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5G Vision and Design

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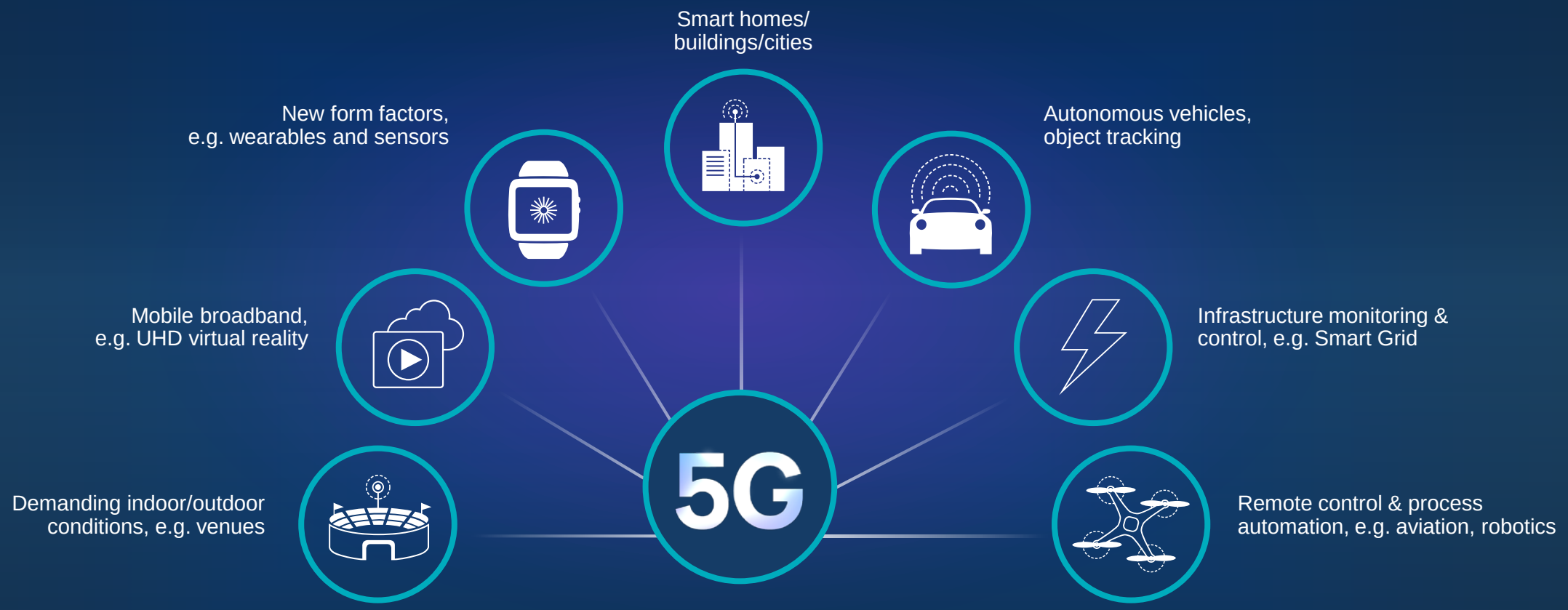
This presentation addresses potential use cases and views on characteristics of 5G technology and is not intended to reflect a commitment to the characteristics or commercialization of any product or service of Qualcomm Technologies, Inc. or its affiliates.

5G will enhance existing and expand to new use cases



Enhanced Mobile Broadband

Faster, more uniform user experiences

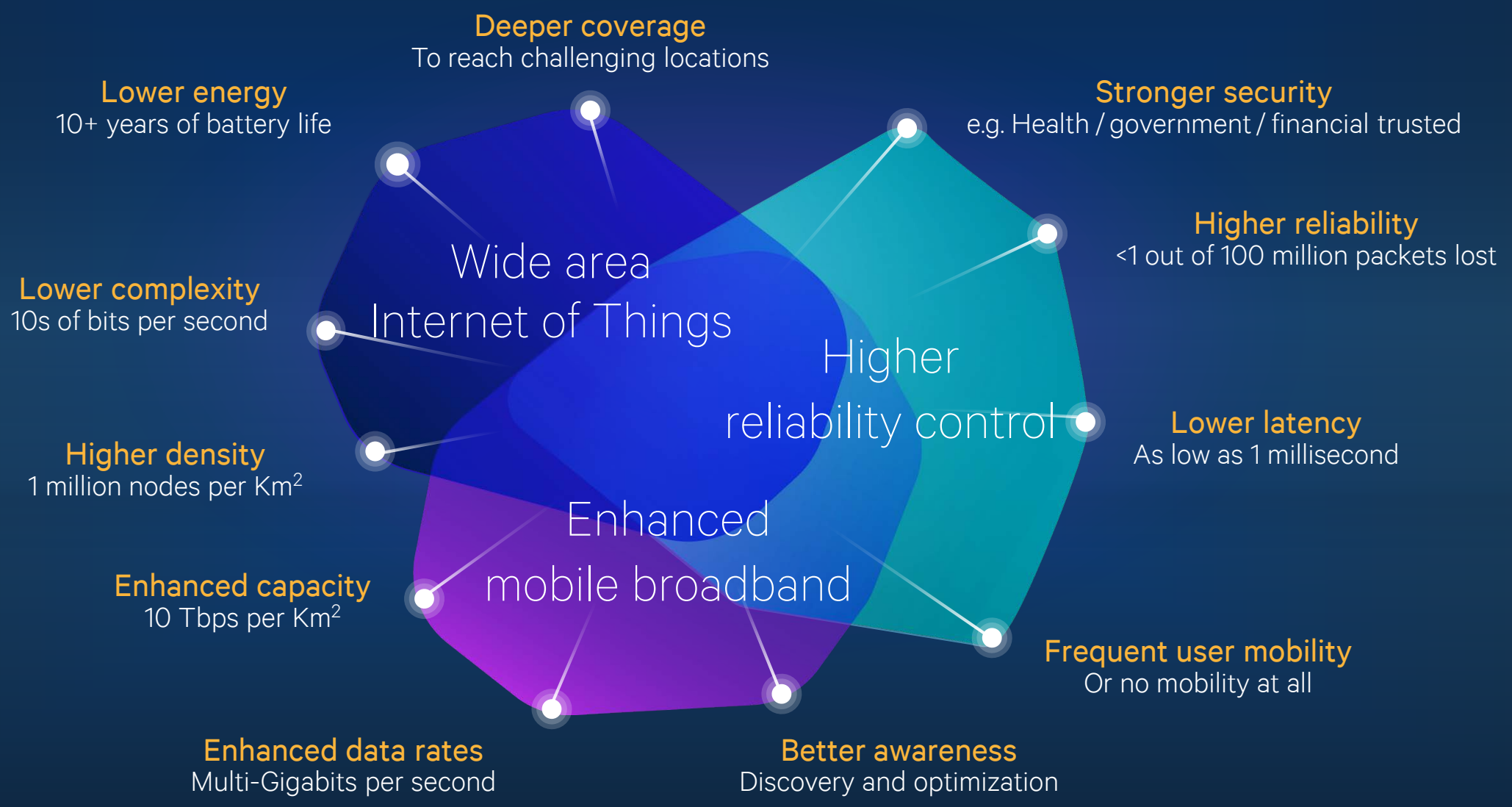
Wide Area Internet of Things

More efficient, lower cost communications with deeper coverage

Higher-Reliability Control

Lower latency and higher reliability

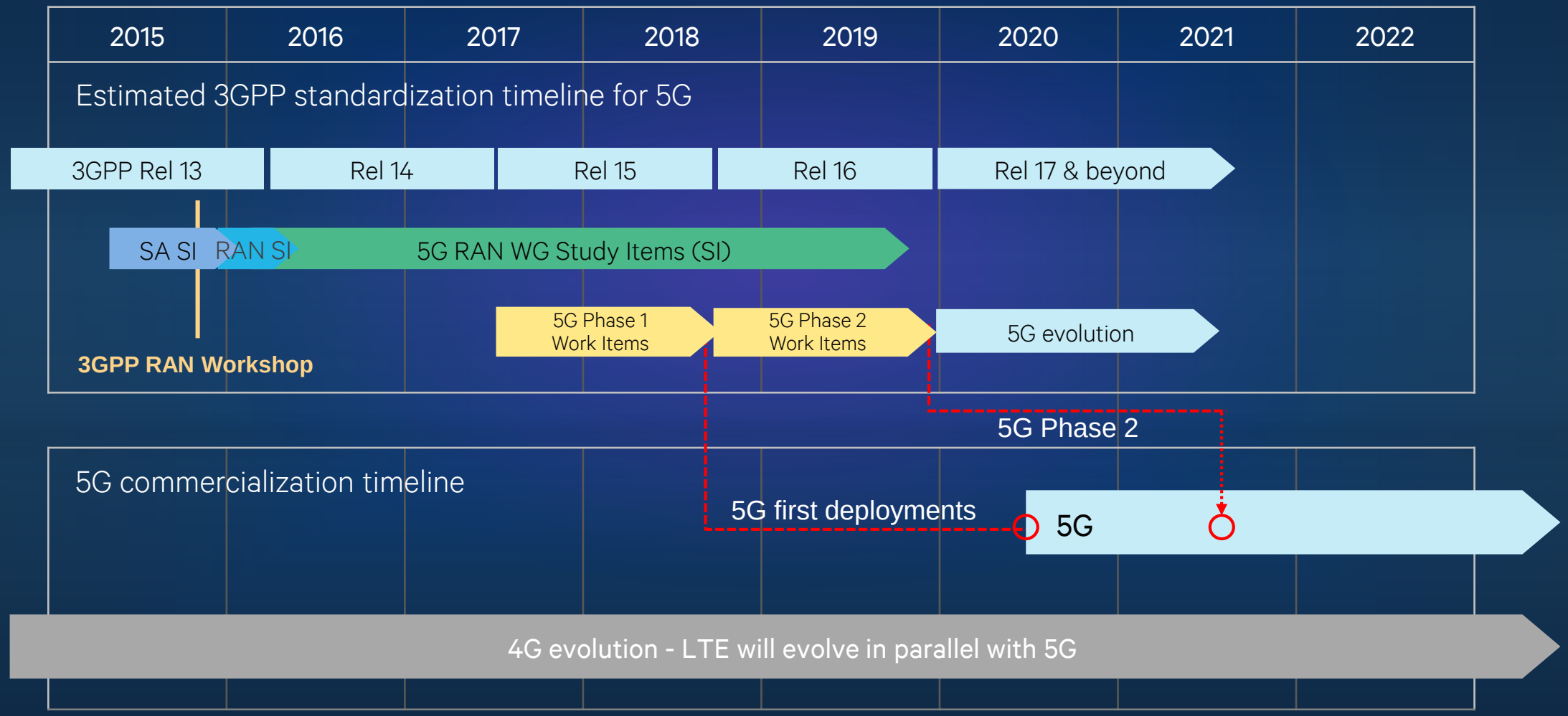
Scalable across a broad variation of requirements



Based on target requirements for the envisioned 5G use cases

Current 3GPP timeline delivers 5G spec for 2020 launch*

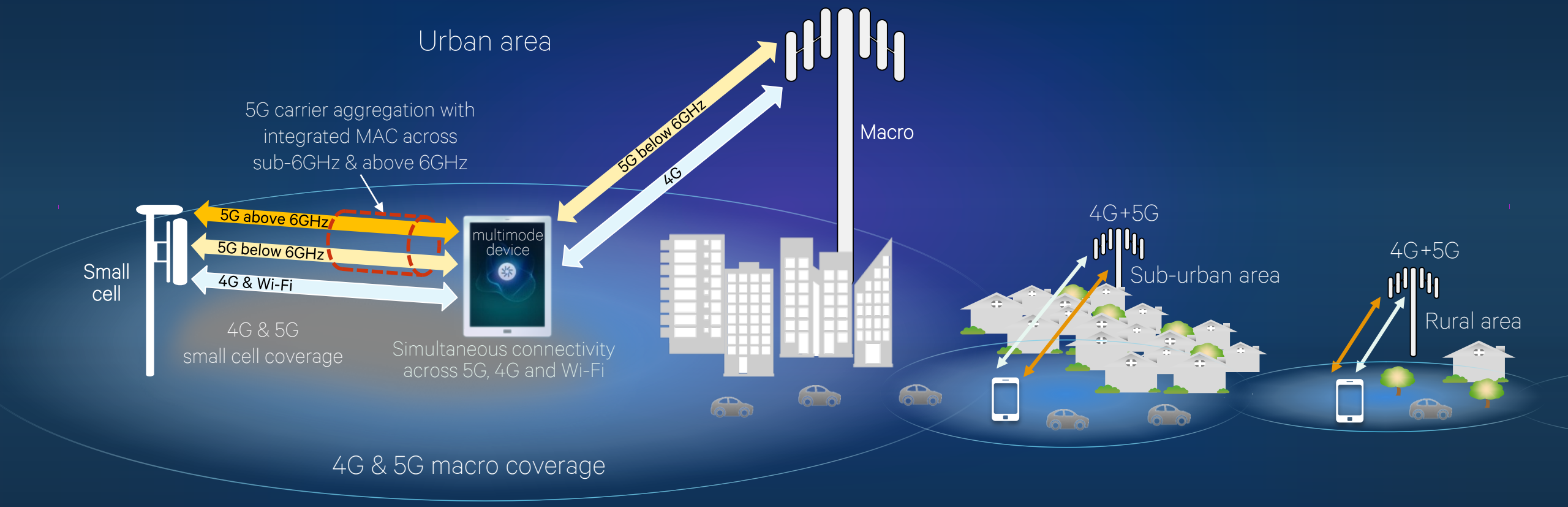
Anticipated 5G commercialization timeline – our view



* For information on 3GPP's 5G timeline, see: http://www.3gpp.org/news-events/3gpp-news/1734-ran_5g

Multi-connectivity across bands & technologies

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



Leverage 4G investments to enable phased 5G rollout

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

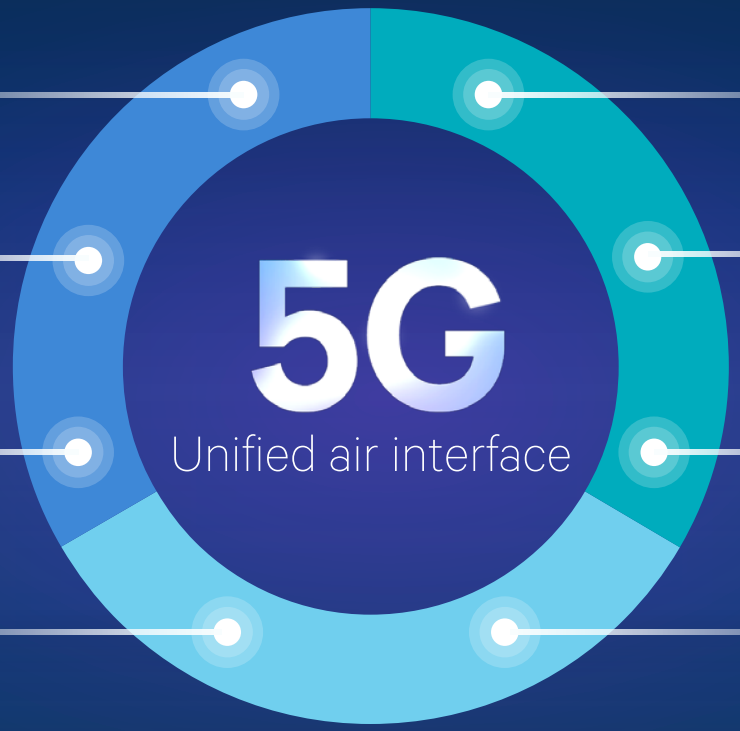
Diverse services and devices

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

Multiplexing of lower latency and more-reliable traffic and nominal traffic

From high user mobility to no mobility at all

From wide area macro to indoor / outdoor hotspots



Diverse deployments

Optimized OFDM-based waveforms

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

A common, more flexible framework

To more efficiently multiplex services and features—designed for forward compatibility

Advanced wireless technologies

Such as massive MIMO, more robust mmWave and a self-contained TDD design

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

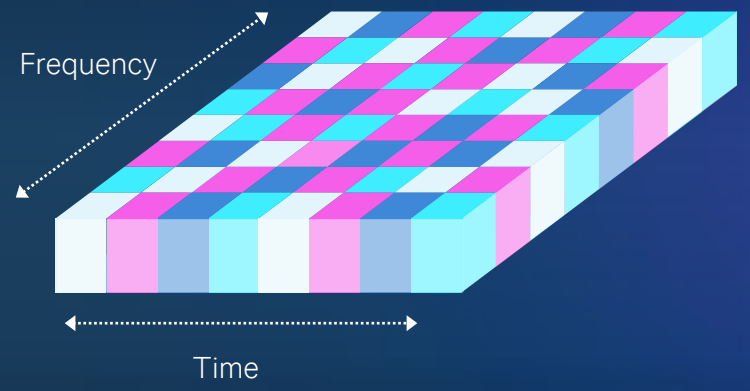
- Lower complexity, narrower bandwidth
- Lower energy waveform
- Optimized link budget
- Decreased overheads
- Managed multi-hop mesh

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

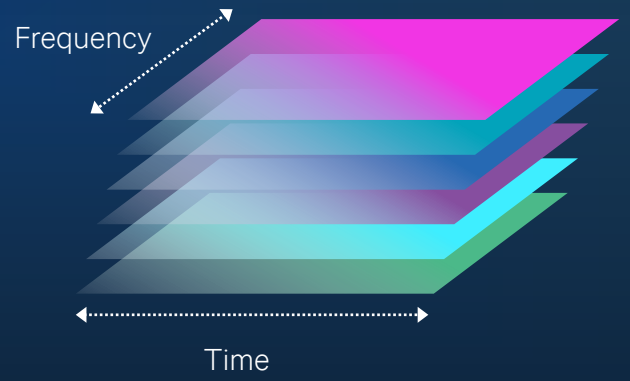
More efficient framework for MIMO spatial multiplexing – higher spectral efficiency

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

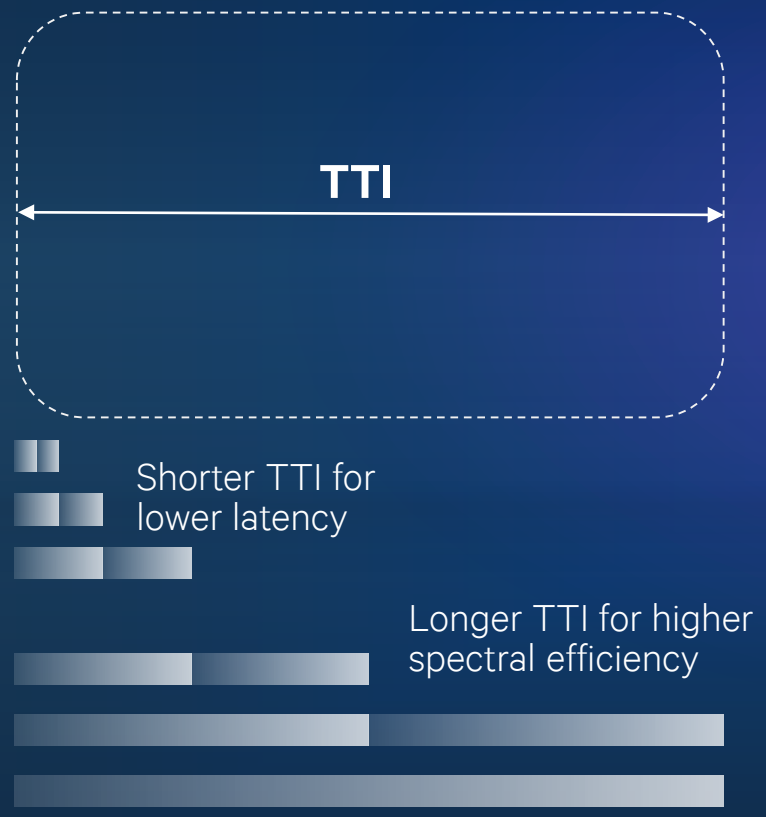
Enable asynchronous, non-orthogonal, contention-based access that is well suited for sporadic uplink transmissions of small data bursts (e.g. IoT)



A more detailed analysis of 5G optimized waveforms and multiple access is available in the appendix of this presentation

Scalability to much lower latency

Scalable TTI for diverse latency & QoS requirements



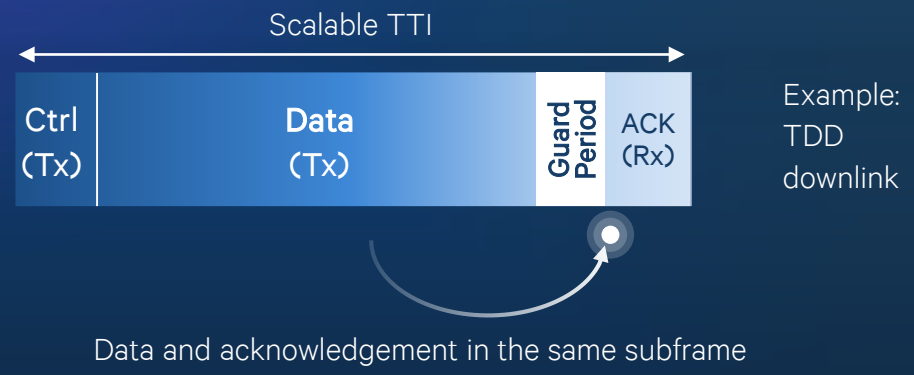
Order of magnitude lower Round-Trip Time (RTT) than LTE today

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

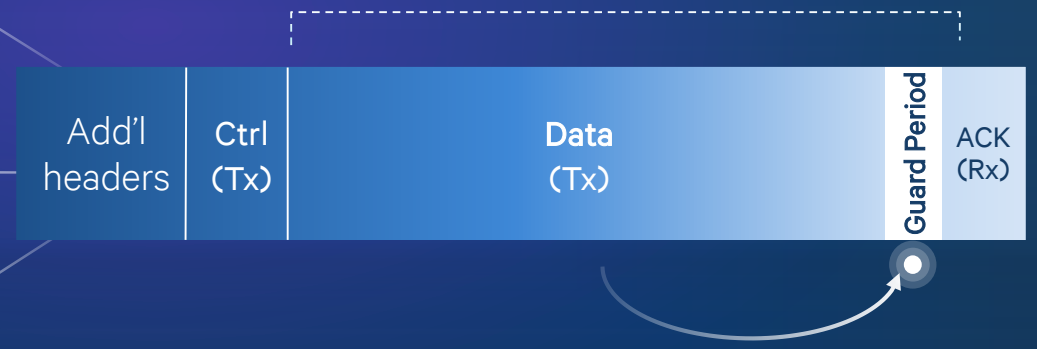
Leveraging channel reciprocity in UL transmission for DL beamforming training

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

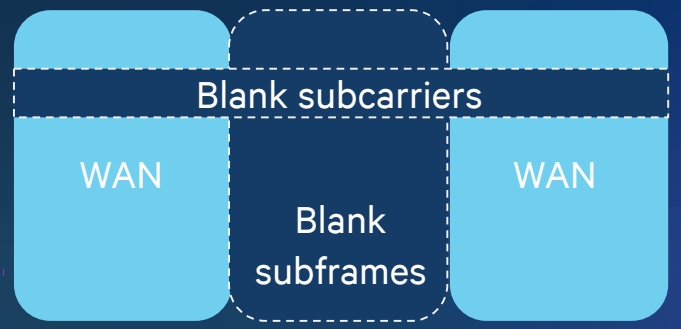


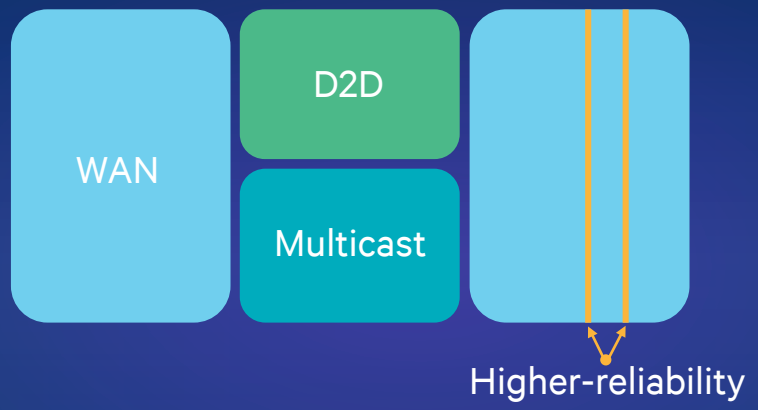
Example: TDD downlink

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

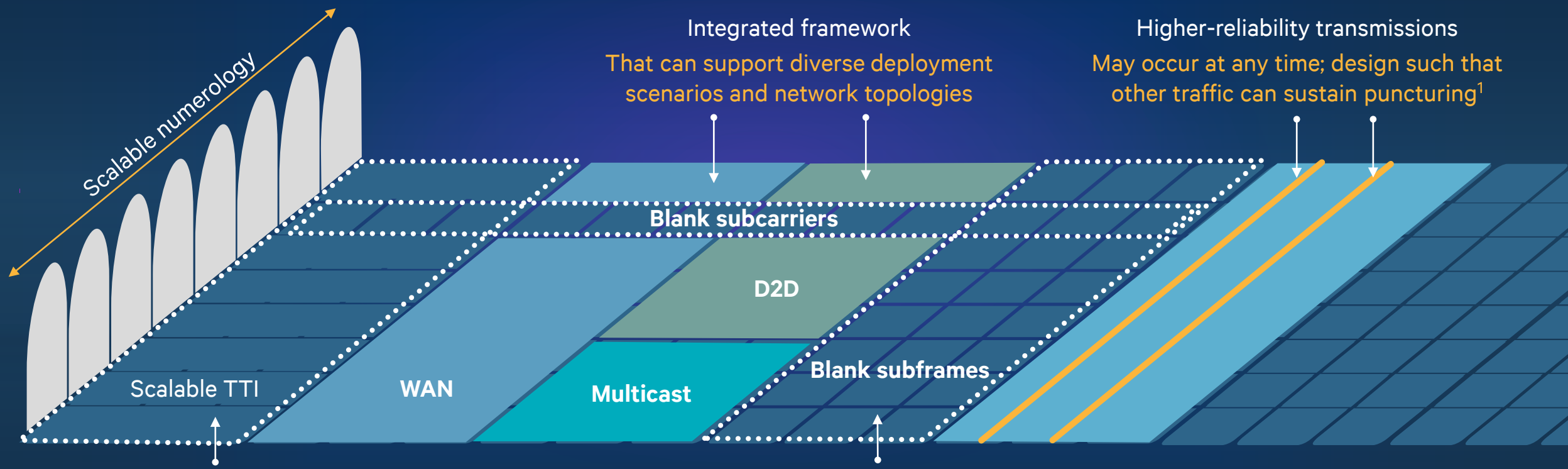
Common frame structure

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



Scalable transmission time interval (TTI)

For diverse latency requirements — capable of latencies an order of magnitude lower than LTE

Forward compatibility

With support for blank subframes and frequency resources for future services/features

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

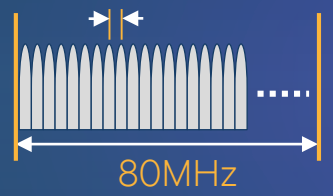
Scalable OFDM numerologies

To meet diverse spectrum bands/types and deployment models

Outdoor and macro coverage
FDD/TDD <3 GHz

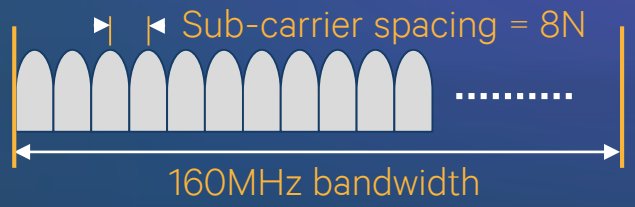
Sub-carrier spacing = N
(extended cyclic prefix)

Outdoor and small cell
TDD > 3 GHz

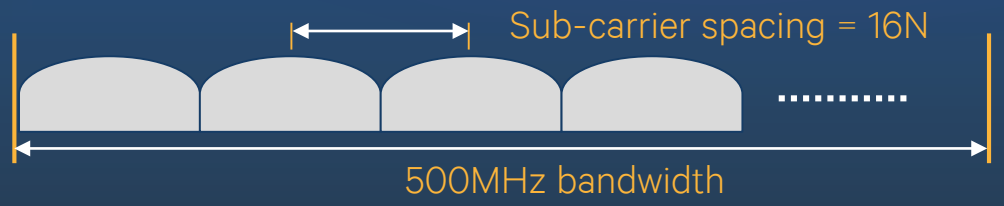


Sub-carrier spacing = 2N
(normal cyclic prefix)

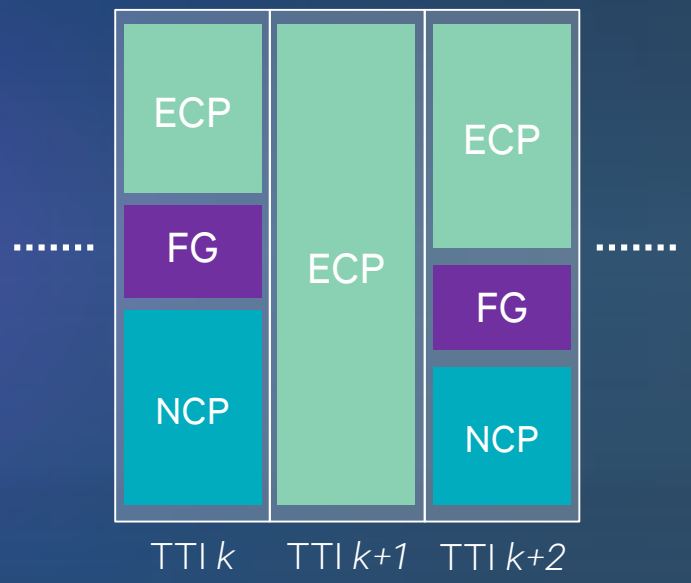
Indoor wideband
TDD e.g. 5 GHz
(Unlicensed)



mmWave
TDD e.g. 28 GHz



Example usage models and channel bandwidths

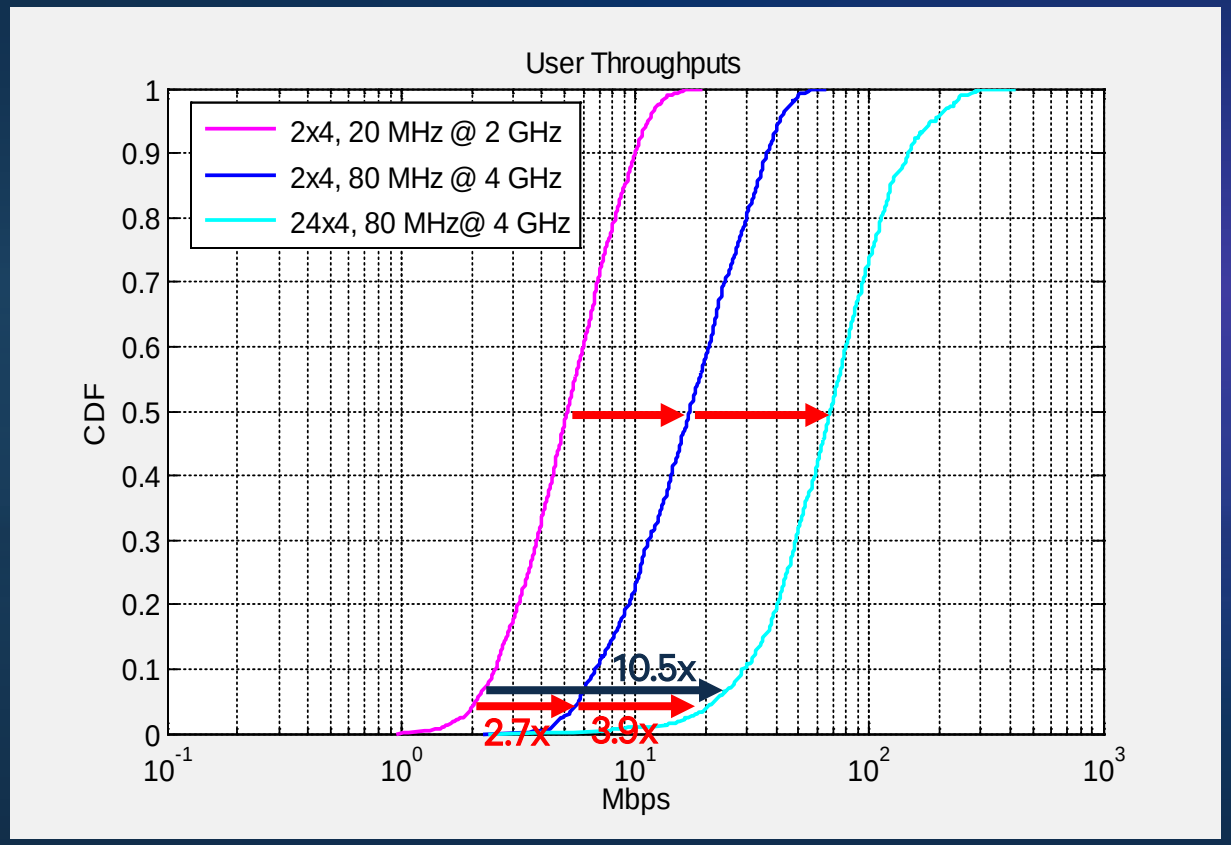


Numerology multiplexing

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, 2.4x Massive MIMO. Using 5-pertantile throughput for cell edge throughput.

Realizing the mmWave opportunity for mobile broadband

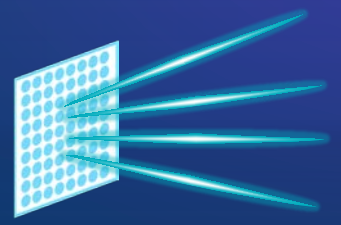
The enhanced mobile broadband opportunity

- 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

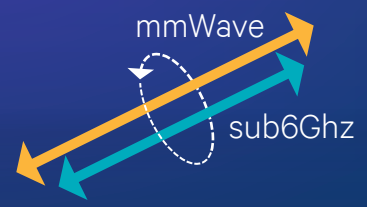
- Robustness results from high path loss and susceptibility to blockage
- Device cost/power and RF challenges at mmWave frequencies

5G Solutions



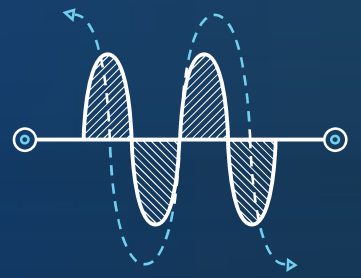
Smart beamforming & beam tracking

Increase coverage and minimize interference



Tighter interworking with sub 6 GHz

Increase robustness and faster system acquisition

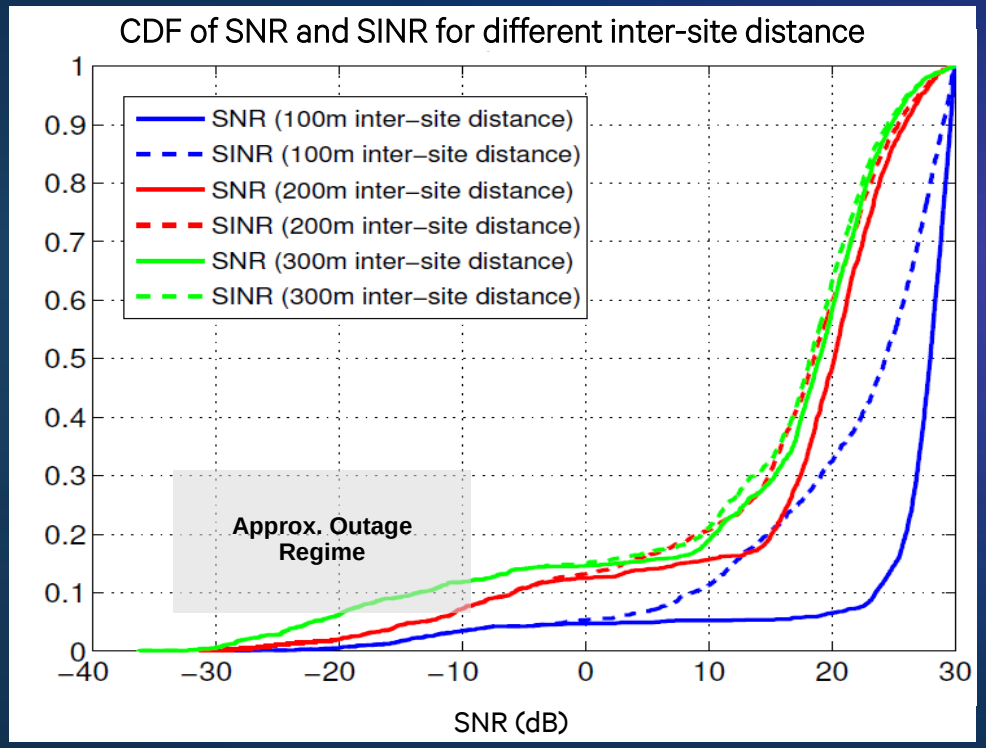


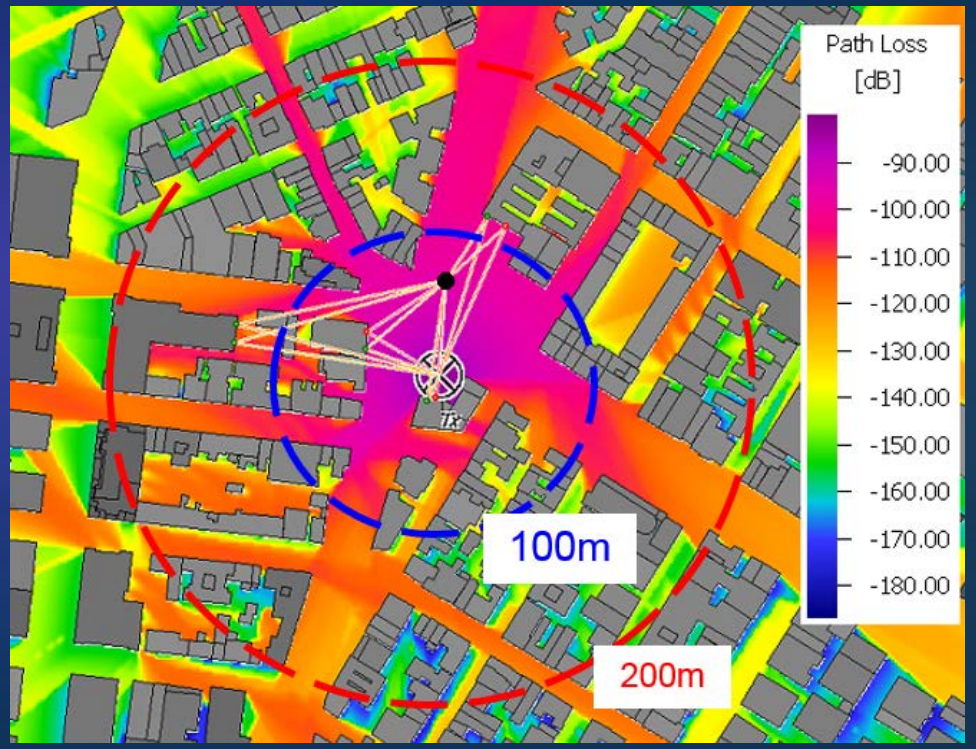
Phase noise mitigation in RF components

For lower cost, lower power devices

Directional beamforming improves mmWave coverage and reduces interference

28GHz: Outdoor to Outdoor Path Loss & Coverage





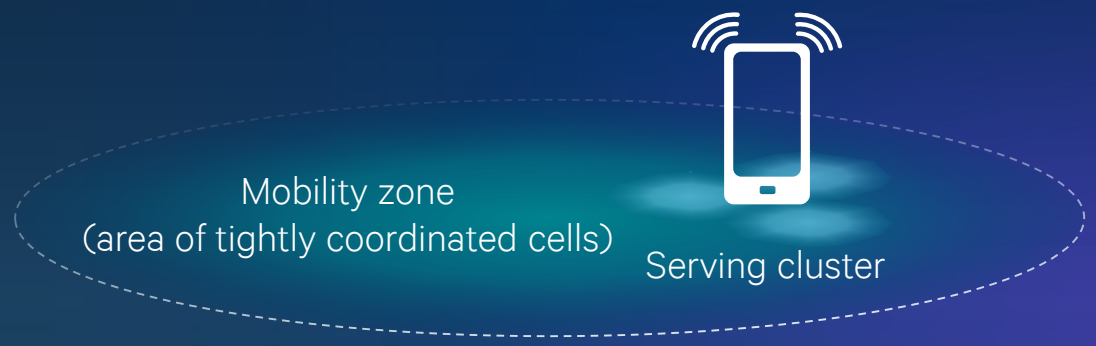
* Mahattan 3D map, Results from ray-tracing

- 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

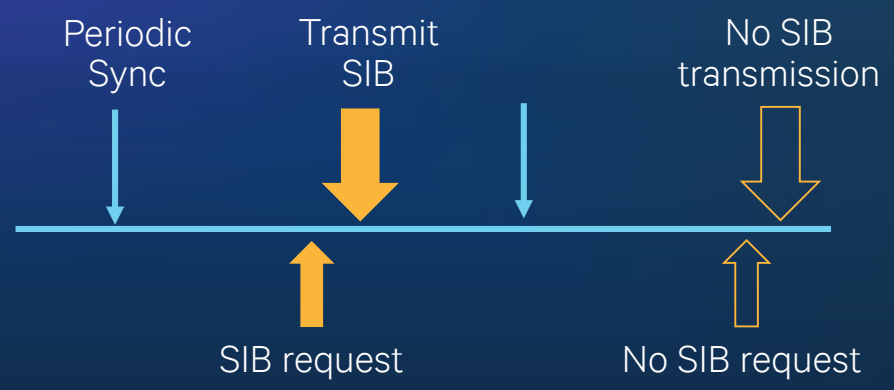


Lightweight mobility for device energy savings

- 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;

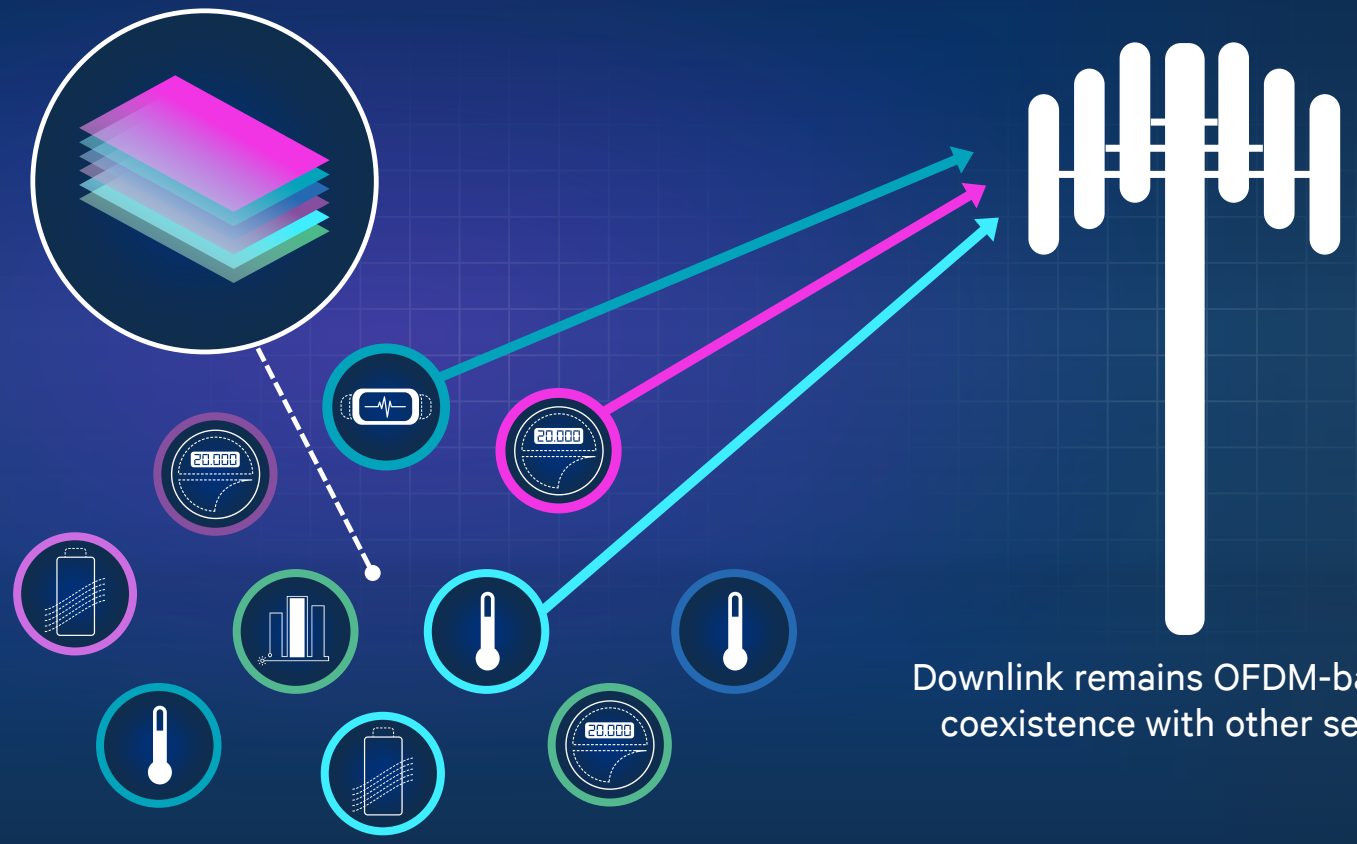
[2] May dynamically revert to broadcast system info when needed, e.g. system info changes

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



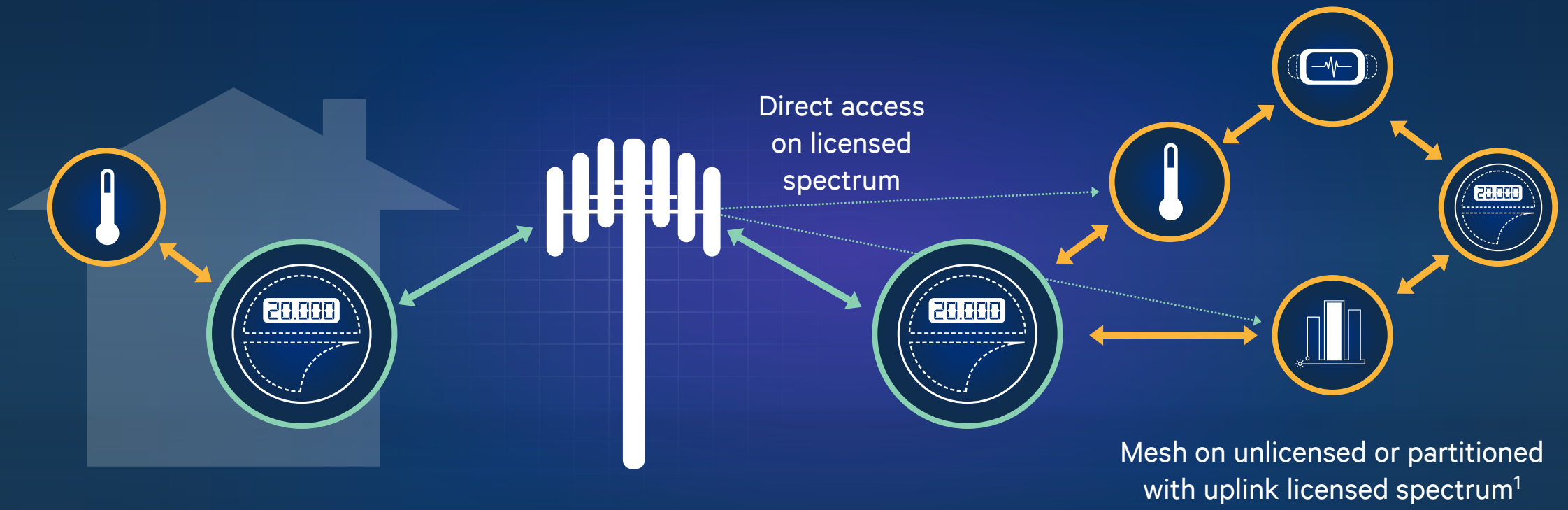
Downlink remains OFDM-based for coexistence with other services

Increased battery life

Scalability to high device density

Better link budget

Support for multi-hop mesh with WAN management

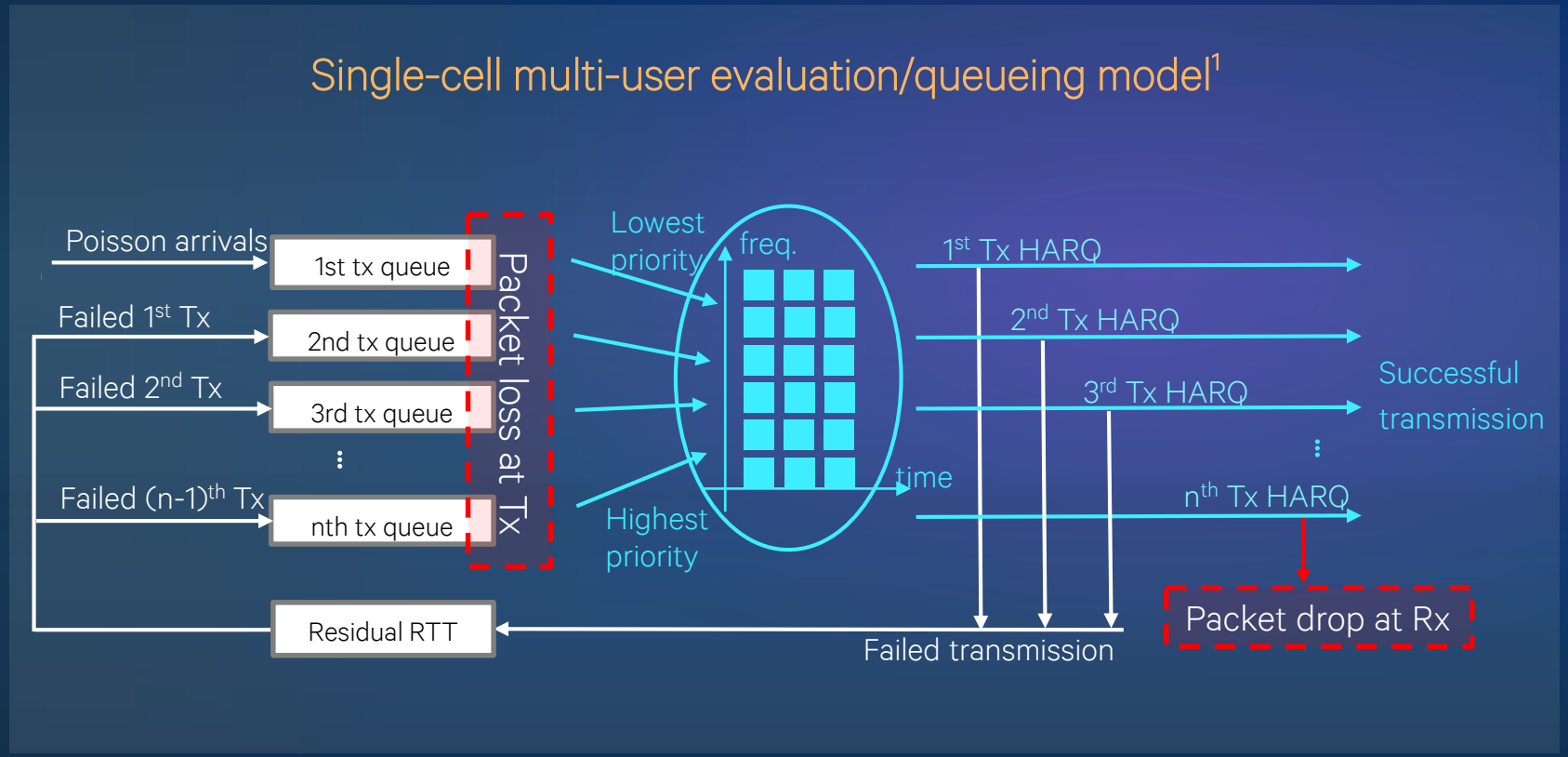


Problem: uplink coverage | Due to low power devices and challenging placements, e.g. in basement

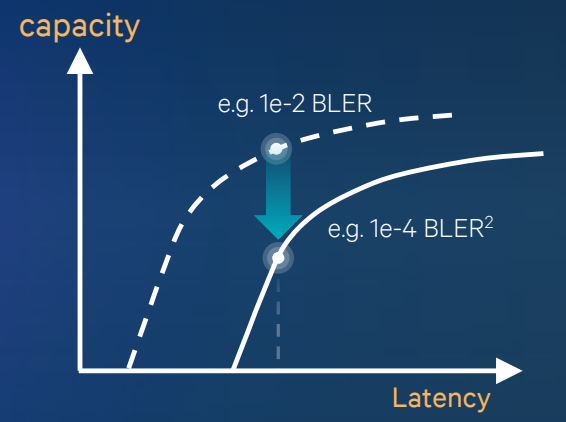
Solution: managed uplink mesh | Uplink data relayed via nearby devices—uplink mesh but direct downlink.

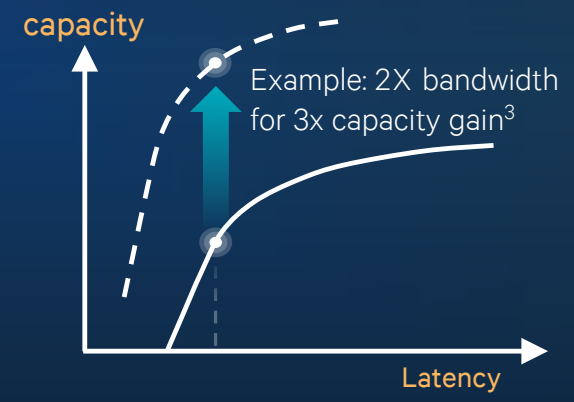
[1] Greater range and efficiency when using licensed spectrum, e.g. protected reference signals . Network time synchronization improves peer-to-peer efficiency

Hard latency bound and PHY/MAC design



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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