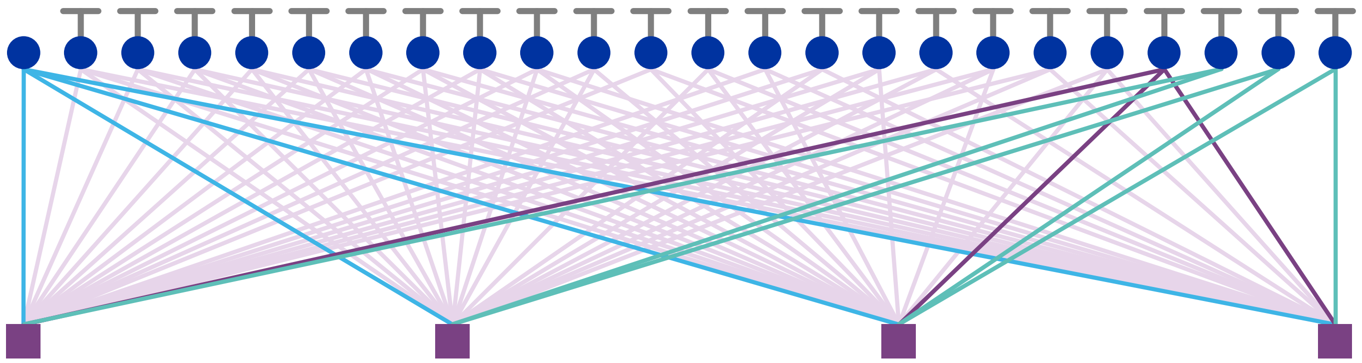
Optimized mmWave design for mobile

To meet cost, power and thermal constraints

Learn more at: www.qualcomm.com/documents/promise-5g-mmwave-how-do-we-make-it-mobile

Delivering advanced 5G NR channel coding

ME-LDPC[1] codes more efficient than today's LTE Turbo codes at higher data rates



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

Designing Polar coding for control channels

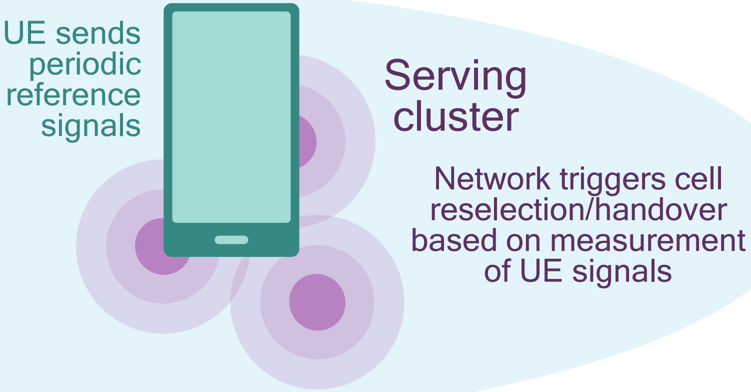
[1] Multi-Edge Low-Density Parity-Check;

Device-centric mobility management in 5G NR

Control plane improvements to improve energy and overhead efficiency

Edgeless mobility zone

(area of tightly coordinated cells)

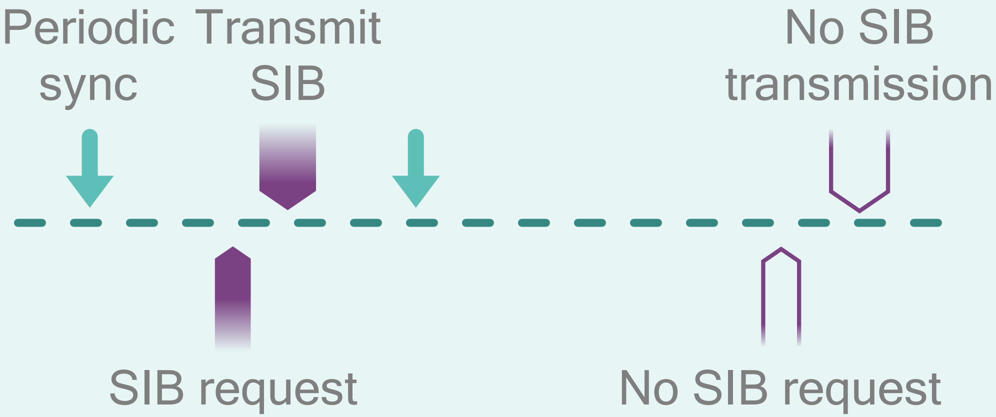


Lightweight mobility for device energy savings

- 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]



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

5G

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

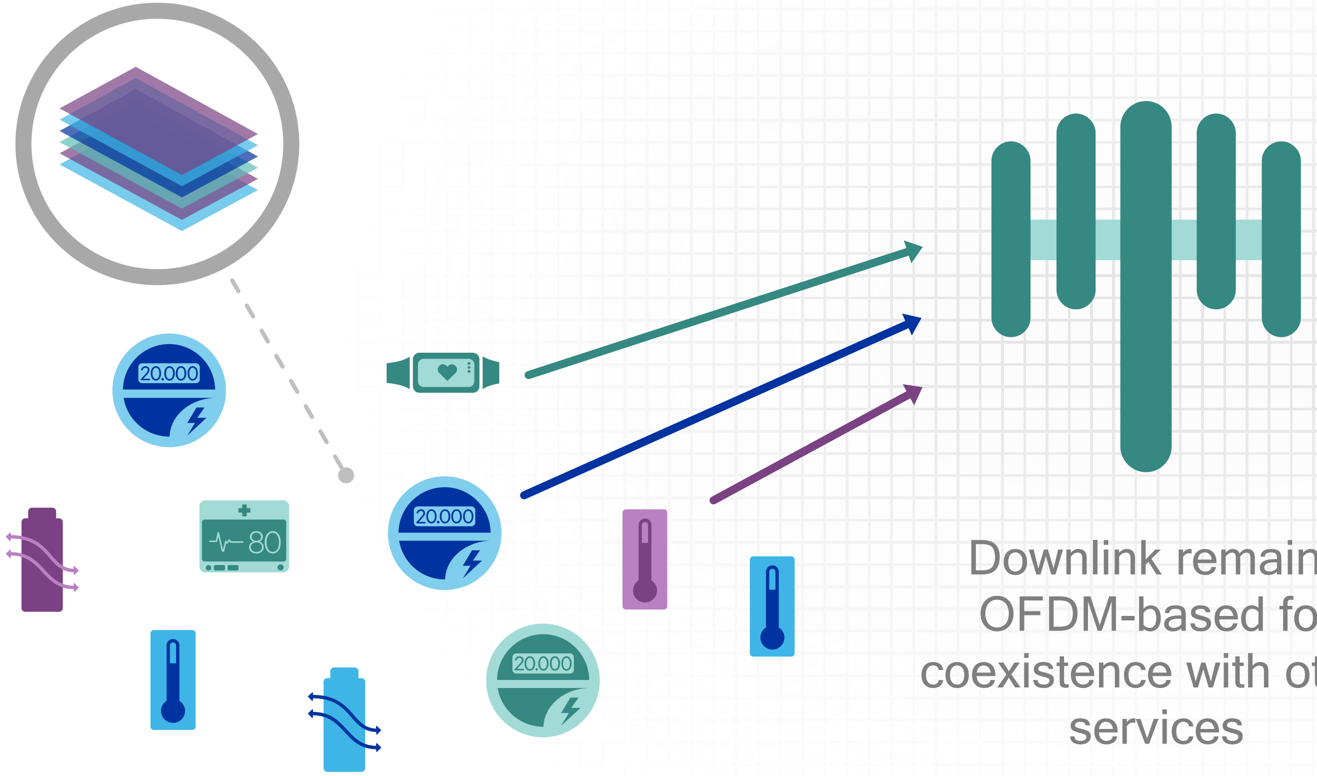
[1] Resource Spread Multiple Access

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

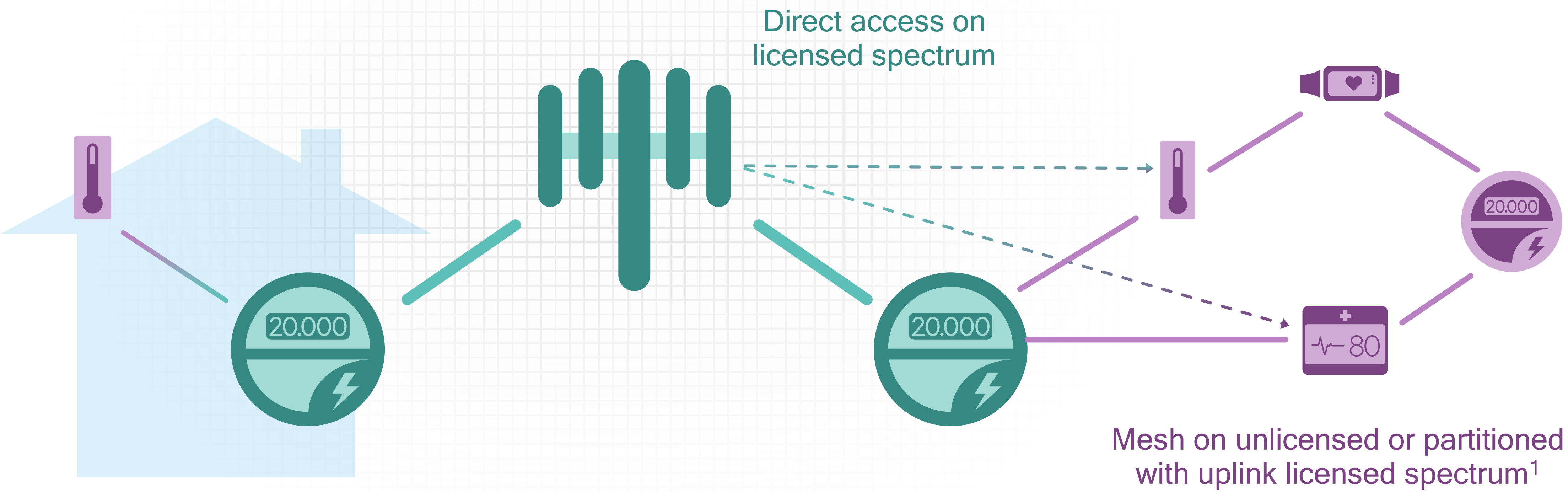
- Eliminates signaling overhead for assigning dedicated resources
- Allows devices to transmit data asynchronously
- Capable of supporting full mobility



Downlink remains OFDM-based for coexistence with other services

Increased battery life | Scalability to massive # of things | Better link budget

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

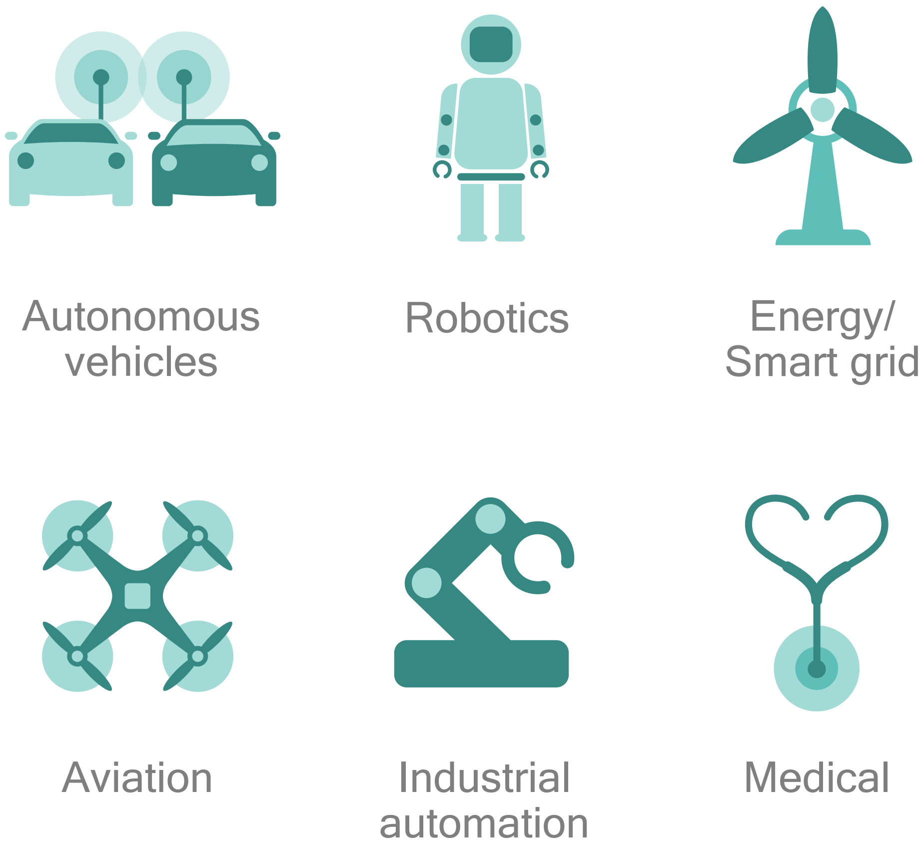
High reliability

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

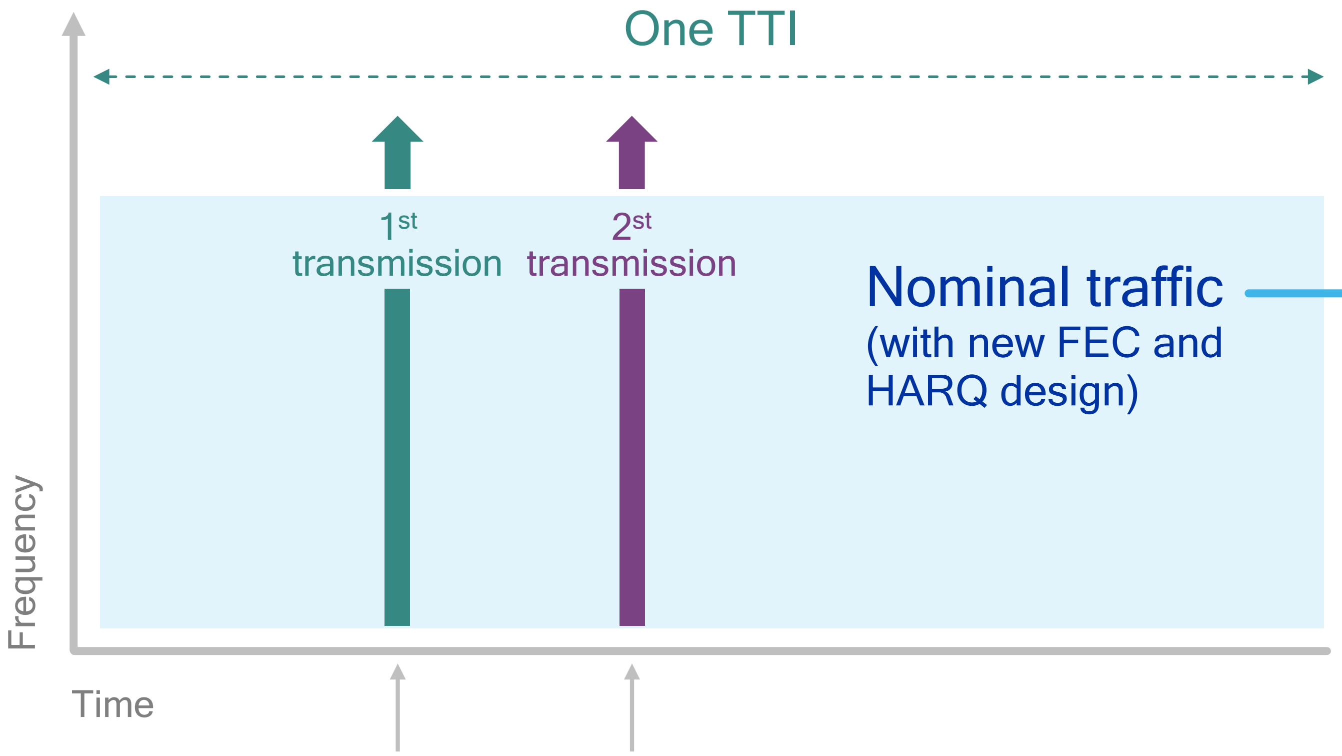
Ultra-high availability
Simultaneous links to both 5G and LTE for failure tolerance and extreme mobility

Strong e2e security
Security enhancements to air interface, core network, & service layer across verticals[1]

[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)



Design such that other traffic can sustain puncturing from mission-critical transmission

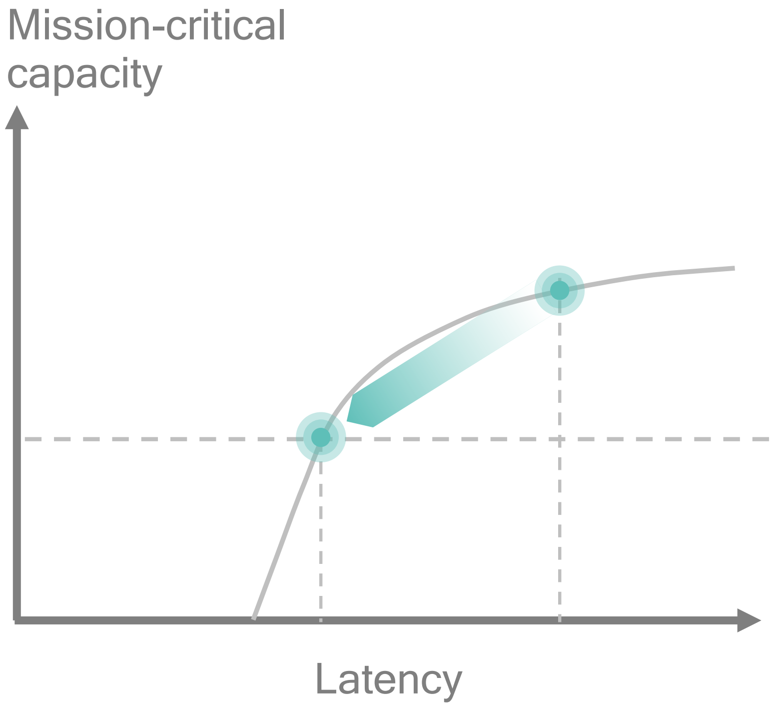
Mission-critical transmission
may occur at any time and cannot wait for scheduling

Opportunity for uplink RSMA non-orthogonal access using OFDM waveforms

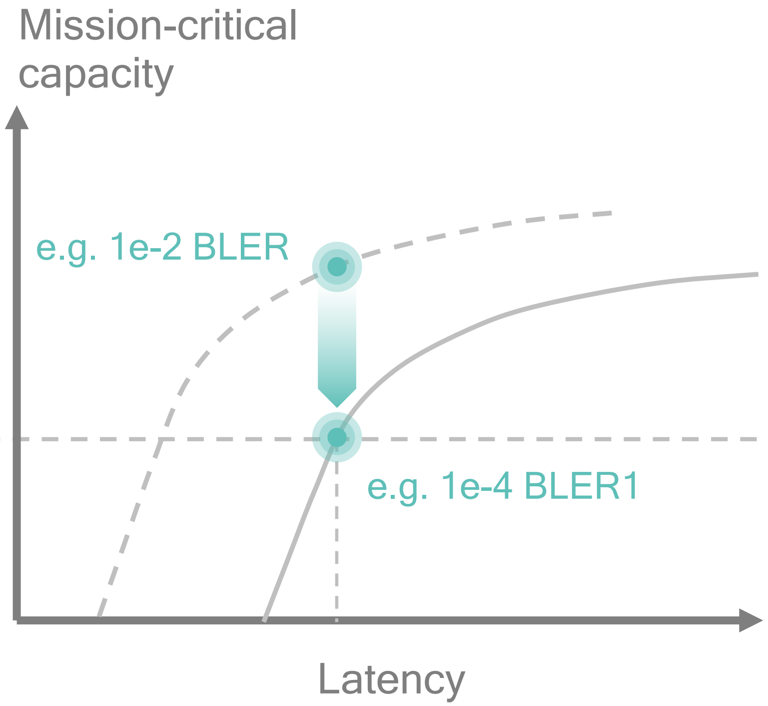
New 5G design allows for optimal trade-offs

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

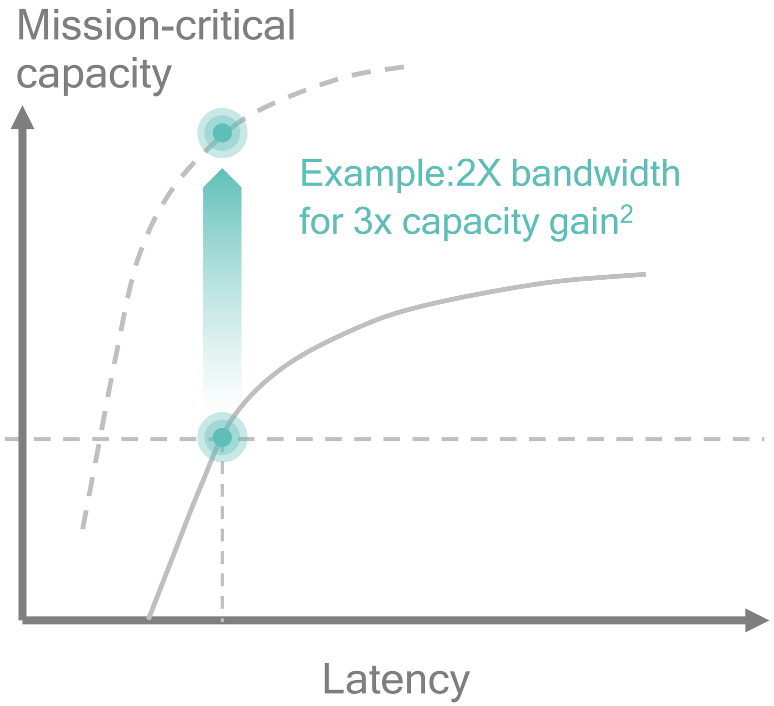
Latency vs. capacity…



Reliability vs. capacity…



But wider bandwidth can offset reductions



[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.

5G Shared Spectrum

5G
NR

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

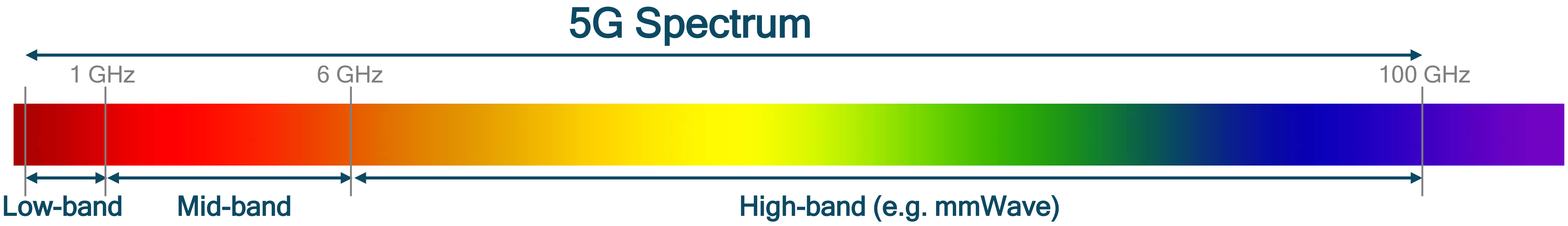
High bands above 24 GHz (mmWave)
Extreme bandwidths

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

The FCC is driving key spectrum initiatives to enable 5G

Across low-band, mid-band, and high-band including mmWave



Low-band

Broadcast Incentive Auction

- First stage auction opened up 126 MHz in 600 MHz band
- 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]

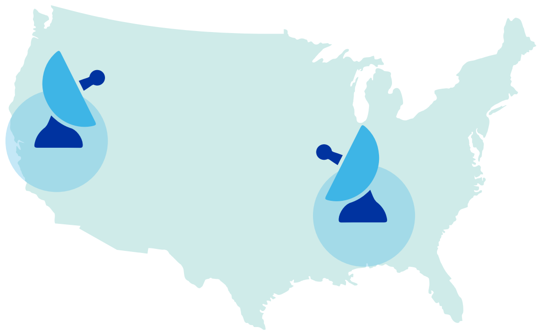
- Opening up 11 GHz in multiple mmWave bands
- 70% of newly opened spectrum is shared or unlicensed
- Unanimously approved by FCC with additional candidate bands identified for IMT-2020

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.

Shared/unlicensed spectrum is important for 5G

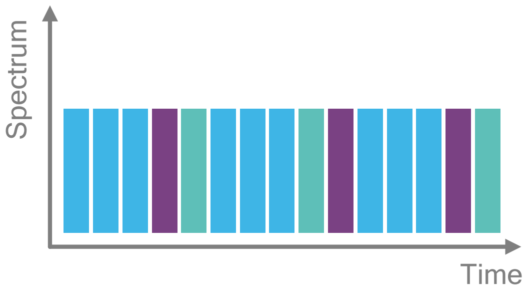
Unlocking more spectrum

Shared spectrum can unlock spectrum that is lightly used by incumbents



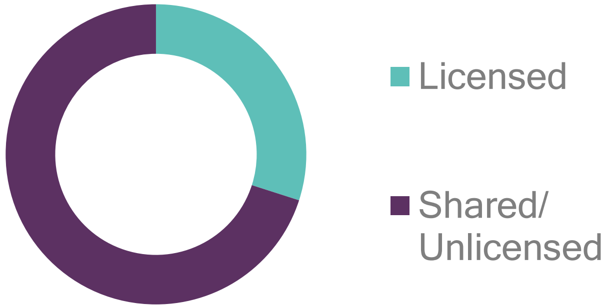
High spectrum utilization

Spectrum sharing has the potential to increase spectrum utilization



A lot of spectrum may be shared/unlicensed

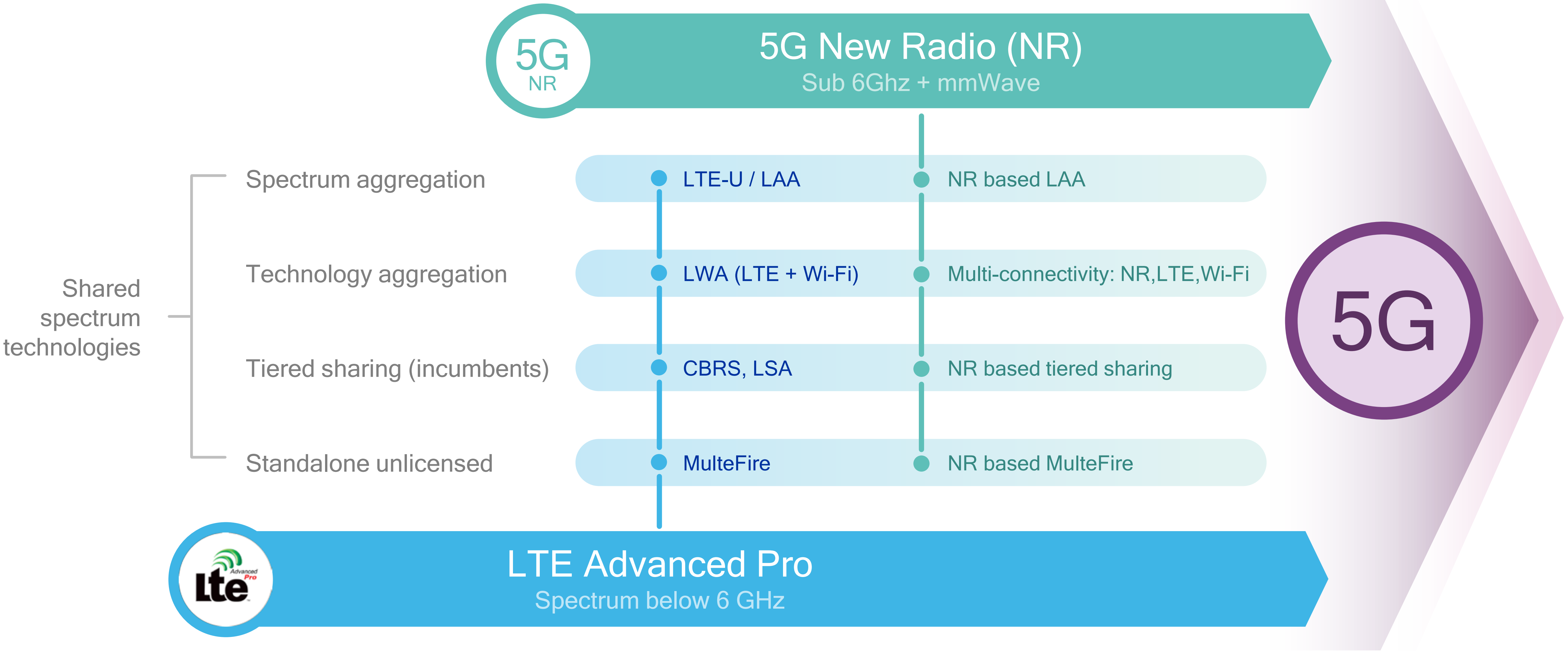
FCC recent decision on high-band spectrum included a significant portion of shared/unlicensed[1]



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.

Pioneering 5G shared spectrum today

Building on LTE-U/LAA, LWA, CBRS/LSA and MulteFire[1]

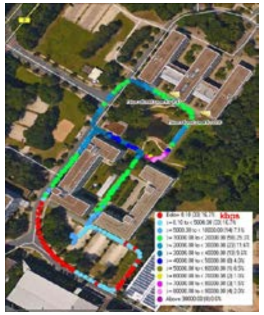


1) Licensed-Assisted Access (LAA), LTE Wi-Fi Link Aggregation (LWA), Citizen Broadband Radio Service (CBRS), Licensed Shared Access (LSA)

LTE is the high performance option in unlicensed spectrum

LAA ~2X coverage outdoors compared to Wi-Fi[1]

LAA



LWA (Wi-Fi)

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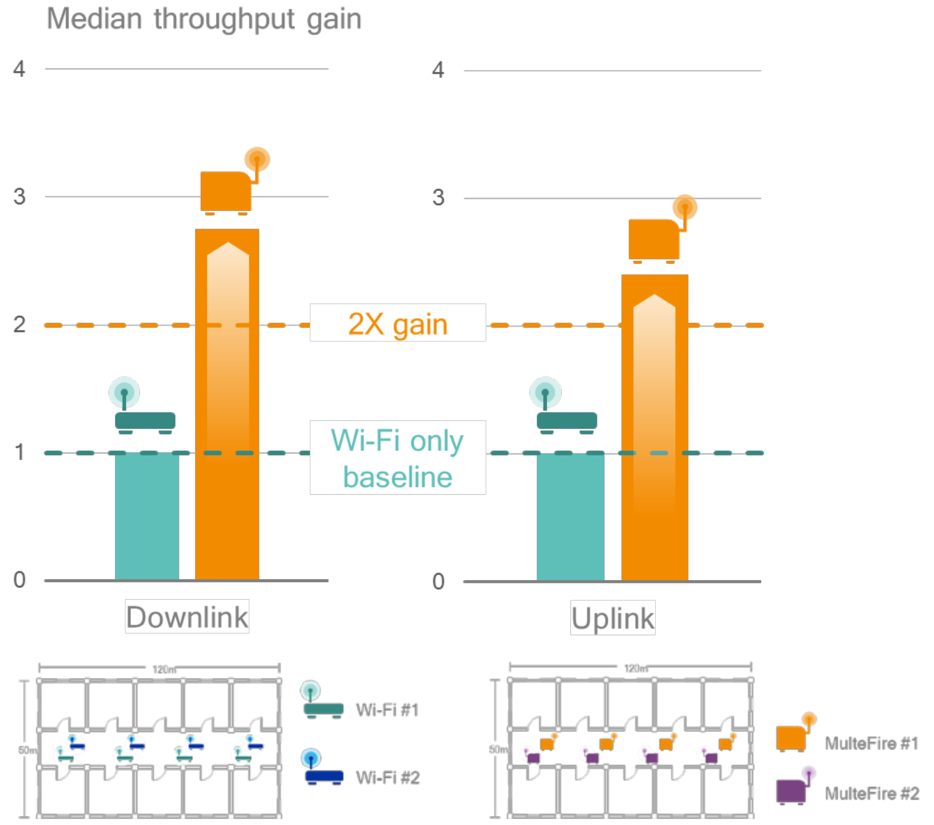
Downlink coverage in unlicensed

Mbps	Wi-Fi	LAA
>10	24% of route	60% of route (x2.5)
>1	39% of route	71% of route (x1.8)
>0	47% of route	82% of route (X1.7)

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 Based on geo-binned measurements over test route; 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

CBRS introduces a 3-tiered shared spectrum

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

Tier 1
Incumbents

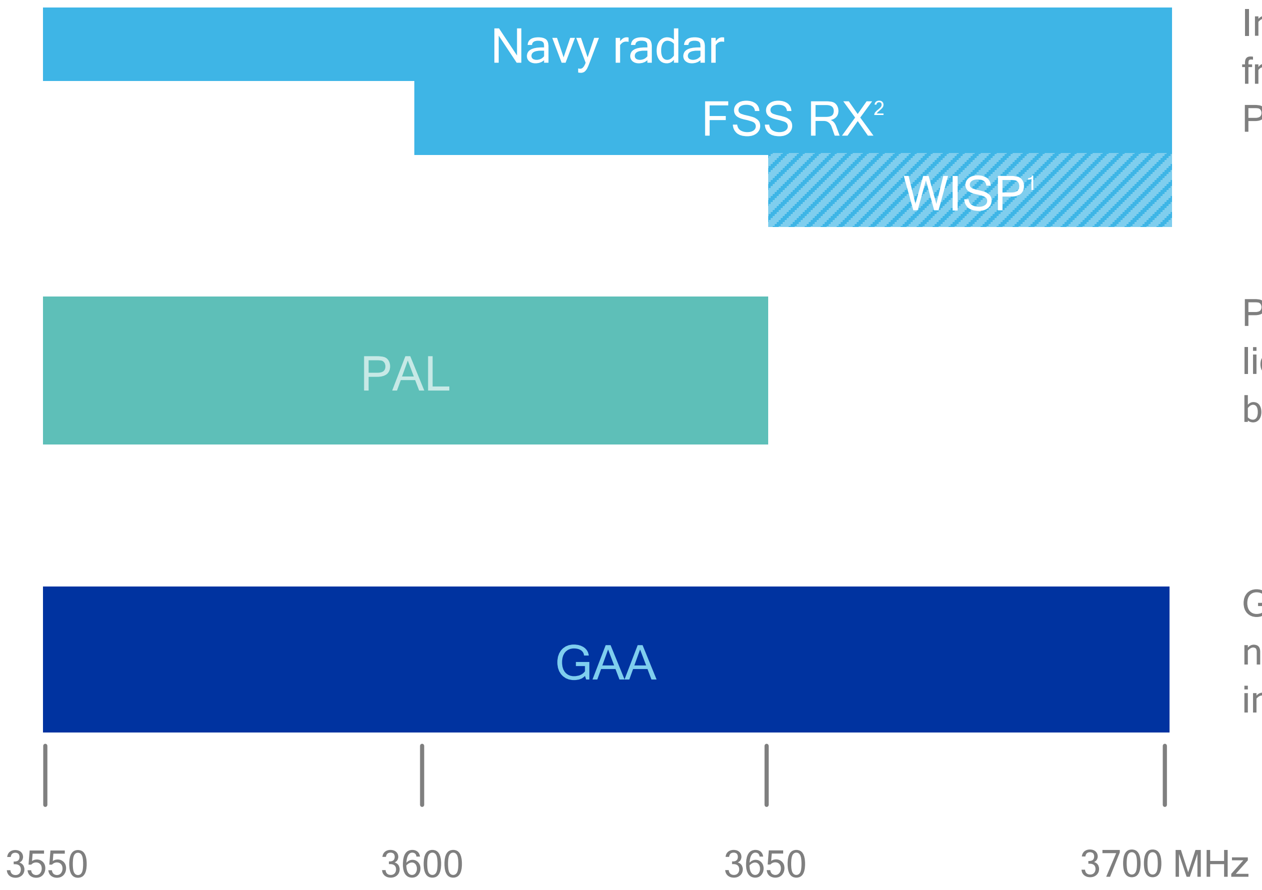
Incumbents are protected from interference from PAL and GAA

Tier 2
Priority Access Licenses (PAL)

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

Tier 3
General Authorized Access (GAA)

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

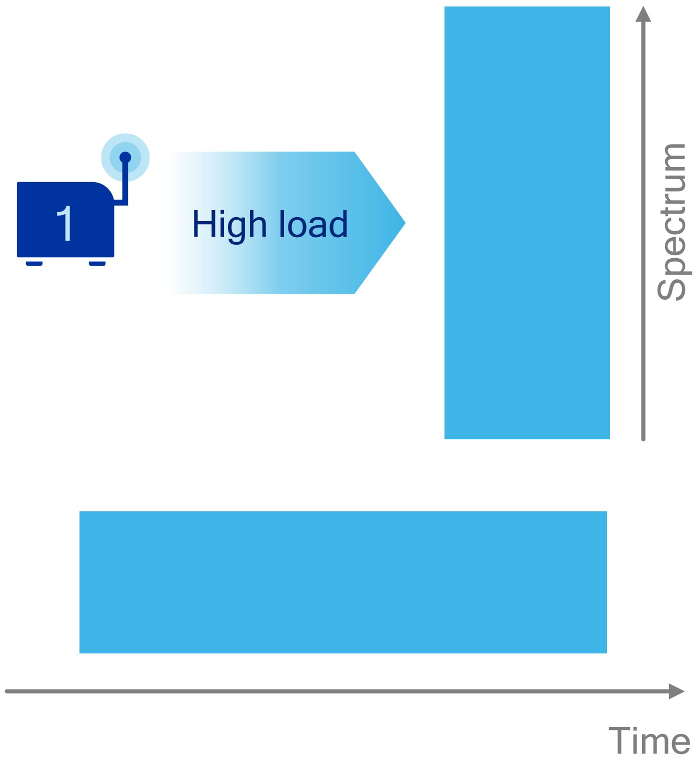


1) Wireless ISP transitioning from incumbent to PAL/GAA after 5 years; 2) Fixed satellite service - receiving only; 3) Citizen Broadband Radio Service (CBRS)

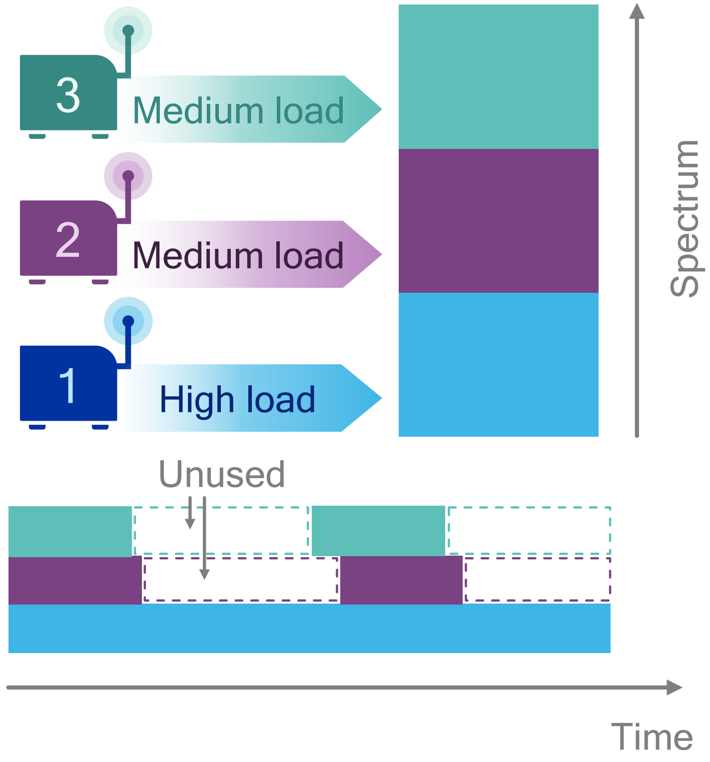
MulteFire helps GAA scale to multiple deployments

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

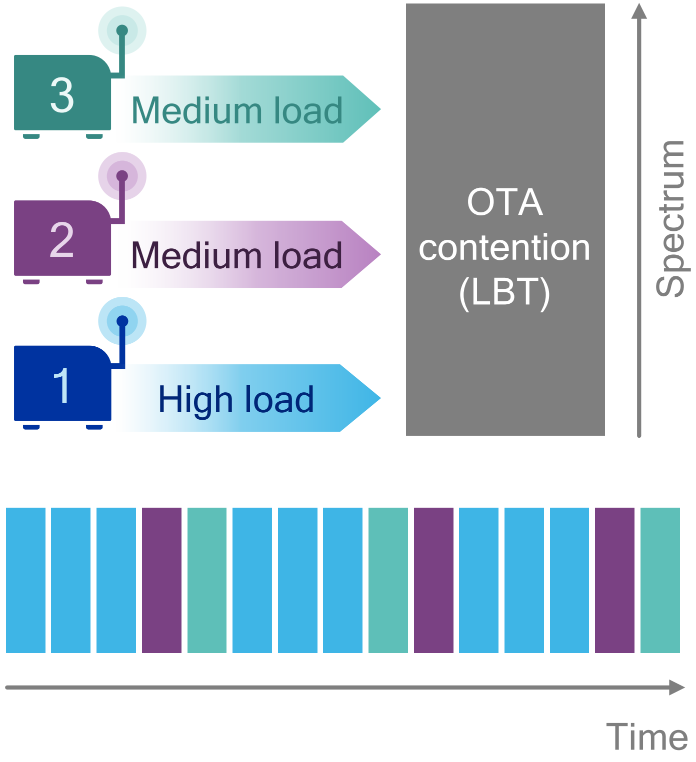
Highest spectrum efficiency with one LTE-TDD deployment



Multiple LTE-TDD deployments with reduced channel size, spectrum may become underutilized[1, 2]

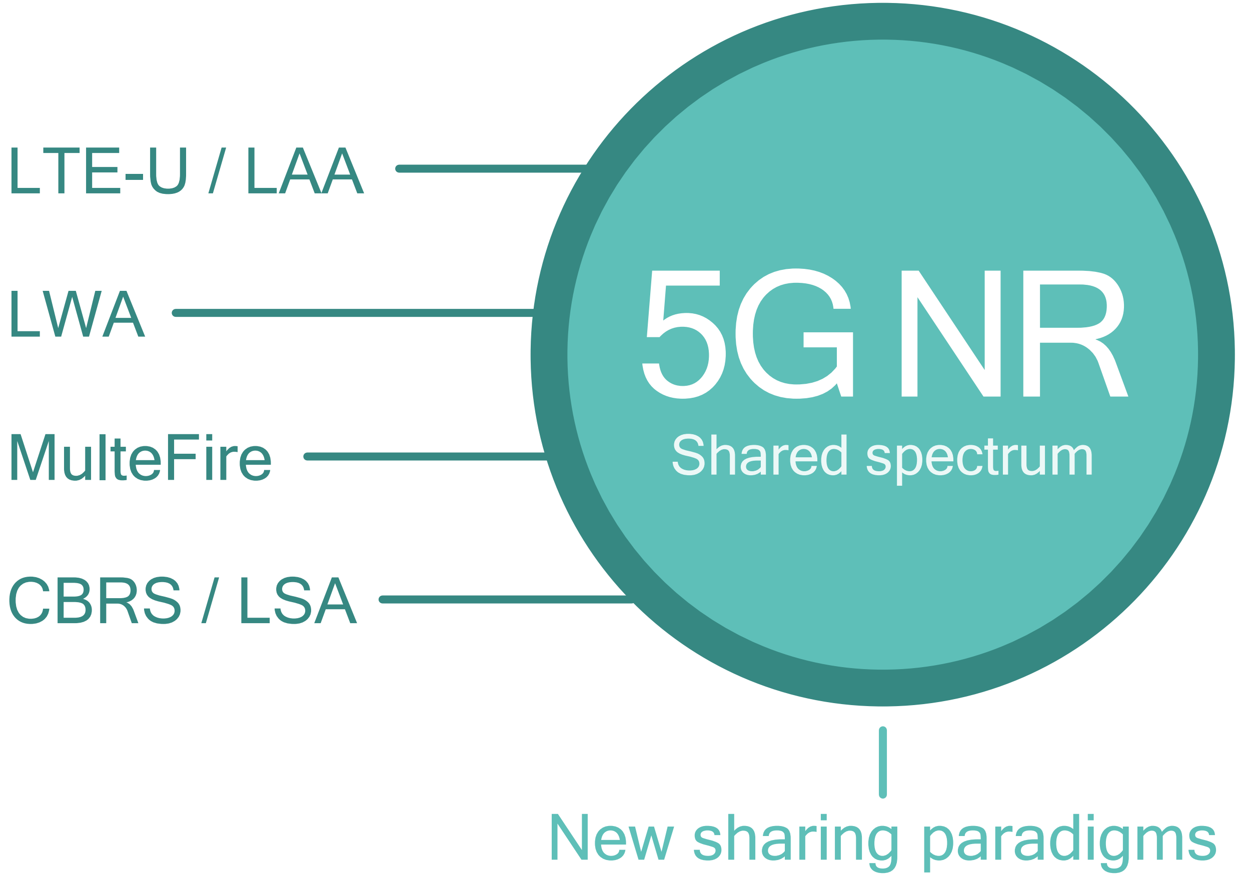


MulteFire brings trunking efficiency from sharing a wide channel to improve spectrum utilization[1,3]



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.

Designed to take advantage of new sharing paradigms



Flexible radio

- Scalable numerology: narrow-to-wideband
- Spectrum from sub-6GHz to mmWave
- Self-contained integrated sub-frames

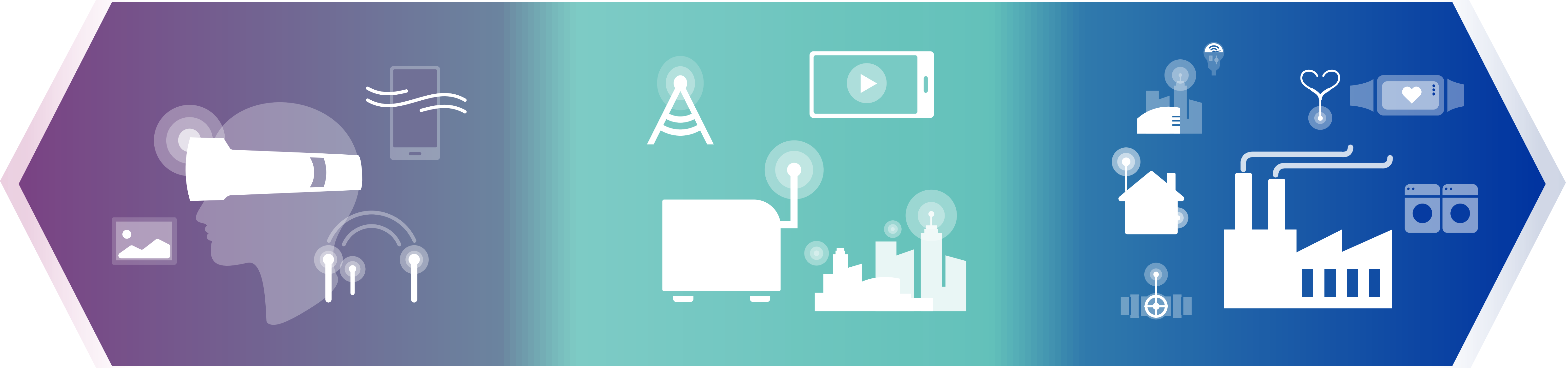
Flexible unlicensed operation

- 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

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

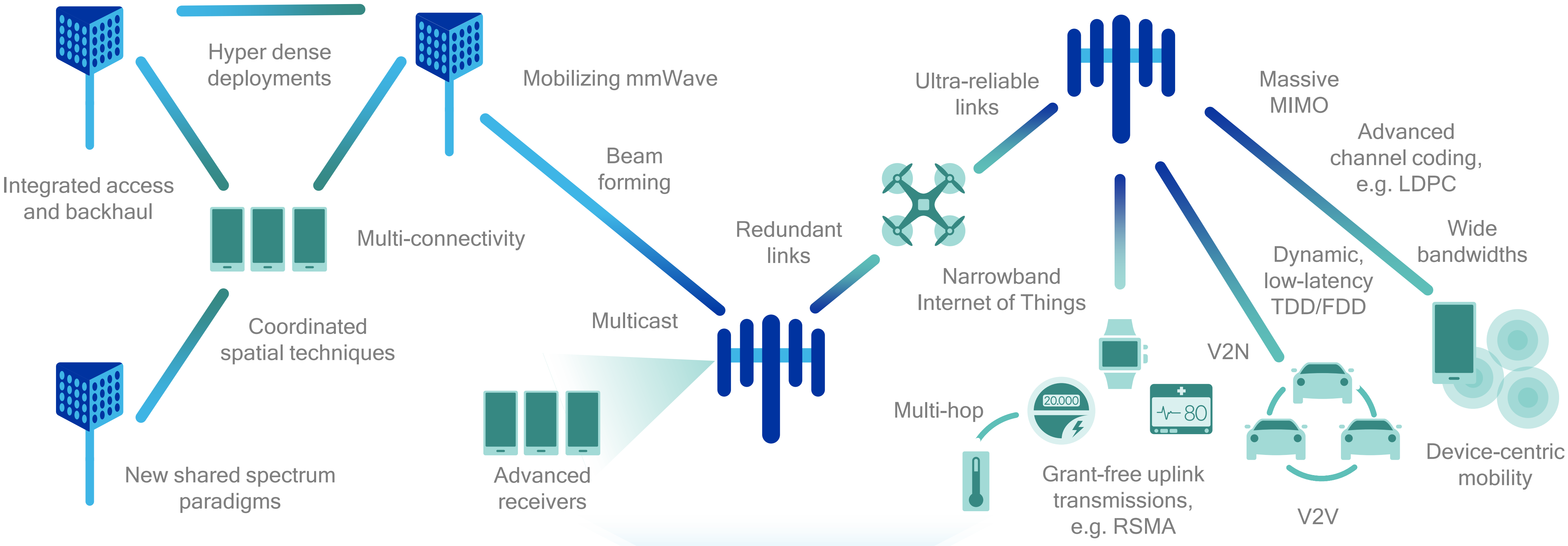
Shared/unlicensed spectrum opens up opportunity to service different IoT verticals, e.g., a private IoT network

Challenges and Design Aspects for 5G Wireless Networks

Talk Outline

- Background on evolution of cellular wireless networks
- Technical goals and timeline for 5G
- 5G design aspects
  - Air interface overall
  - Mobile broadband
  - Mission critical
  - Massive IOT
  - Shared Spectrum
- Q & A and perspectives on research challenges

5G requirements and design across topologies



New levels of capability and efficiency

10x	10x	10x	3x	100x	100x
experienced throughput	decrease in end-to-end latency	connection density	spectrum efficiency	traffic capacity	network efficiency

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

Thank you

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