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5G systems design across services

QUALCOMM
TECHNOLOGIES, INC.

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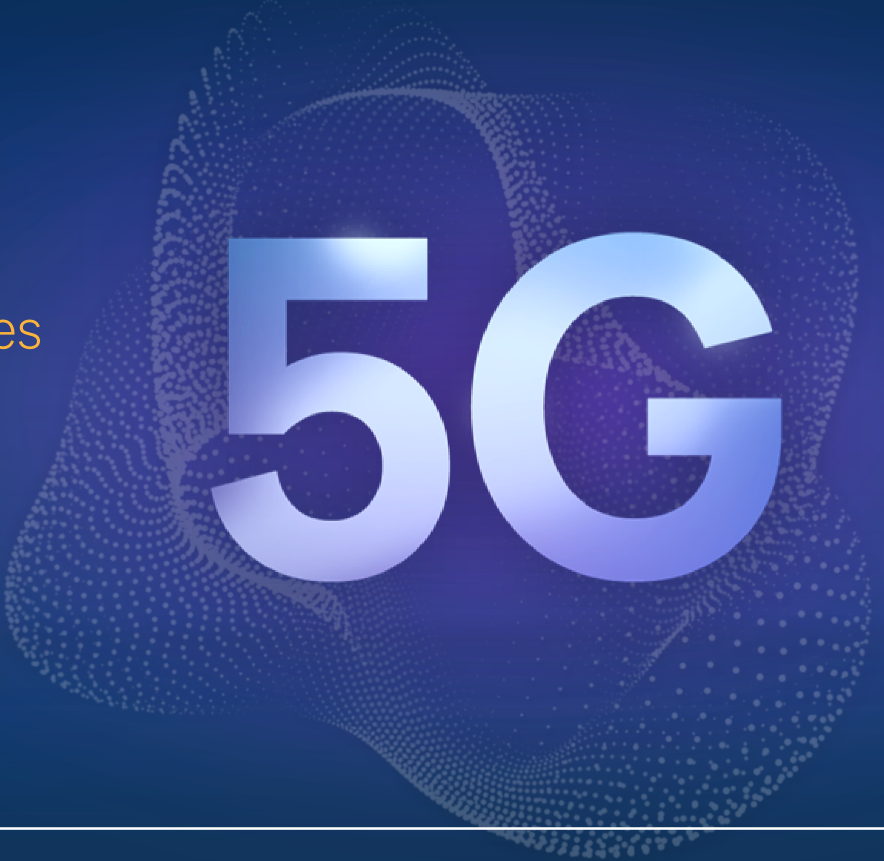
5G to meet significantly expanding connectivity needs

Building on the transformation started in 4G LTE



Connecting
new industries and devices

Enabling
new services

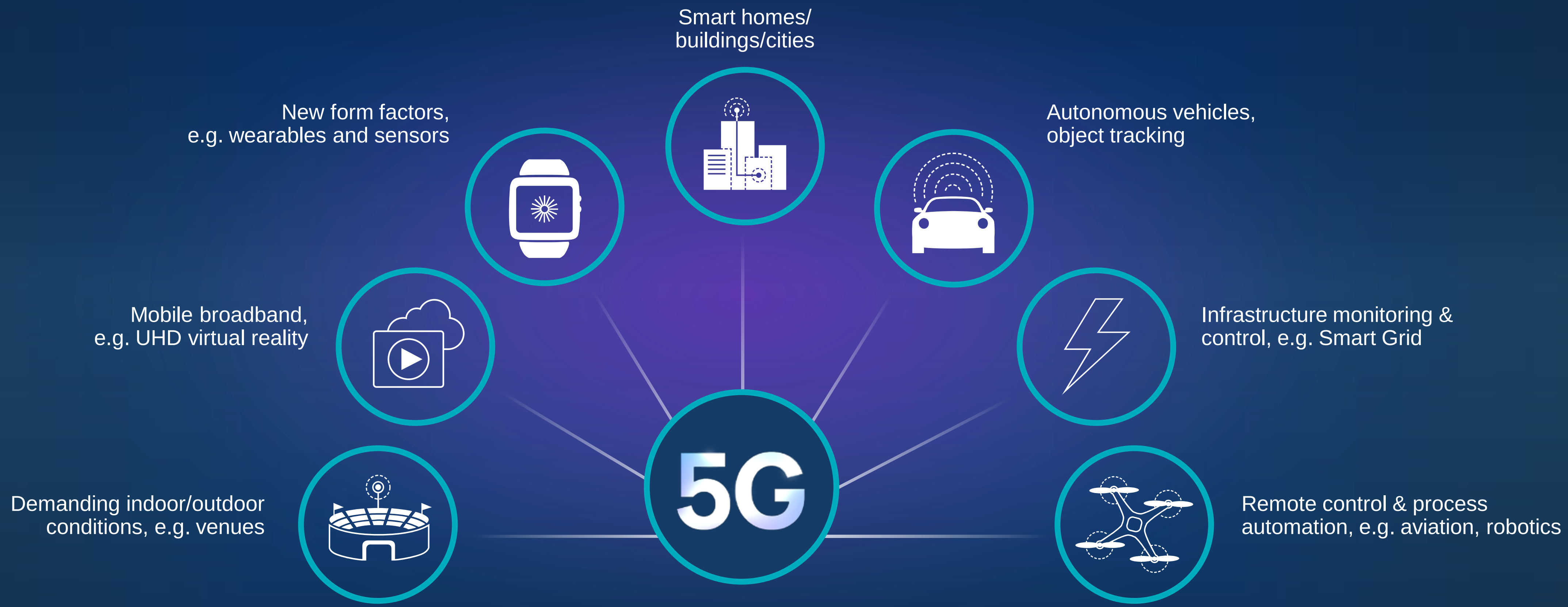
Empowering
new user experiences

Scalable
To an extreme variation of requirements

Uniform Experience
Improved user experiences with new ways of connecting

Unified
Across diverse spectrum types/bands, services and deployments

5G will enhance existing and expand to new use cases



Enhanced Mobile Broadband

Faster, more uniform user experiences

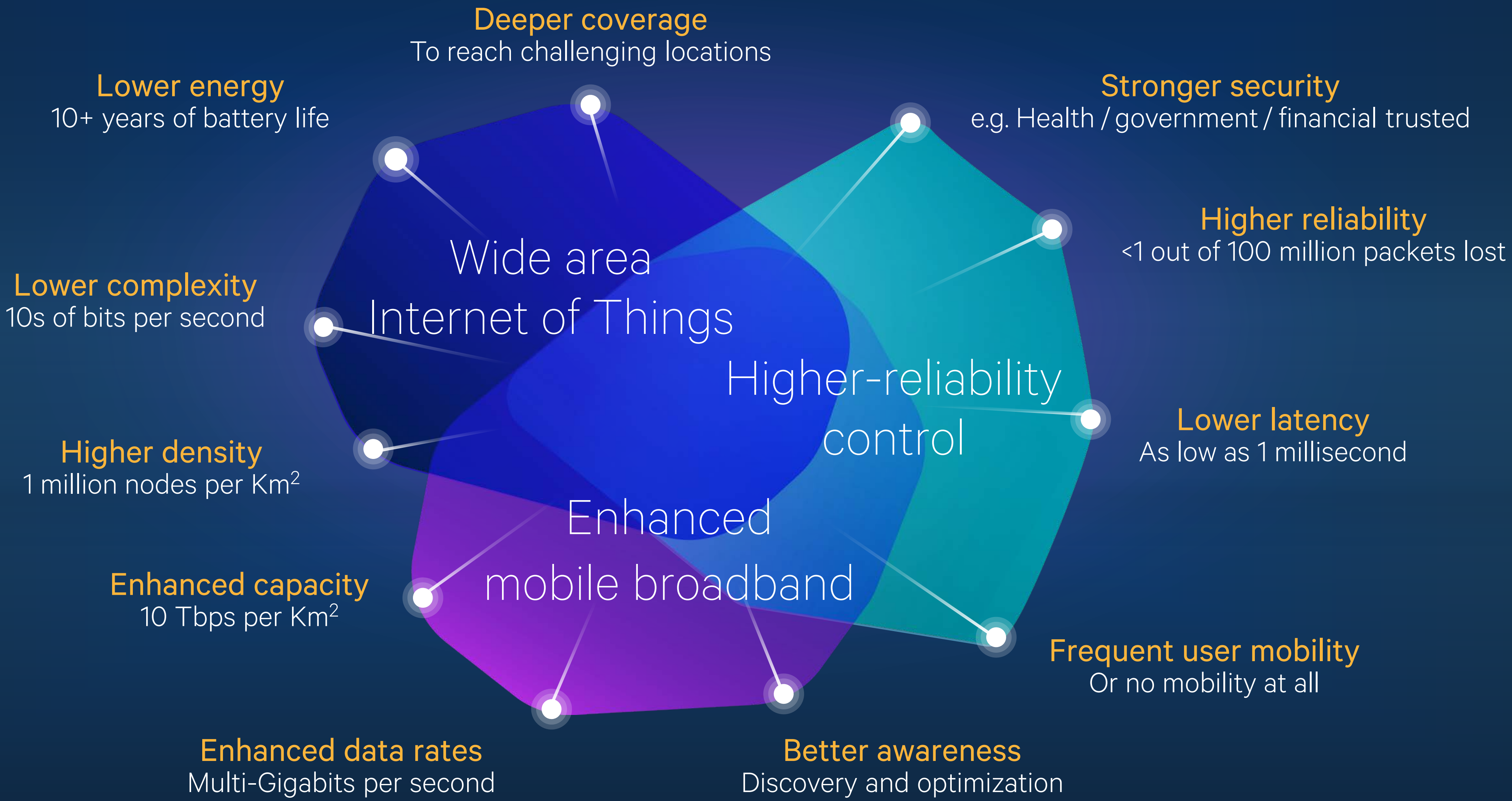
Wide Area Internet of Things

More efficient, lower cost communications with deeper coverage

Higher-Reliability Control

Lower latency and higher reliability

Scalable across a broad variation of requirements



Based on target requirements for the envisioned 5G use cases

In parallel: driving 4G and 5G to their fullest potential

Expanding and evolving LTE Advanced – setting the path to 5G

5G

A new much more capable 5G platform for low and high (above 6Ghz) spectrum

- Enable wide range of new services and lower cost deployment and operation
- For new spectrum available beyond 2020, including legacy re-farming

4G LTE LTE Advanced

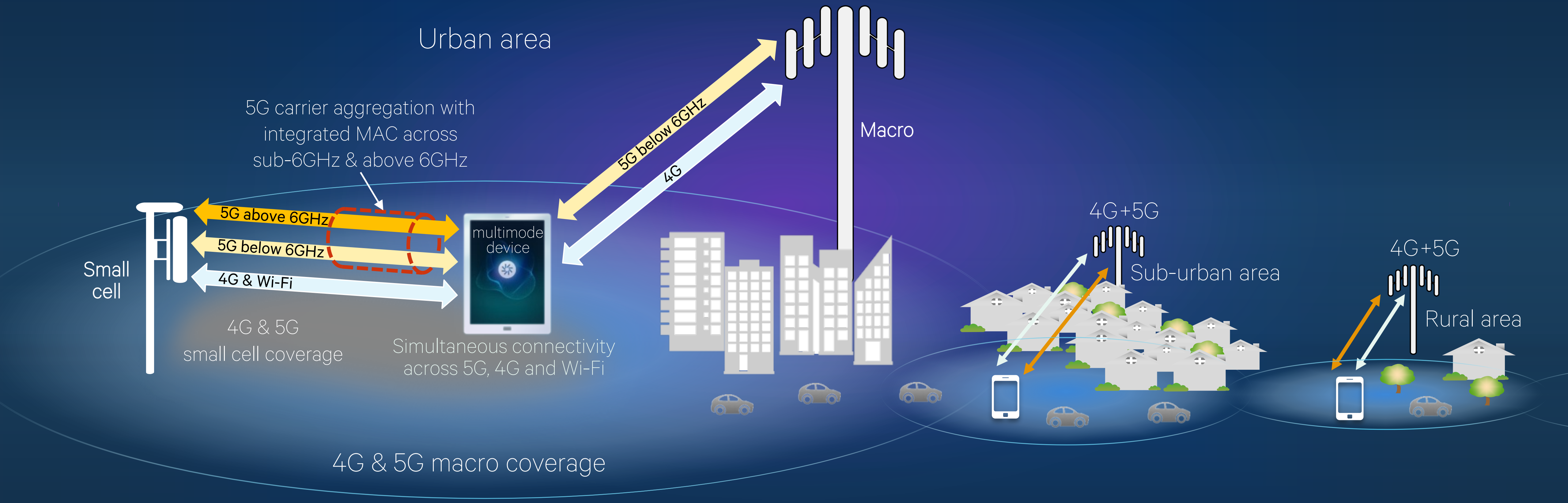
Backward-compatible evolution beyond Rel-13

- Fully leverage LTE spectrum and investments
- For new spectrum opportunities available before 2020

2010 ~2020 2030

Multi-connectivity across bands & technologies

4G+5G multi-connectivity improves coverage and mobility



Leverage 4G investments to enable phased 5G rollout

Diverse spectrum types and bands

From narrowband to ultra-wideband, TDD & FDD

Licensed Spectrum	Shared Licensed Spectrum	Unlicensed Spectrum
Cleared spectrum	Complementary licensing	Multiple technologies
EXCLUSIVE USE	SHARED EXCLUSIVE USE	SHARED USE

Below 1 GHz: longer range, massive number of things

Below 6 GHz: mobile broadband, higher reliability services

Above 6 GHz including mmWave: for both access and backhaul, shorter range

A new 5G unified air interface is the foundation

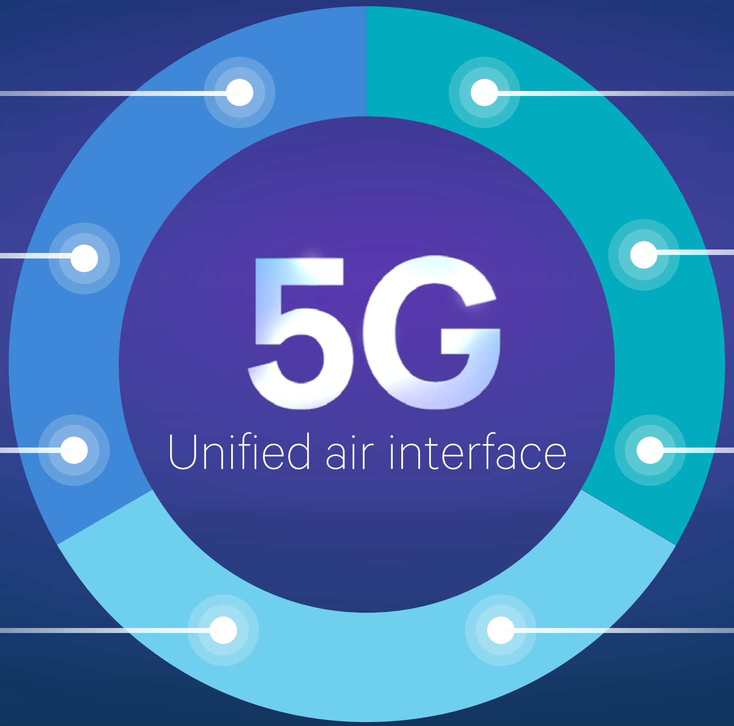
Diverse spectrum

Licensed, shared licensed, and unlicensed spectrum

Spectrum bands below 1 GHz, 1 GHz to 6 GHz, & above 6 GHz (incl. mmWave)

FDD, TDD, half duplex

Device-to-device, mesh, relay network topologies



Diverse services and devices

From wideband multi-Gbps to narrowband 10s of bits per second

Efficient multiplexing of higher-reliability and nominal traffic

From high user mobility to no mobility at all

From wide area macro to indoor / outdoor hotspots

Diverse deployments

Natively incorporate advanced wireless technologies

Key 5G design elements across services

Enhanced Mobile Broadband
Faster, more uniform user experiences

- Scalable to wider bandwidths
- Designed for diverse spectrum types
- Massive MIMO
- More robust mmWave design
- Improved network/signaling efficiency
- Native HetNets & multicast support
- Opportunistic carrier/link aggregation

Wide-Area Internet of Things
More efficient, lower cost communications

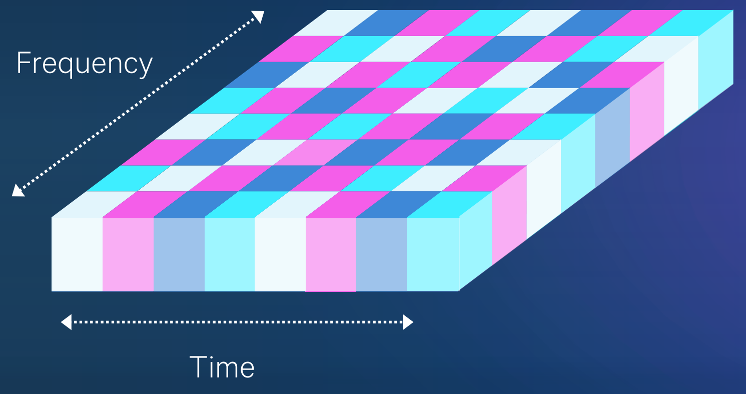
- Lower complexity, narrower bandwidth
- Lower energy waveform
- Optimized link budget
- Decreased overheads
- Managed multi-hop mesh

Higher-Reliability Control
Lower latency and more reliable links

- Lower latency bounded delay
- Optimized PHY/pilot/HARQ
- Multiplexing with nominal
- Simultaneous, redundant links
- Grant-free transmissions

Optimized waveforms and multiple access

With heavy reliance on the OFDM family adapted to new extremes



OFDM family the right choice for mobile broadband and beyond

Scalable waveform with lower complexity receivers

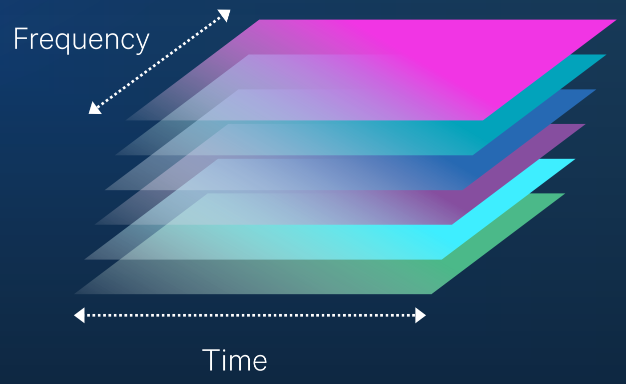
More efficient framework for MIMO spatial multiplexing – higher spectral efficiency

Allows enhancements such as windowing/filtering for enhanced localization

SC-OFDM well suited for uplink transmissions in macro deployments

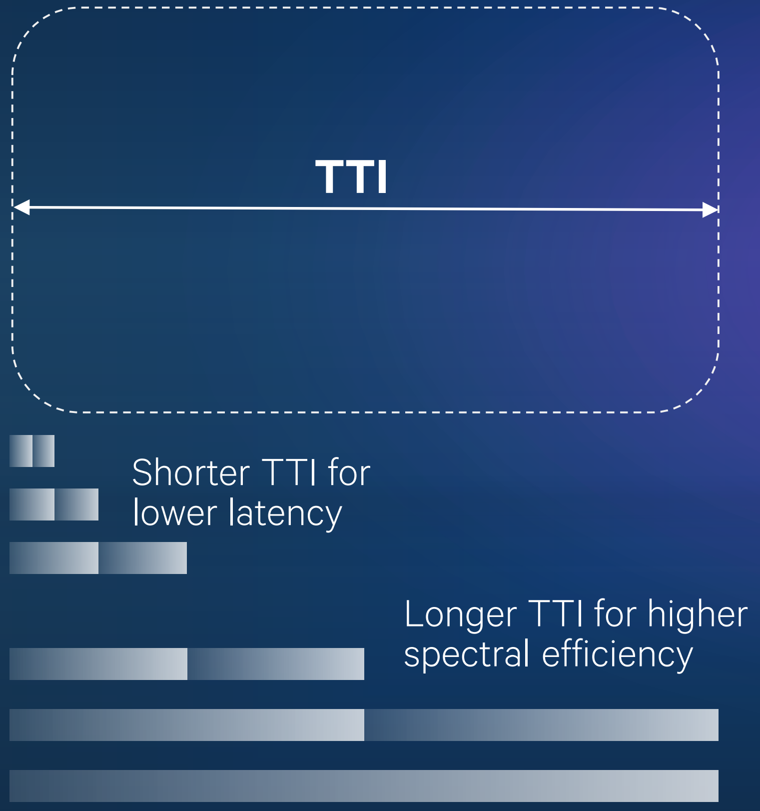
Resource Spread Multiple Access (RSMA) for target use cases

Enable asynchronous, non-orthogonal, contention-based access that is well suited for sporadic uplink transmissions of small data bursts (e.g. IoT)



Scalability to much lower latency

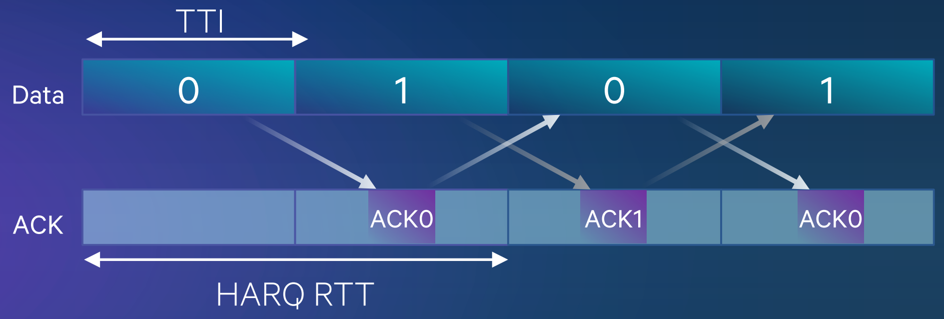
Scalable TTI for diverse latency & QoS requirements



Order of magnitude lower Round-Trip Time (RTT) than LTE today

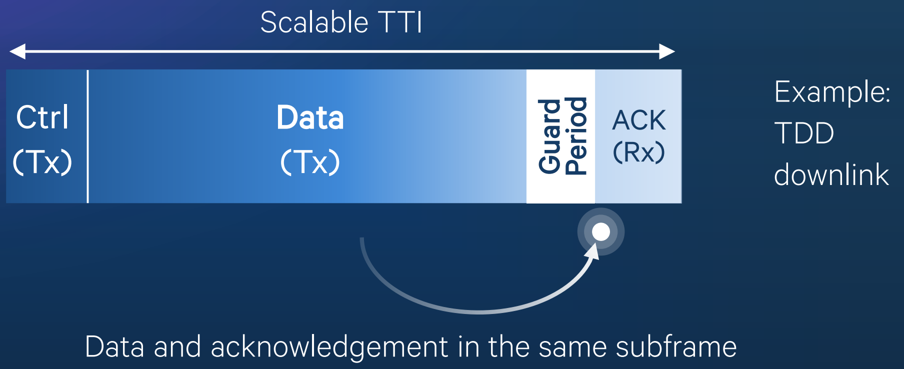
FDD

Fewer (variable) interlaces for HARQ[1]



TDD

Self-contained design reduces RTT



[1] Compared to LTE's 8 HARQ interlaces

Self-contained TDD subframe design

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

Unlicensed spectrum

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

Massive MIMO

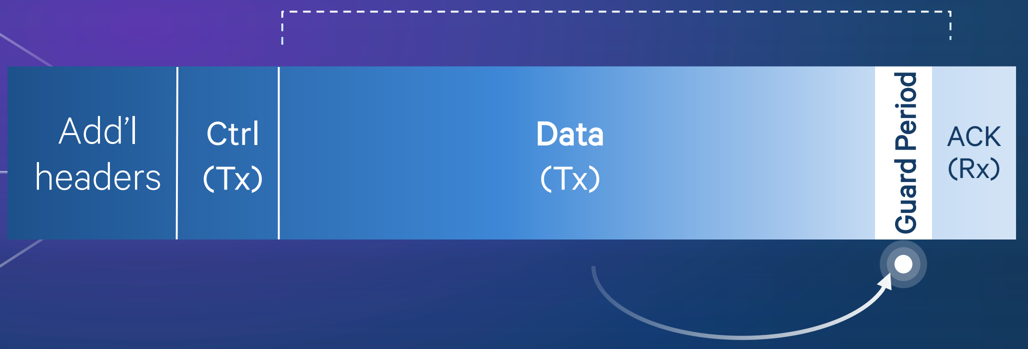
Leveraging channel reciprocity in UL transmission for DL beamforming training

D2D, mesh and relay

Headers for e.g. direction of the link for dynamic distributed scheduling

Adaptive UL/DL configuration

More flexible capacity allocation; also dynamic on a per-cell basis

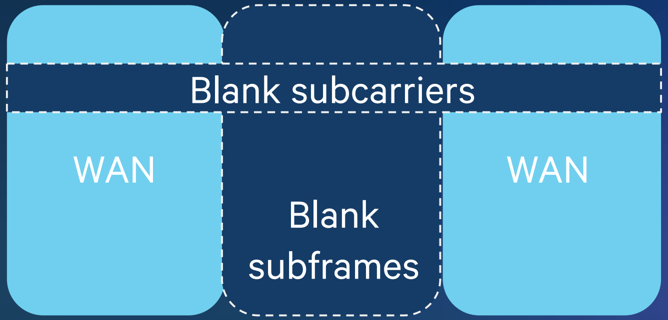


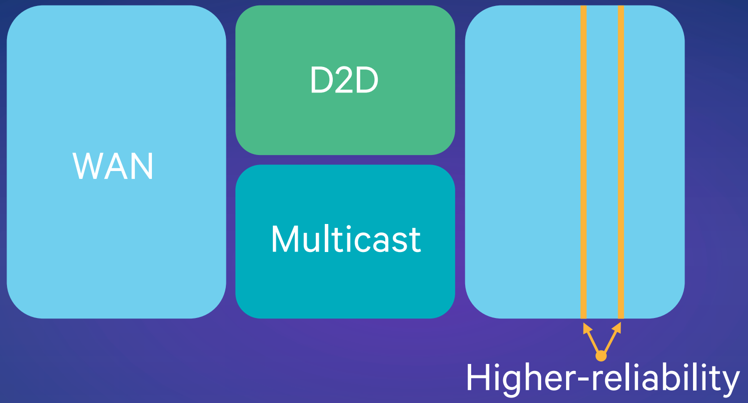
Example: TDD downlink

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

Designing Forward Compatibility into 5G

Flexibly phase-in future features and services





Blank resources[1]

Enable future features/service to be deployed in the same frequency in a synchronous and asynchronous manner

Service multiplexing

E.g. nominal traffic designed to sustain puncturing from higher-reliability transmissions or bursty interference

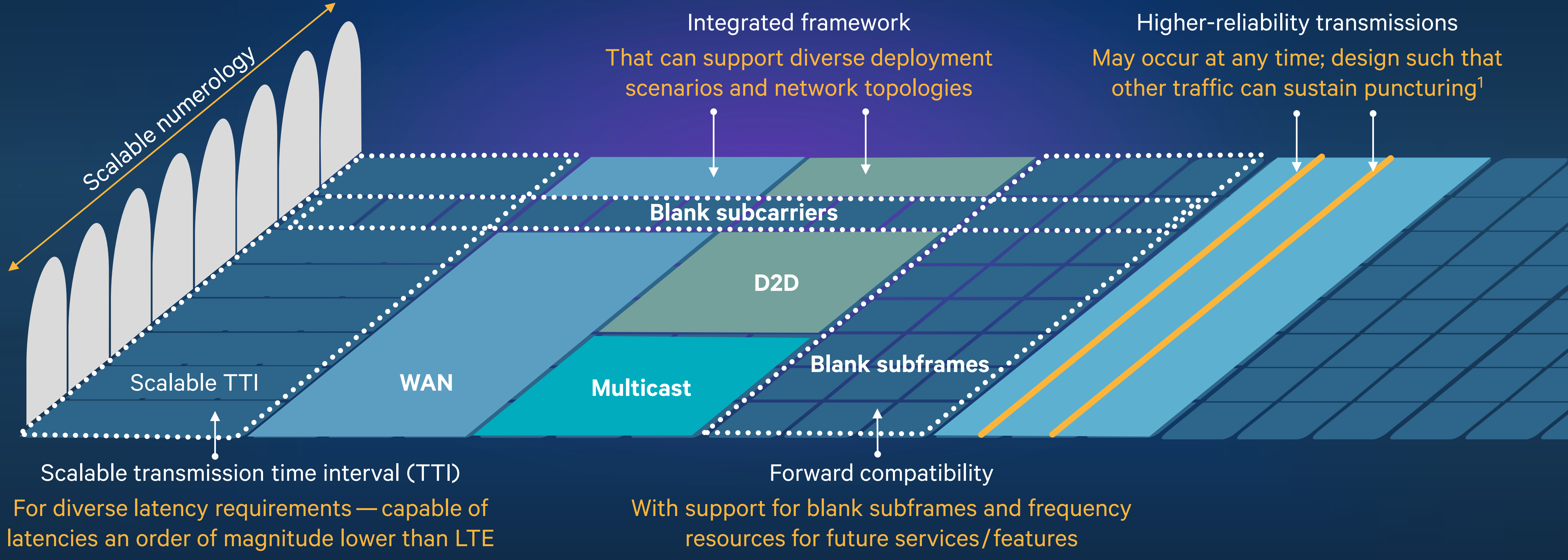
Common frame structure

Enable future features to be deployed on a different frequency in a tightly integrated manner, e.g. 5G sub 6 GHz control for mmWave

[1] 'Blank' resources may still be utilized , but designed in a way to not limit future feature introductions

A more flexible framework with forward compatibility

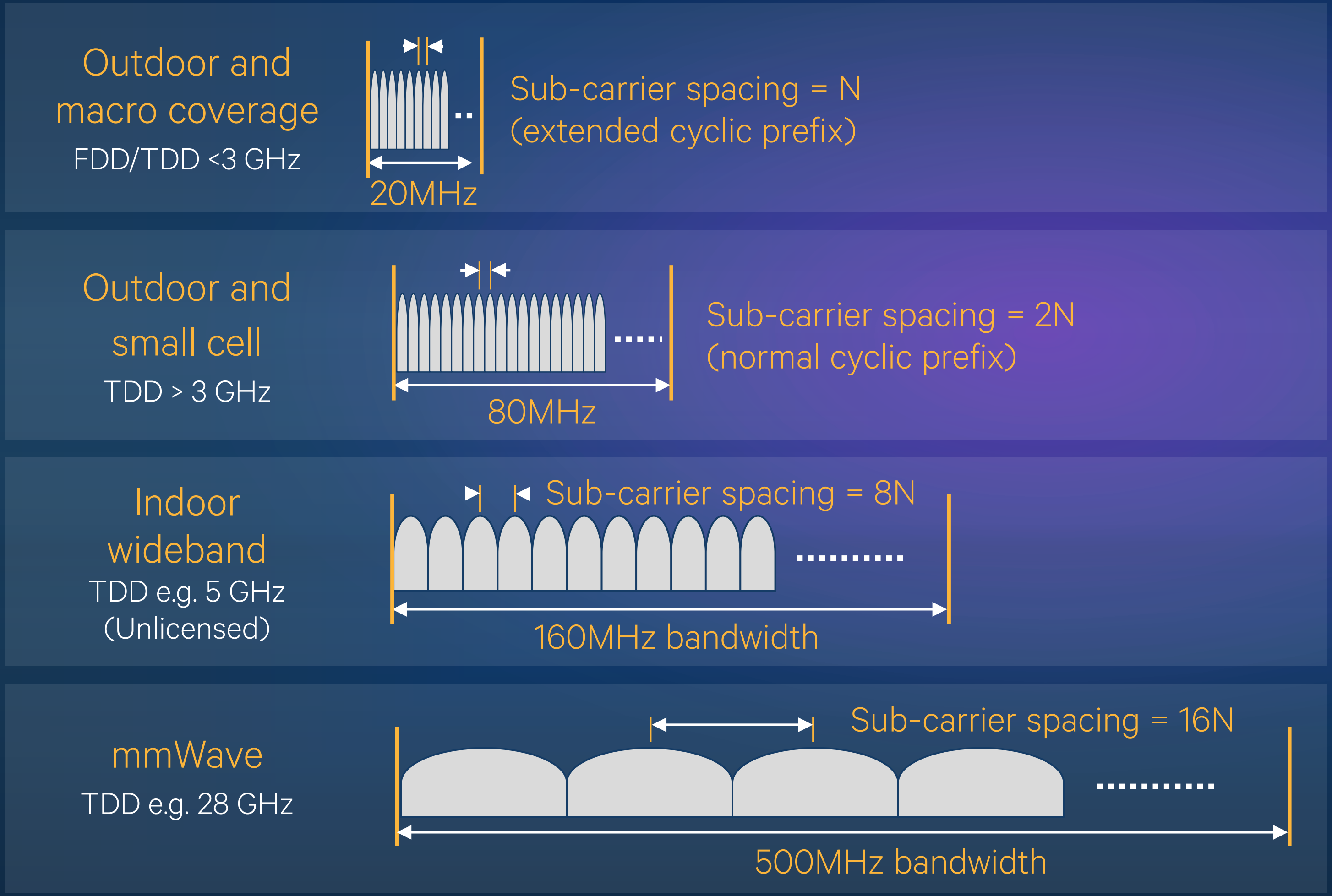
Designed to multiplex envisioned & unforeseen 5G services on the same frequency



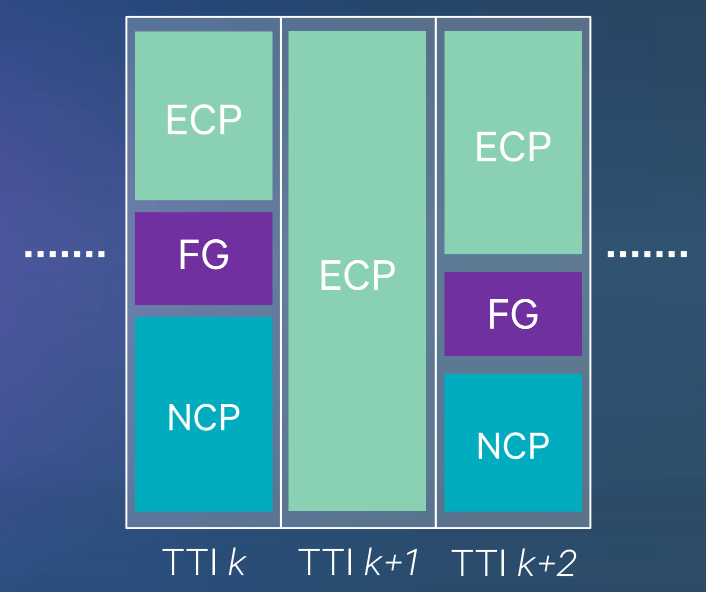
[1] Nominal 5G access to be designed such that it is capable to sustain puncturing from higher-reliability transmission or bursty interference

Scalable OFDM numerologies

To meet diverse spectrum bands/types and deployment models



Example usage models and channel bandwidths

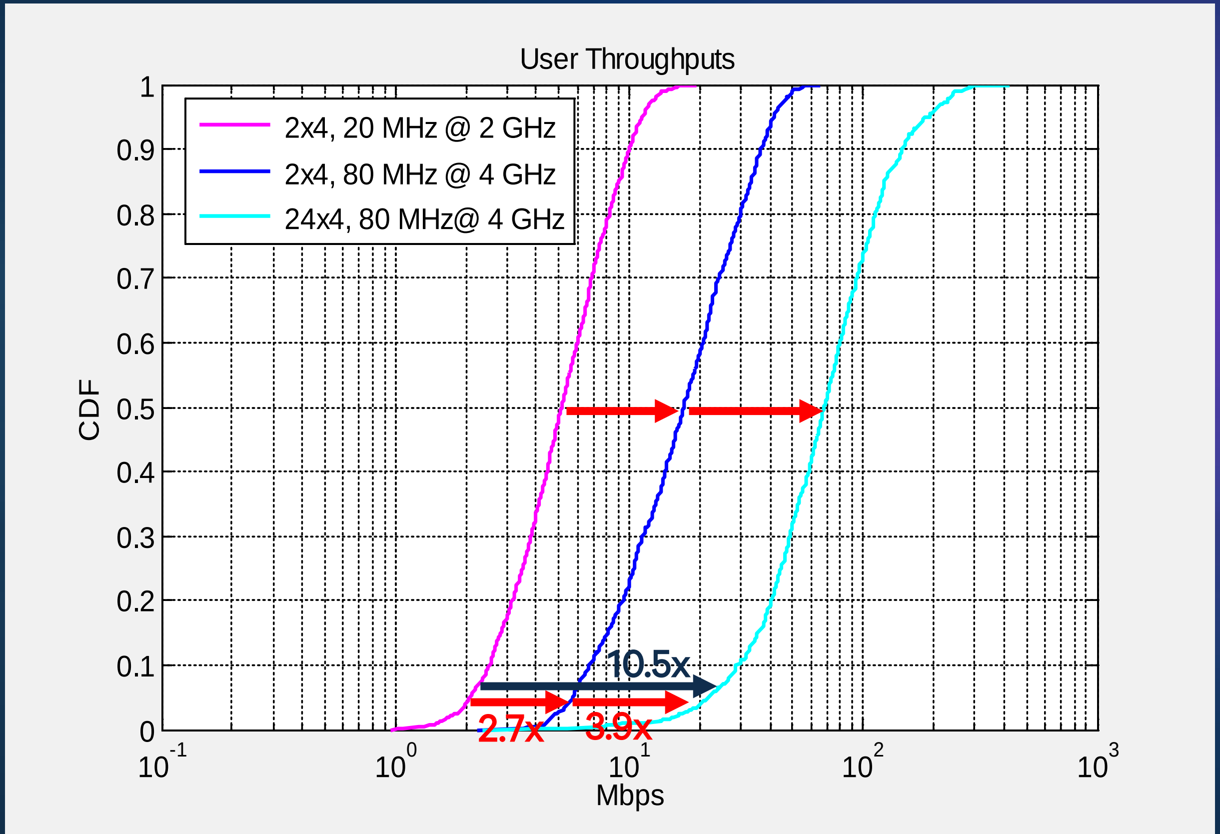


Numerology multiplexing

With flexible guard bands (FG)

Massive MIMO at 4 GHz allows reuse of existing sites

Leverage higher spectrum band using same sites and same transmit power



Significant average and cell-edge through gain from Massive MIMO

Antenna configuration Bandwidth Spectrum band	2x4 20 MHz 2 GHz	2x4 80 MHz 4 GHz	24x4 80 MHz 4 GHz
Cell Edge UE Throughputs (Mbps)	2.1	5.7	22.1
Average Cell Throughputs (Mbps)	58	197	808
Average Cell Spectral Efficiency (bps/Hz)	2.9	2.5	10.1

Source: Qualcomm simulations; Macro-cell with 1.7km inter-site distance, 46 dBm Tx power at base station,, 20MHz@2GHz and 80MHz@4GHz BW TDD, 24x Massive MIMO. Using 5-pertantile throughput for cell edge throughput.

Realizing the mmWave opportunity for mobile broadband

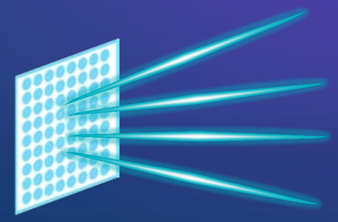
The enhanced mobile broadband opportunity

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

The challenge—'mobilizing' mmWave

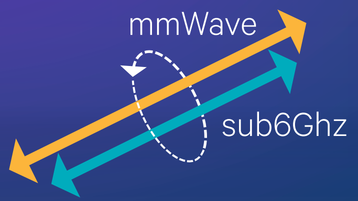
- Robustness results from high path loss and susceptibility to blockage
- Device cost/power and RF challenges at mmWave frequencies

5G Solutions



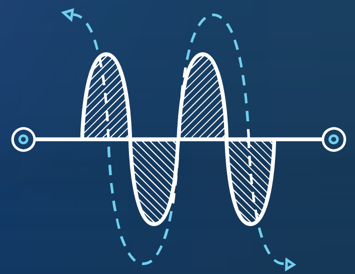
Smart beamforming & beam tracking

Increase coverage and minimize interference



Tighter interworking with sub 6 GHz

Increase robustness and faster system acquisition



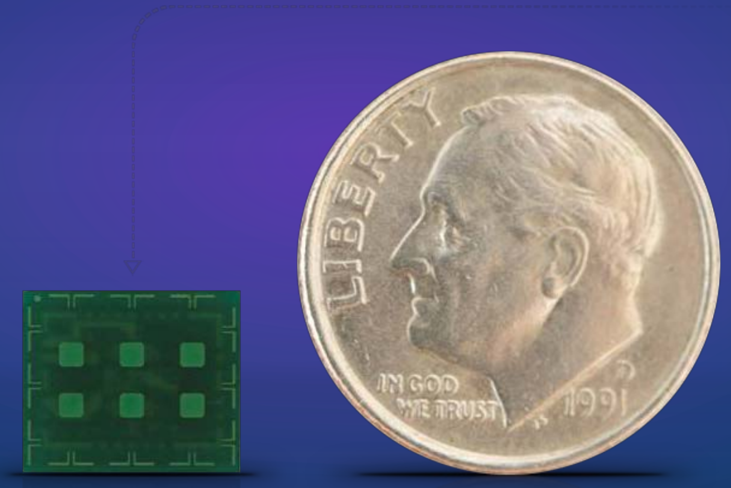
Phase noise mitigation in RF components

For lower cost, lower power devices

Making mmWave a reality for mobile

60 GHz chipset commercial today

For mobile devices, notebooks and access points

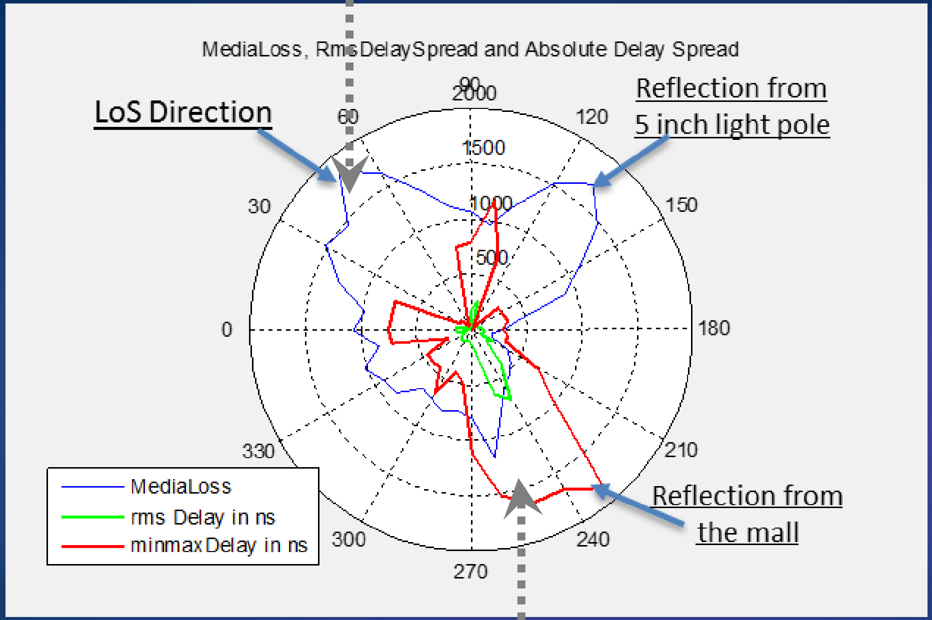


Qualcomm® VIVE™ 802.11ad technology for Qualcomm® Snapdragon™ 810 processor operates in 60 GHz band with a 32-antenna array element

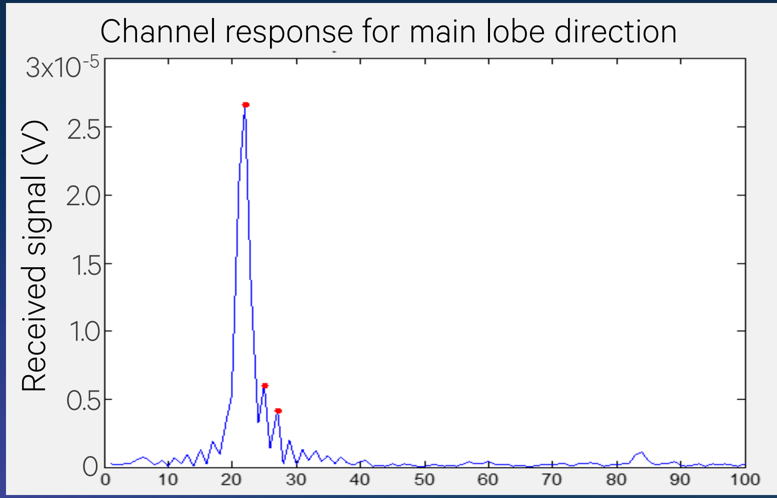
Qualcomm VIVE is a product of Qualcomm Atheros, Inc.; Qualcomm Snapdragon is a product of Qualcomm Technologies, Inc.

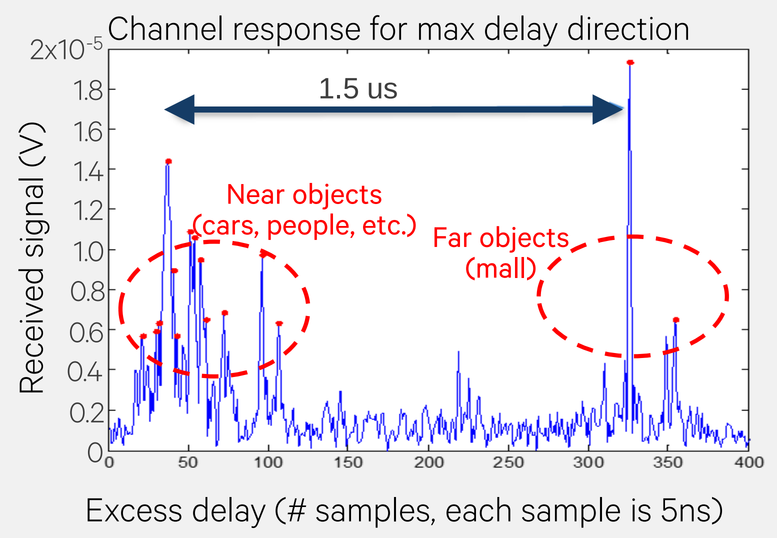
Outdoor propagation measurements

Path loss = 128dB, Azimuth = 50º
(20 dB Horn antenna pointed towards the LOS direction)



Path loss = 142dB
Azimuth = 240º
(20 dB Horn antenna pointed away from the LOS direction)

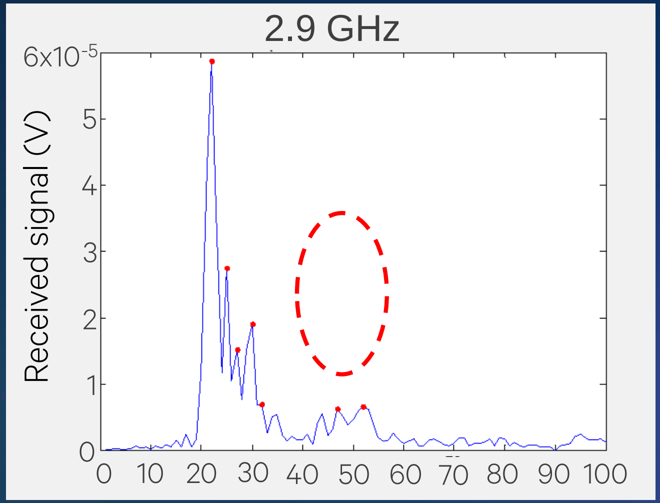


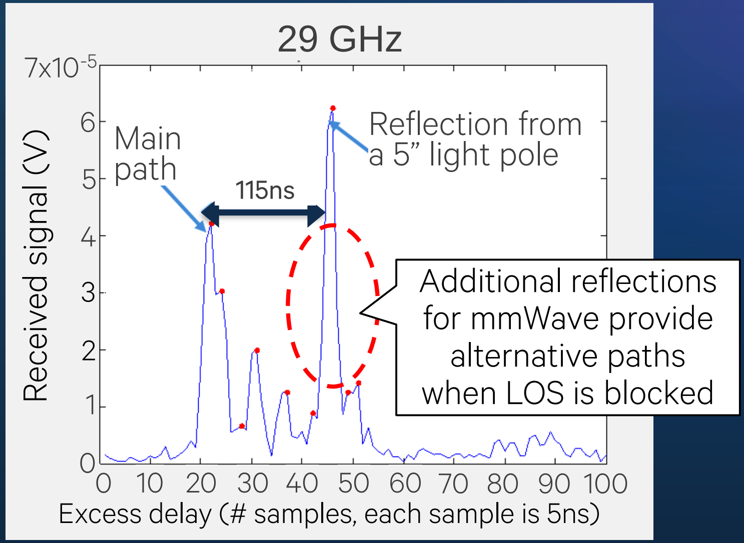


- Directional RMS delay spread not necessarily small for alternate (NLOS) paths ⟶ Important when the LOS path is blocked
- Delay spread not in the main lobe can be much larger than in the main lobe and also needs to be addressed at least during acquisition

Different propagation characteristics across sub-6 GHz & mmWave

Channel response from omni-directional antennas





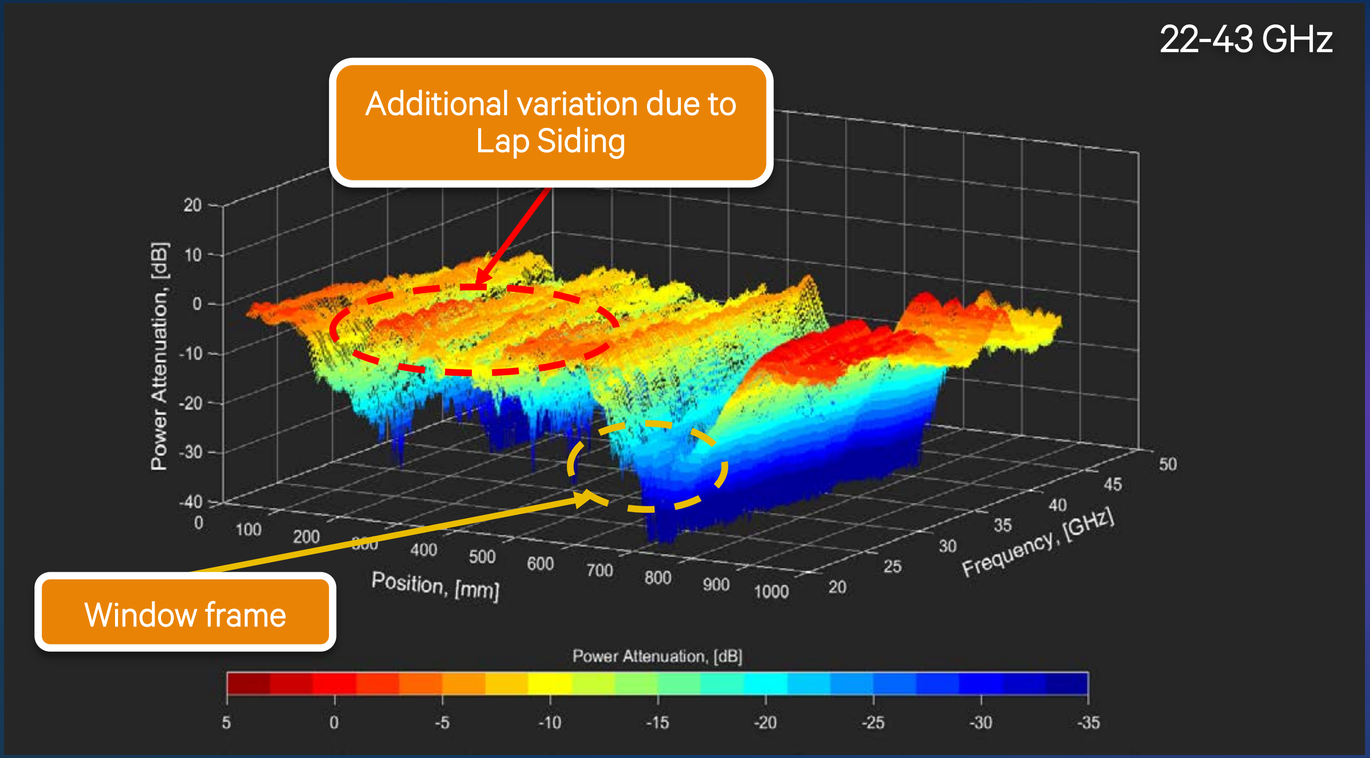
Key takeaways from measurements

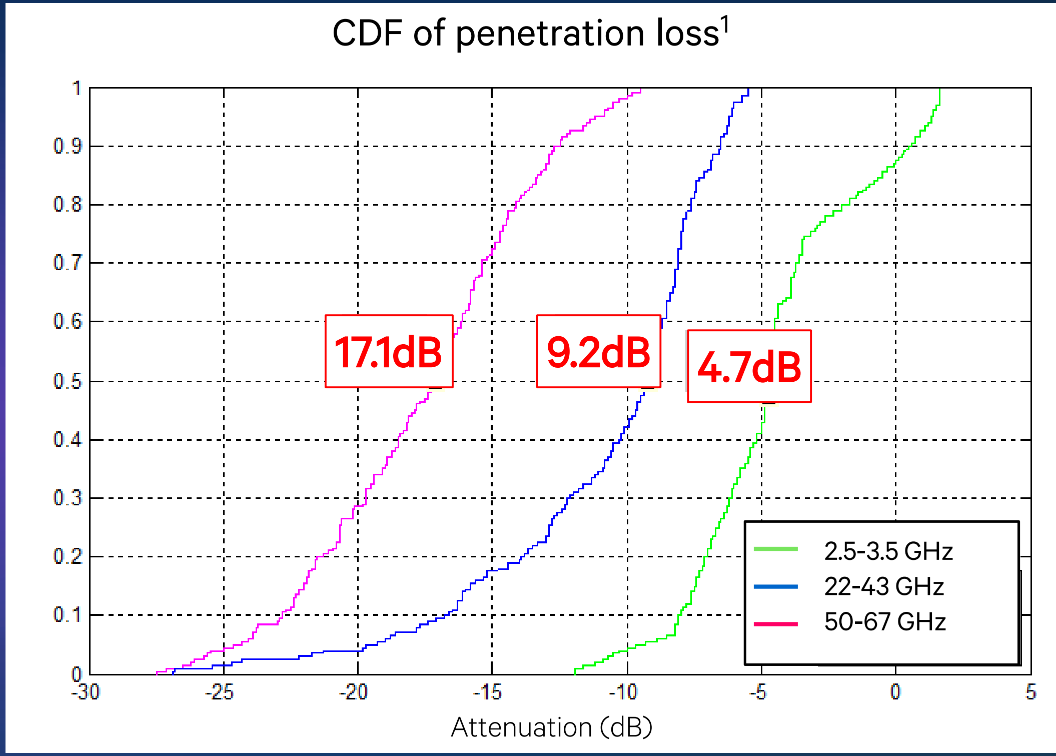
- Outdoor path loss (media loss) at 29GHz is ~*20% higher* than at 2.9GHz*, but generally similar in macro-features
- Delay spread at 29GHz is higher than at 2.9GHz, but no direct correspondence between carrier frequency and delay spread (radar cross-section effect)
- RMS delay spread around 200-300 ns in outdoor and < 100 ns in indoor settings
- Small objects contribute as incidental reflectors much more at 29GHz than at 2.9GHz
- Small objects in boresight affect propagation at 29GHz more than 2.9GHz due to easier diffraction around the objects at lower frequency
- Delay spread seen with high gain directional antennas can be *larger* than with omni-directional antennas; using directional antenna does not inherently reduce the delay spread

* Path loss (media loss) is referenced to 1m, i.e. total loss from a transmitter antenna to a receiver antenna is PL(1m)+PL. So defined path loss in free space is frequency independent.

Residential home measurements

Penetration loss of exterior residential walls





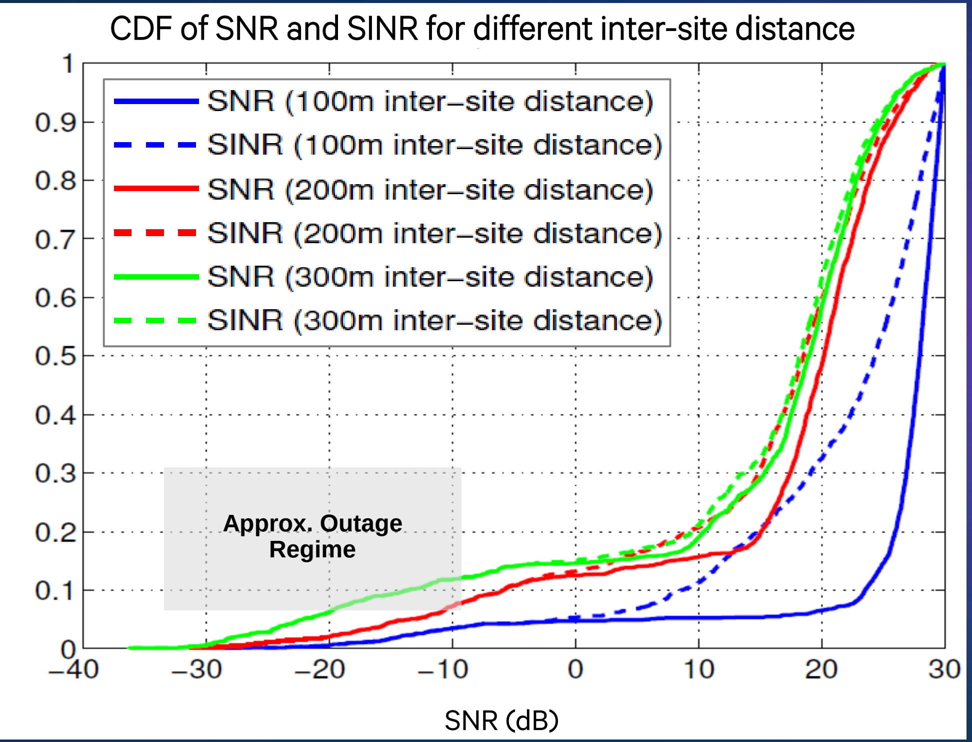
Note: Values in red indicate the 50th percentile penetration loss for the bands

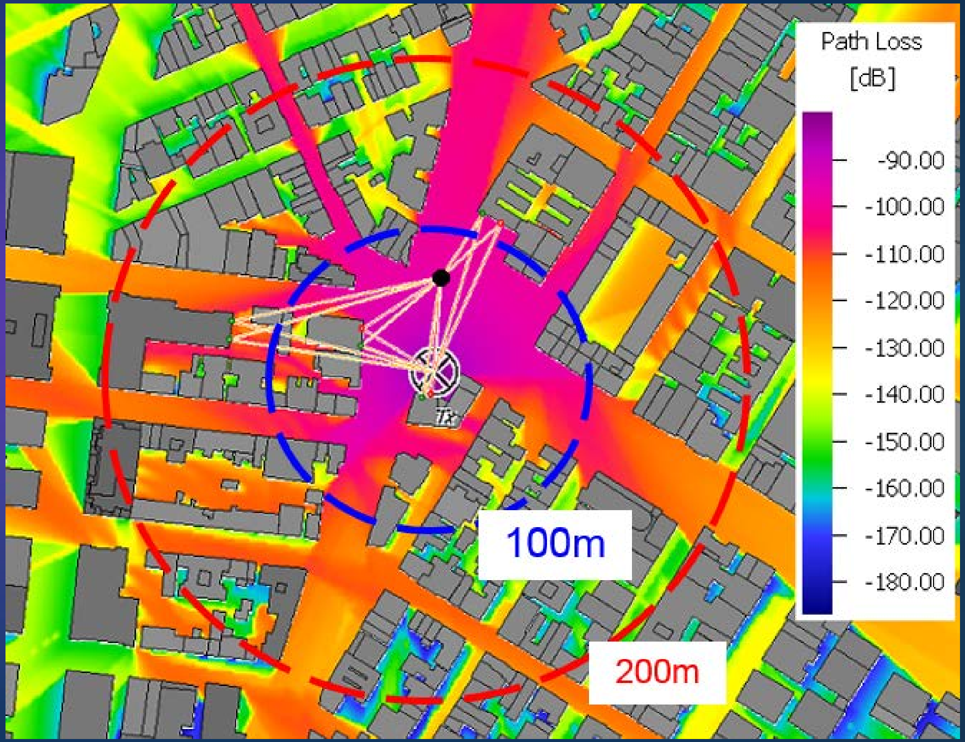
- Larger loss for exterior walls with increased frequency attributed to strand board construction ⟶ much smaller loss at high frequencies for plywood based sheathing
- For interior walls, median penetration loss is smaller and was less than 3dB in most measurements

1. Loss averaged over specified frequency ranges

Directional beamforming improves mmWave coverage and reduces interference

28GHz: Outdoor to Outdoor Path Loss & Coverage





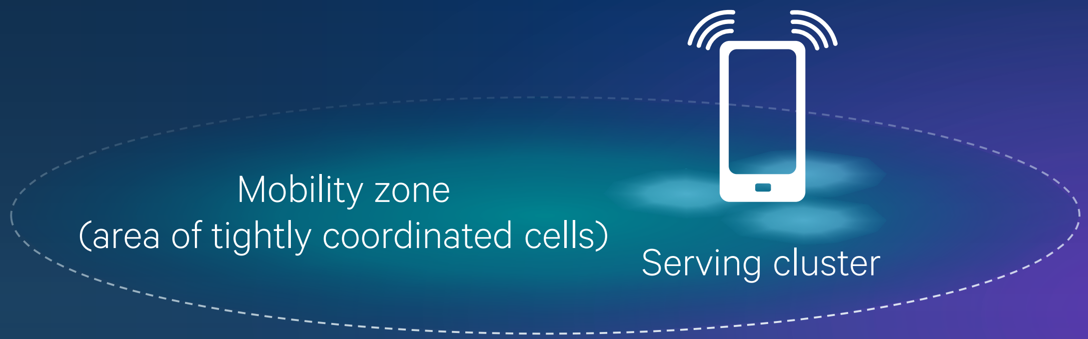
* Mahattan 3D map, Results from ray-tracing

- Both very high and low SINRs observed
- Interference seems to matter at 100-200m ISD, but not at all at 300m

- ~150m dense urban LOS and NLOS coverage using directional beamforming

Device-centric mobility management in 5G

Control plane improvements to improve energy and overhead efficiency

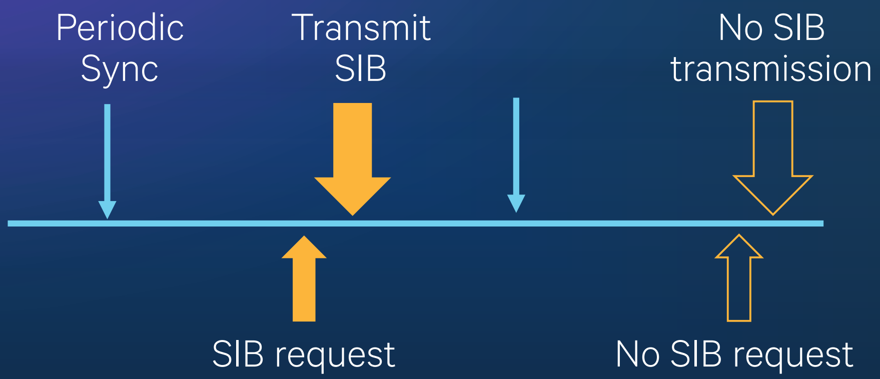


Lightweight mobility for device energy savings

- 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]



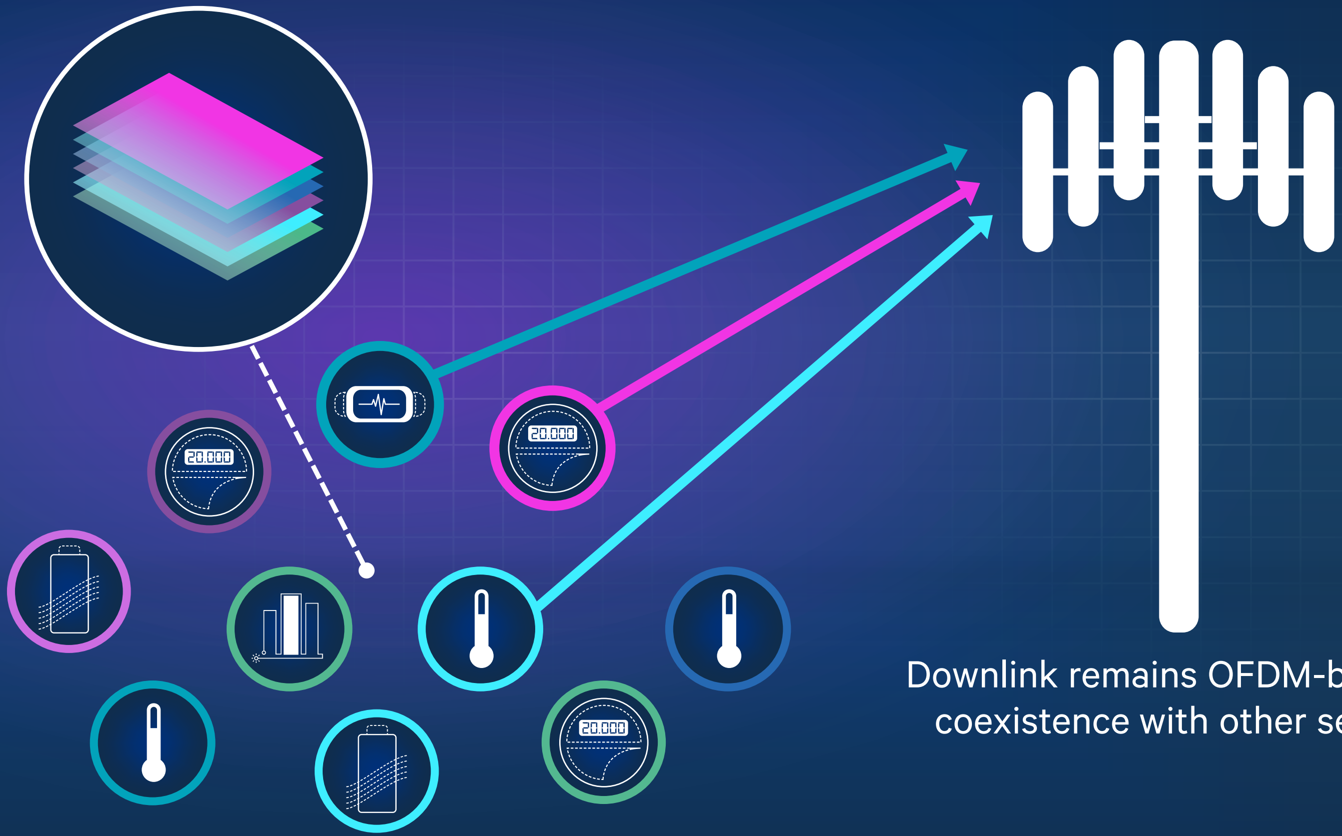
[1] Coordinated MultiPoint is an LTE Advanced feature to send and receive data to and from a UE from several access nodes to ensure the optimum performance is achieved even at cell edges;
[2] May dynamically revert to broadcast system info when needed, e.g. system info changes

Non-orthogonal RSMA for more efficient IoT communications

Characterized by small data bursts in the 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



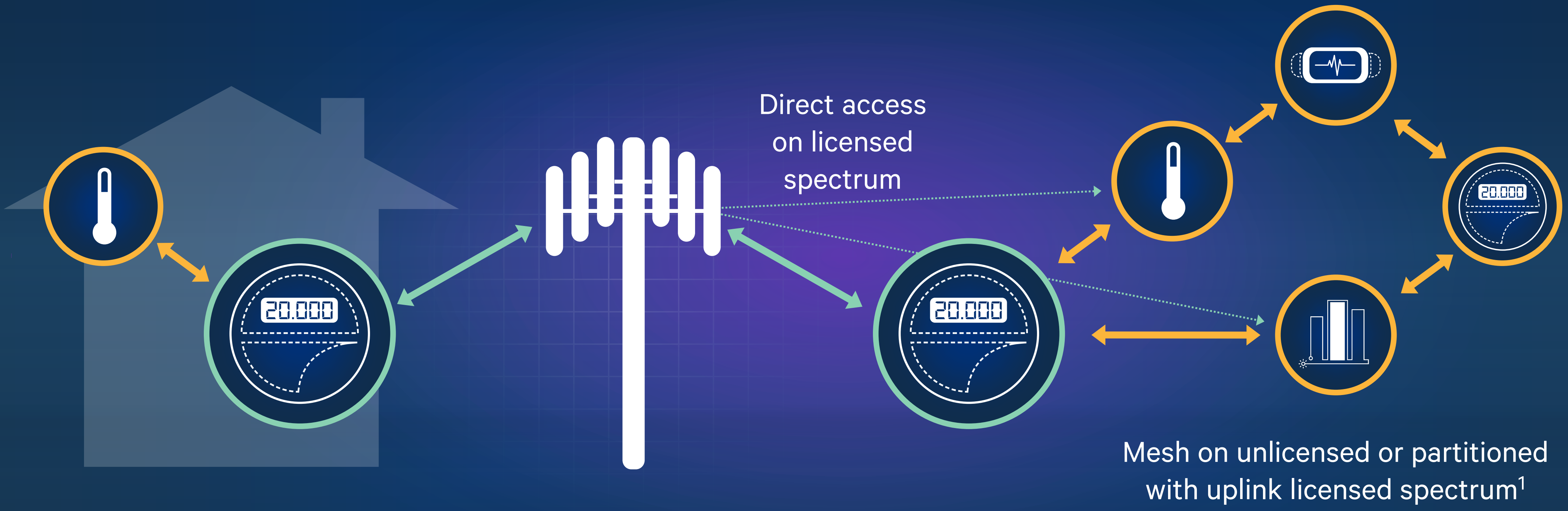
Downlink remains OFDM-based for coexistence with other services

Increased battery life

Scalability to high device density

Better link budget

Support for multi-hop mesh with WAN management



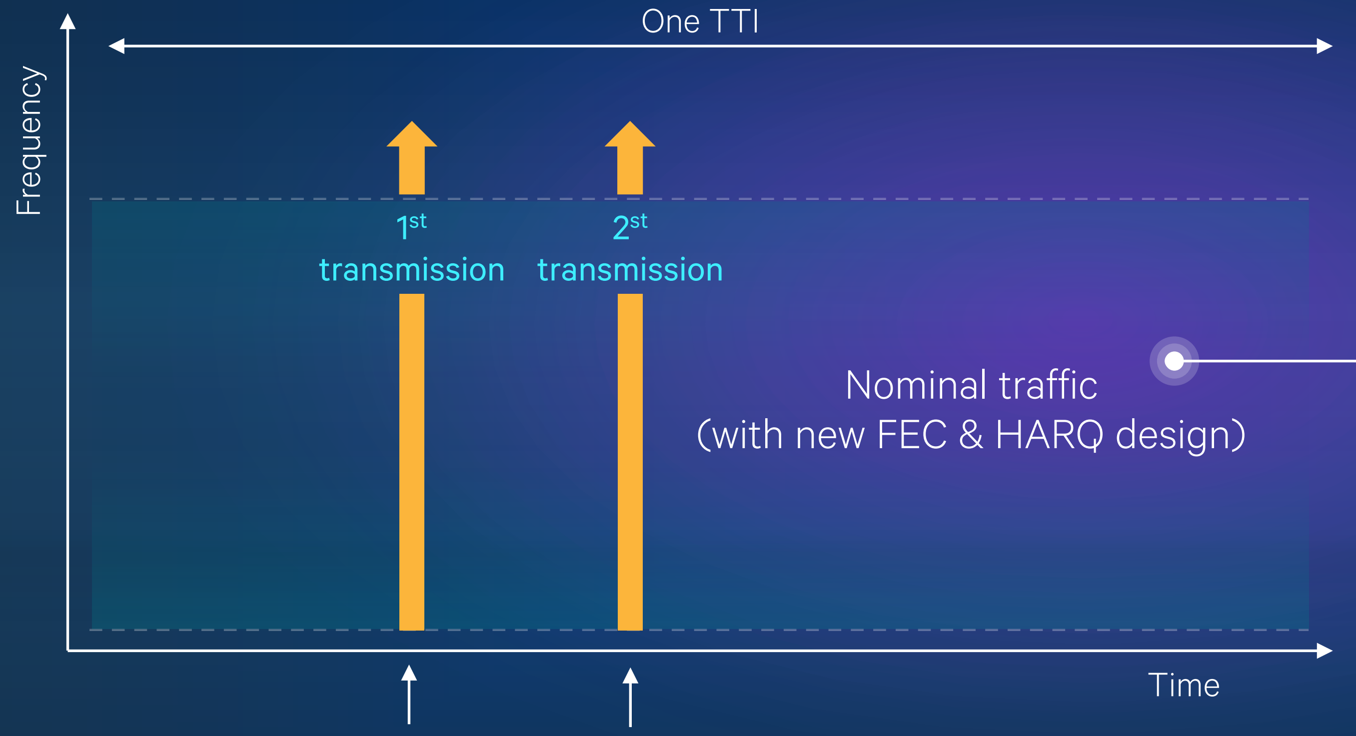
Problem: uplink coverage | Due to low power devices and challenging placements, e.g. in basement

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

Efficient multiplexing of higher-reliability and nominal traffic

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



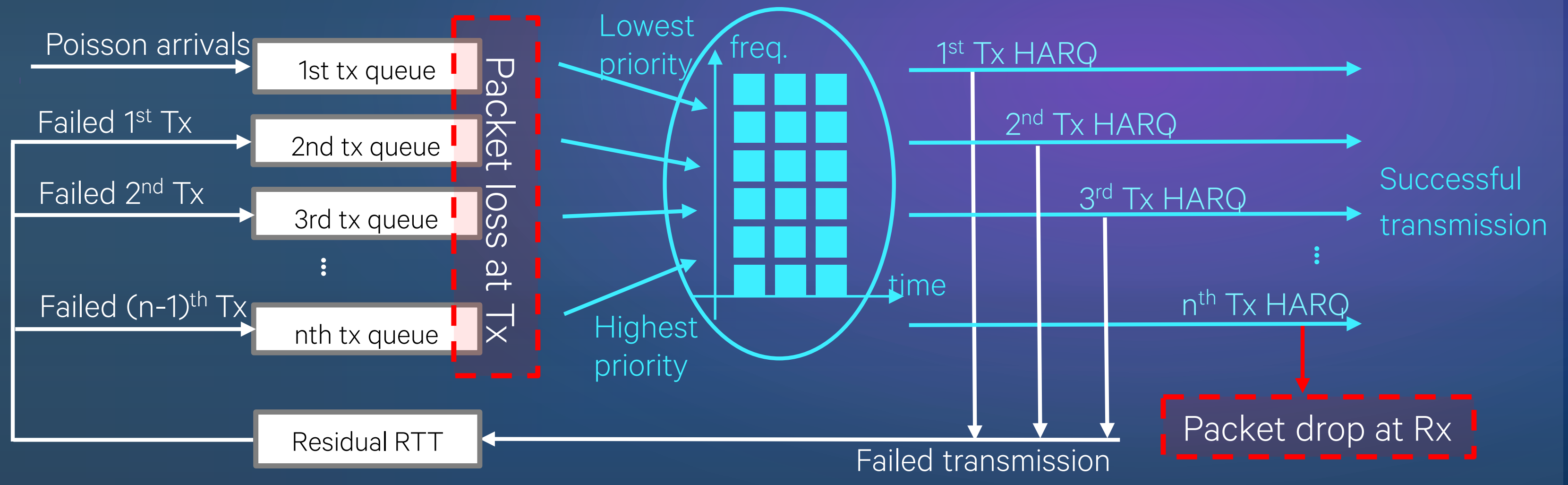
Design such that other traffic can sustain **puncturing** from higher-reliability transmission

Higher-reliability transmission
may occur at any time and cannot wait for scheduling

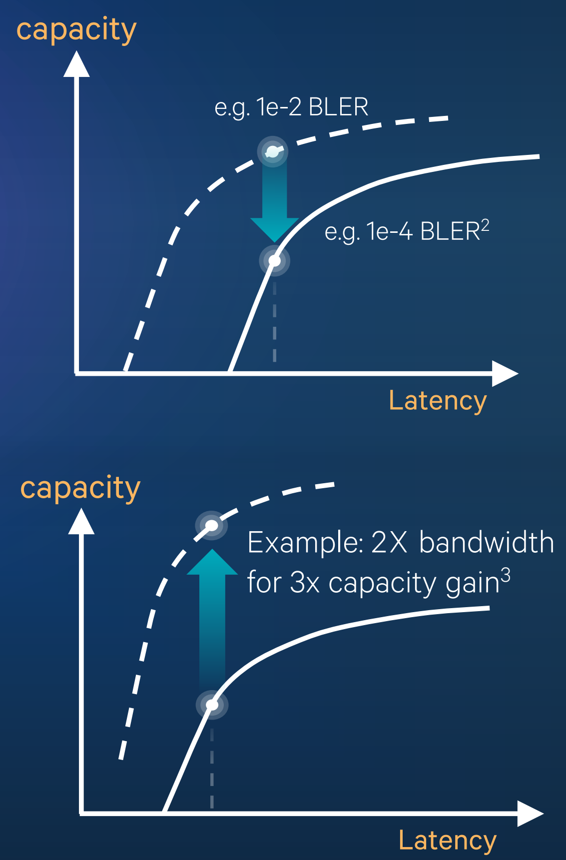
Opportunity for **uplink RSMA** non-orthogonal access using OFDM waveforms

Hard latency bound and PHY/MAC design

Single-cell multi-user evaluation/queueing model[1]



5G design must consider the tradeoffs among capacity, latency and reliability



1. Causes of packet drop: a, last transmission fails at Rx, b, delay exceeds deadline at Tx queues
2. Low BLER Block Error Rate, required to achieve higher-reliability with a hard delay bound
3 All data based on Qualcomm simulations with approximate graphs and linear scales. 3x gain when increasing from 10Mhz to 20Mhz for 1e-4 BLER.

Thank you

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