Highlights of 5G and the Internet of Things

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Progressing technologies toward 5G

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

Scaling to connect the Internet of Things

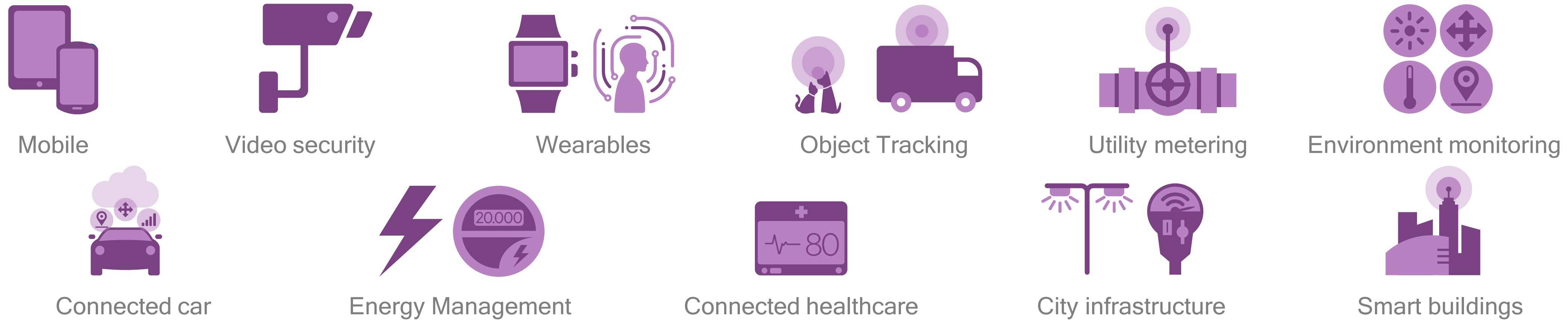
← Scaling up in performance and mobility

Scaling down in complexity and power →

LTE Advanced	LTE Cat-1	eMTC (Cat-M1)	NB-IOT (Cat-M2)
>10 Mbps	Up to 10 Mbps	Up to 1 Mbps	10s of kbps to 100s of kbps
n x 20 MHz	20 MHz	1.4 MHz narrowband	180 kHz narrowband

LTE Advanced (Today+)

LTE IoT (Release 13+)



Significantly widening the range of enterprise and consumer use cases

New NB-IOT design also part of 3GPP Release 13

Global standard for Low Power Wide Area applications based on licensed spectrum

Scales even further in cost and power

Narrower bandwidth (180 kHz)	Various potential deployment options incl. in-band within LTE deployment[1]
Higher density	Massive number (10s of thousands) of low data rate 'things' per cell
Longer battery life	Beyond 10 years of battery life for certain use cases
Lower device cost	Comparable to GPRS devices
Extended coverage	Deep indoor coverage, e.g. for sensors located in basements (>164 dB MCL)

Addresses a subset of IoT use cases

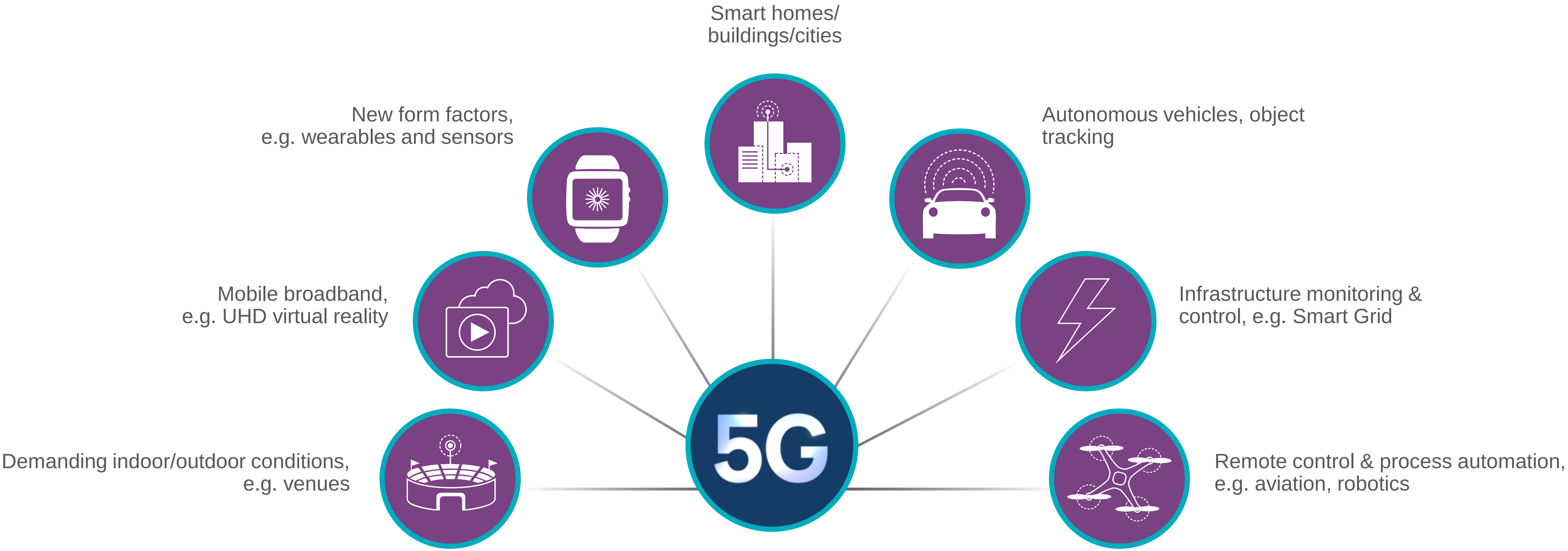
Low data rate	Up to 100s of kbps
Delay tolerant	Seconds of latency
Nomadic mobility	No handover; cell reselection only

Sample use cases

Remote sensors | Object Tracking | Utility metering | Smart buildings

[1] May be deployed in-band, utilizing resource blocks within normal LTE carrier or standalone for deployments in dedicated spectrum including re-farming GSM channels. Also exploring deployments in the unused resource blocks within a LTE carrier's guard-band,

5G will enhance existing and expand to new use cases



Enhanced Mobile Broadband

Faster, more uniform user experiences

Wide Area Internet of Things

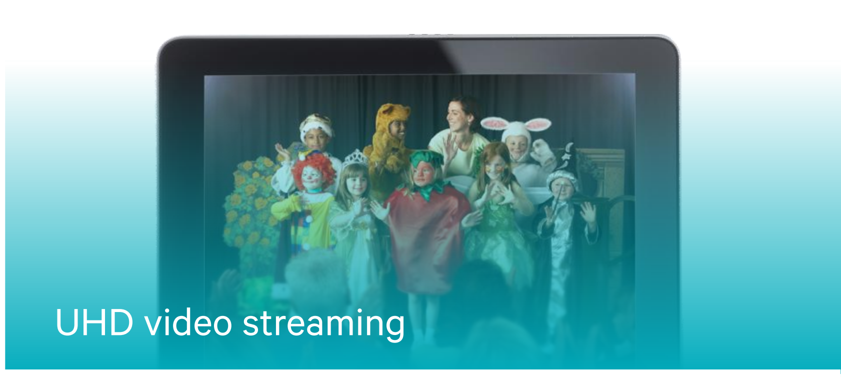
More efficient, lower cost communications with deeper coverage

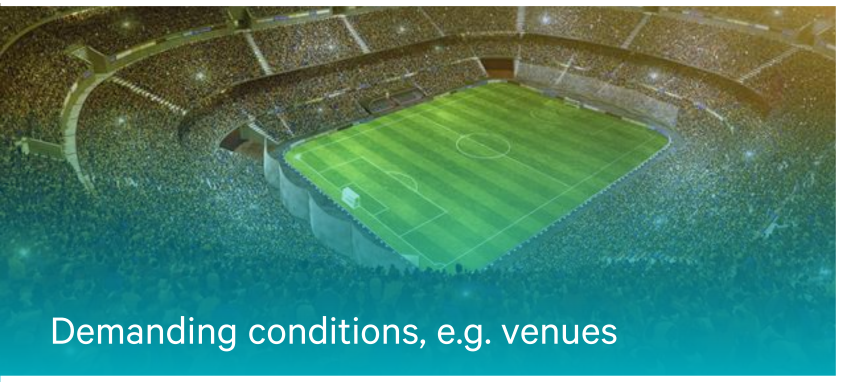
Higher-Reliability Control

Lower latency and higher reliability

Enhanced mobile broadband

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





Higher throughput

multi-gigabits per second

Lower latency

Significantly reduced e2e latency

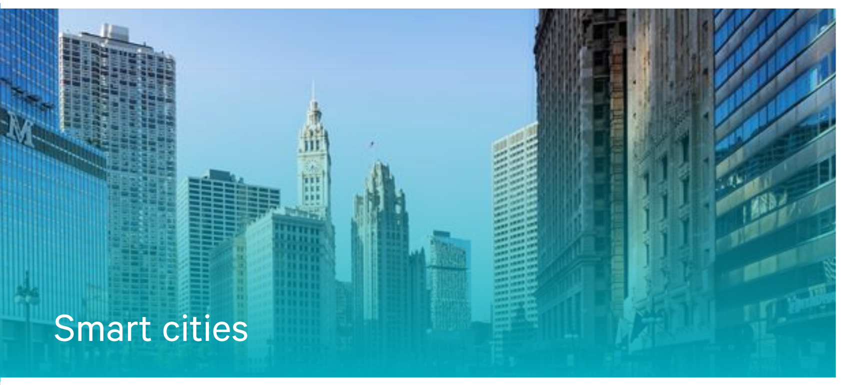
Uniform experience

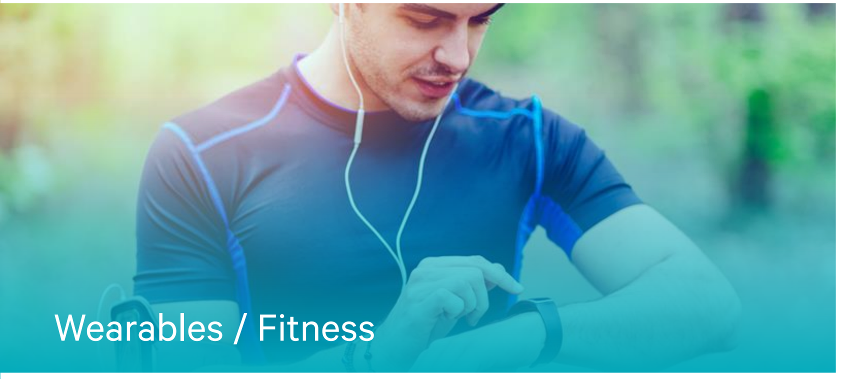
with much more capacity

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

Wide area Internet of Things

Optimizing toward the goal to connect anything, anywhere





Power efficient
Multi-year battery life

Lower complexity
Lower device and network cost

Longer range
Deeper coverage

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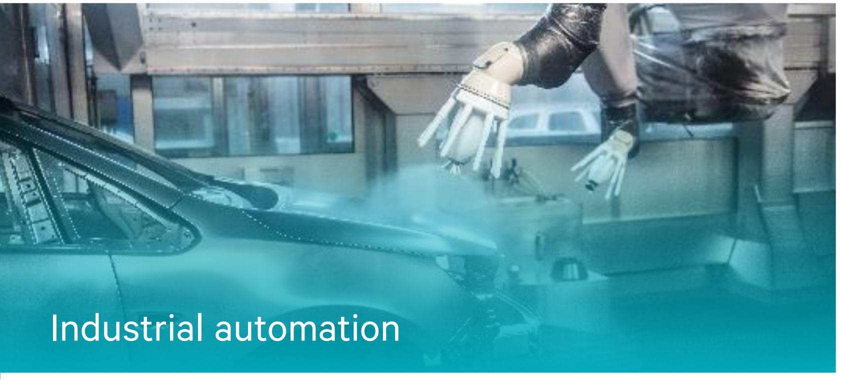
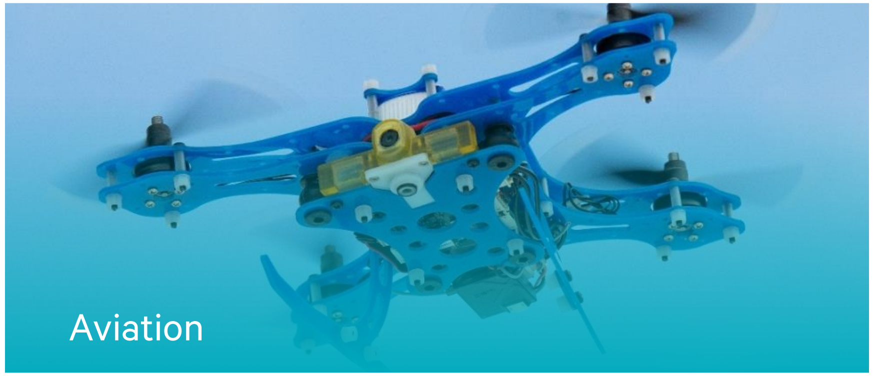
Higher reliability control

Enabling new services with more reliable, lower latency communication links





Higher reliability

Significantly reduced packet loss rate

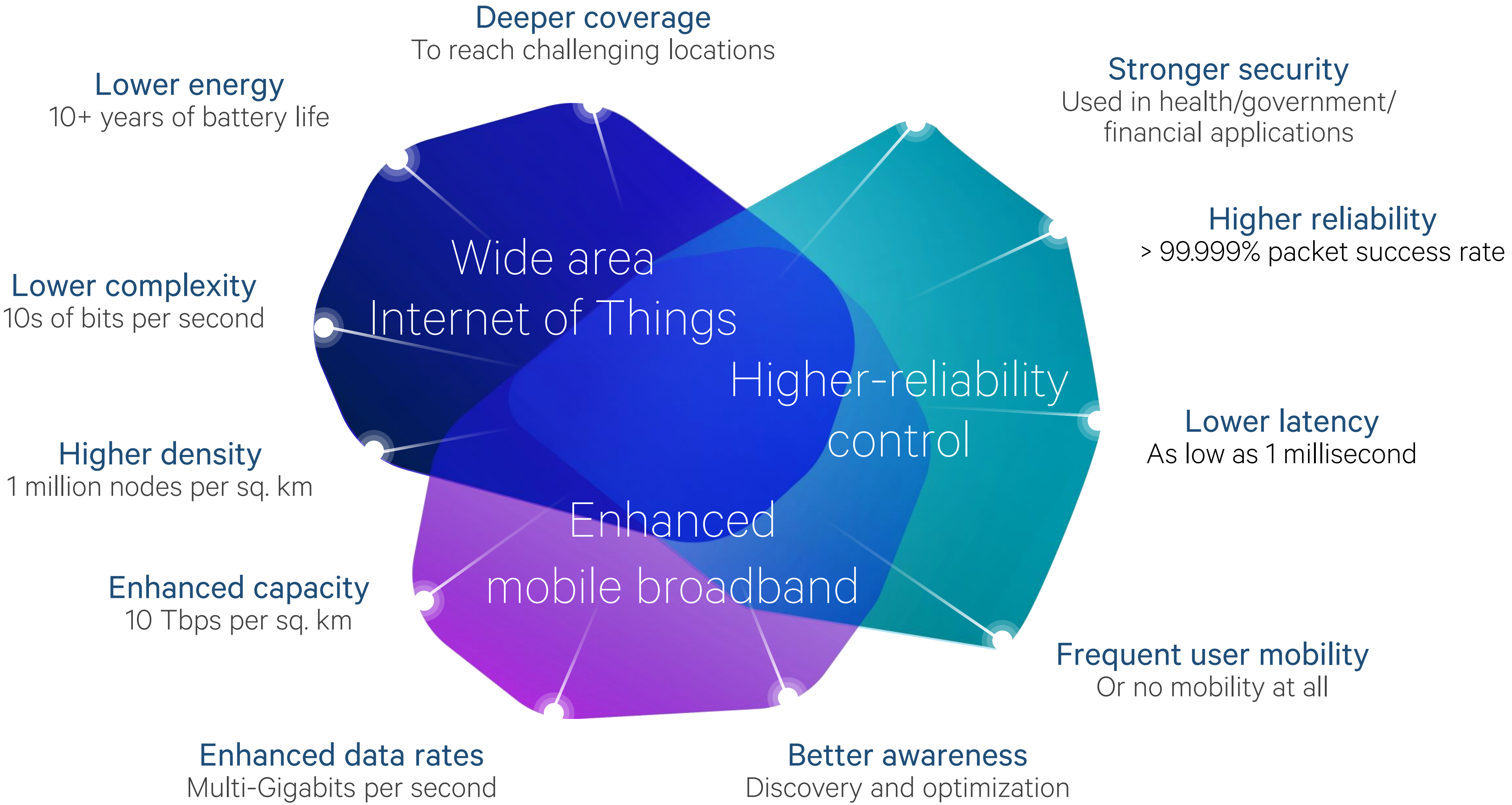
Lower latency

Significantly reduced e2e latency

Higher availability

Multiple links for failure tolerance and mobility

Scalable across a broad variation of requirements



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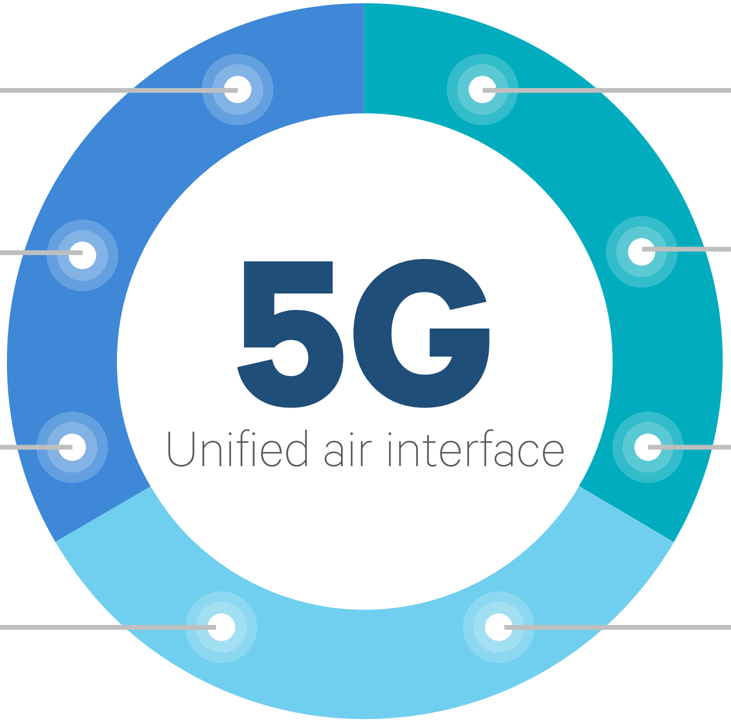
A new 5G unified air interface is the foundation



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

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

Diverse deployments

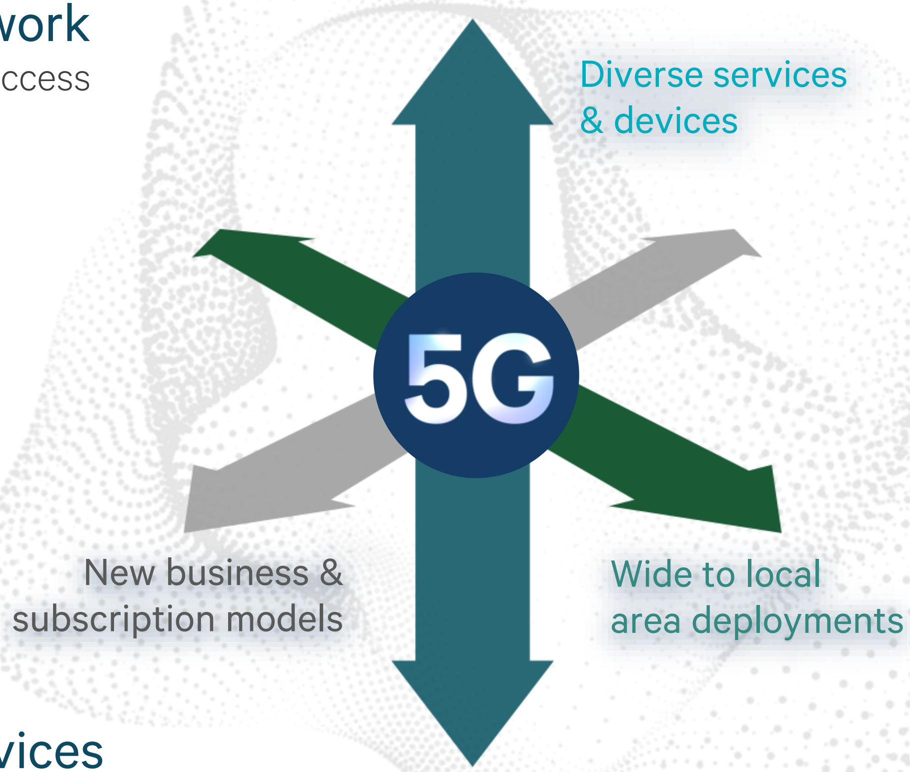
- Device-to-device, mesh, relay network topologies
- From wide area macro to indoor / outdoor hotspots

Delivering a flexible 5G network architecture

Multi-access core network
Continue to evolve 4G LTE and Wi-Fi access

Flexible subscription models
Such as one subscription for multiple devices

Dynamic creation of services
Such as dynamic MVNO or tailored verticals



Dynamic control and user planes
Such as mobility on demand and functions at edge

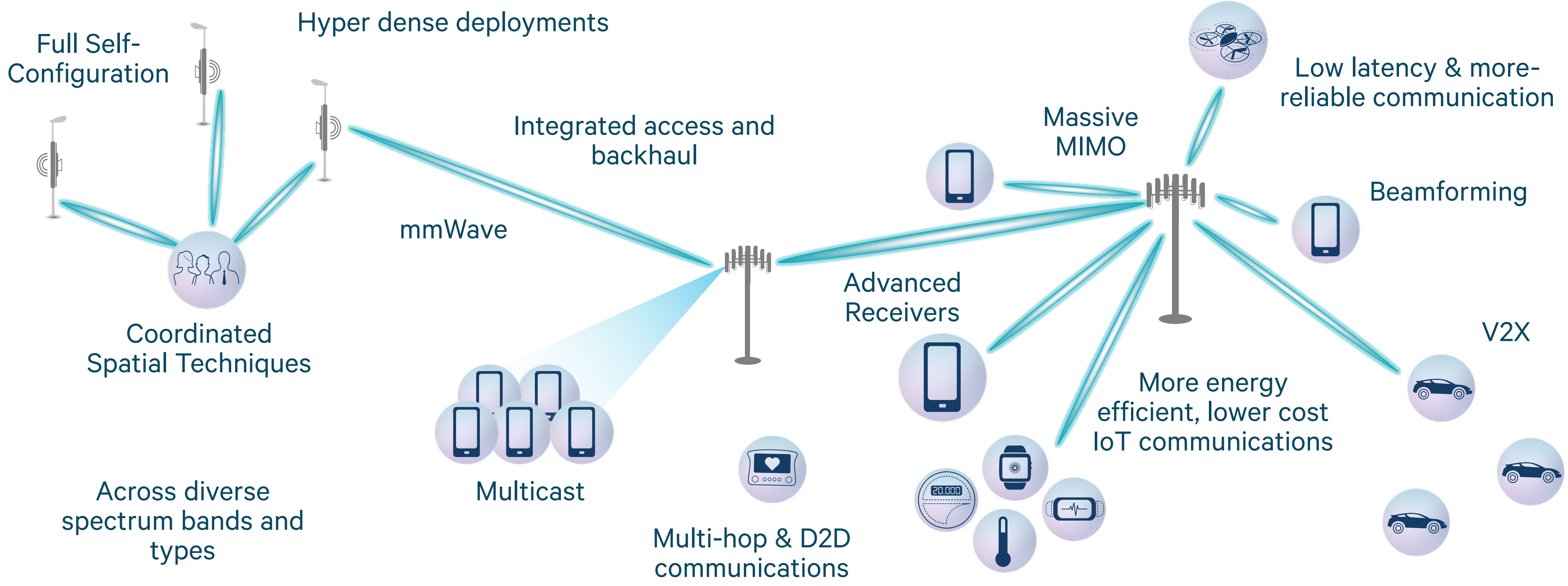
Modular, specialized functions
Not to burden other network services

Configurable end-to-end connectivity
With network and service slicing[1]

[1] Leveraging Network Function Virtualization (NFV) and Software Defined Networking (SDN)

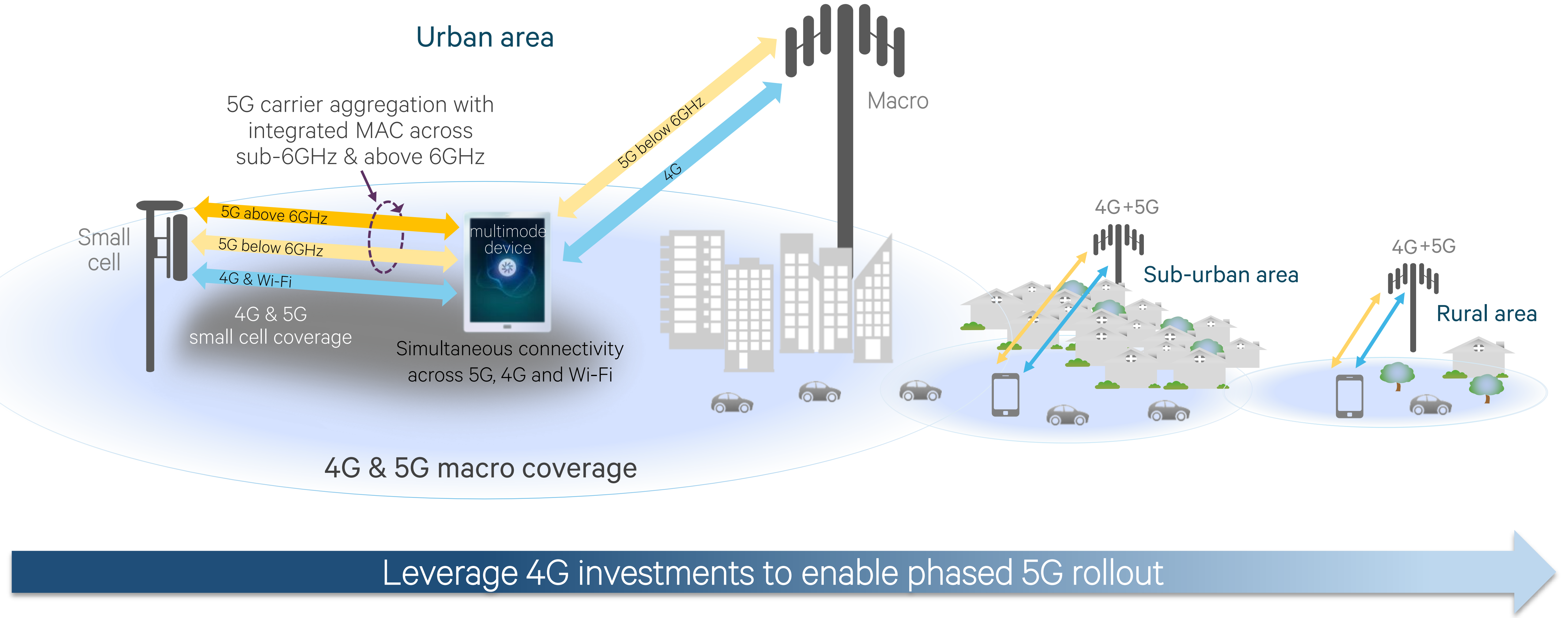
Natively incorporate advanced wireless technologies

Many technology enablers to meet 5G requirements and services



Multi-connectivity across bands & technologies

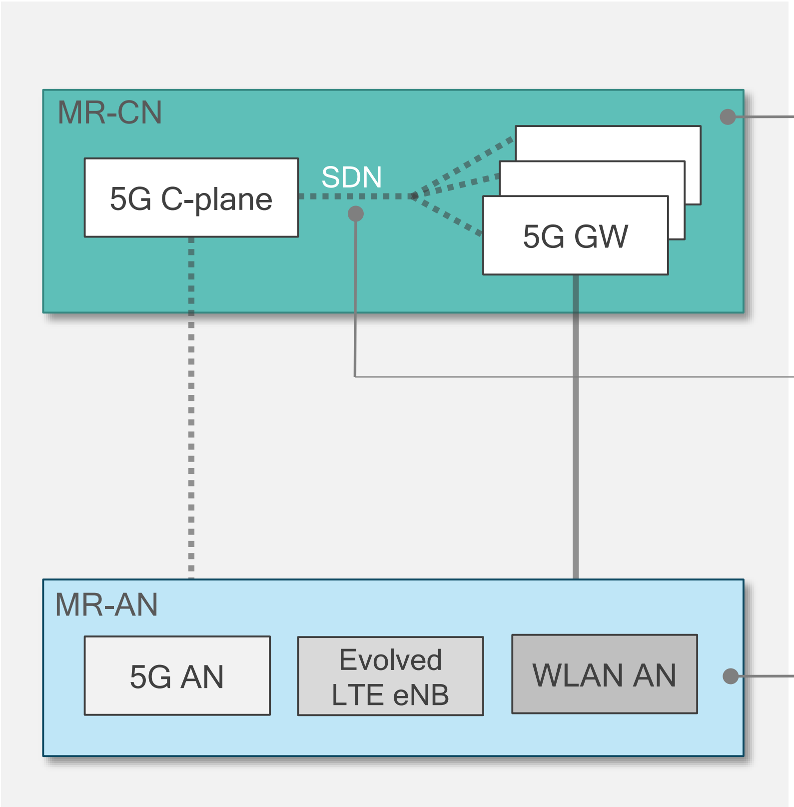
4G+5G multi-connectivity improves coverage and mobility



Multi-RAT access and core networks

Making 5G services available to legacy RAT

5G Multi-RAT network architecture



Multi-RAT core network (MR-CN)

- Common core network to support multiple RATs (5G/LTE/WLAN)
- Improved end-to-end performance for LTE/WLAN

Further separation of control & user planes based on SDN*

- Allows the scaling of the C/U planes separately
  - 4G enables this from the UE perspective only
  - 5G enables this in the core network
- Allows more fine grain traffic management

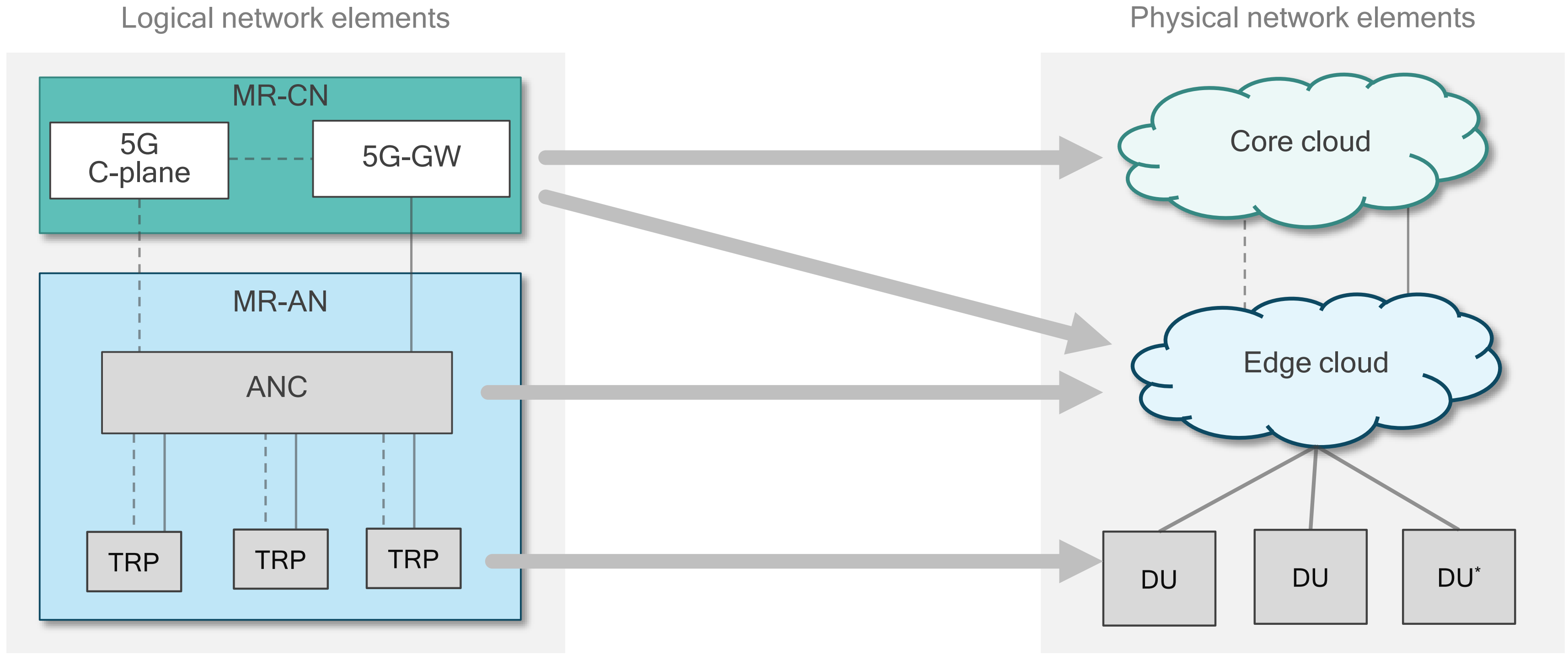
Multi-RAT access network (MR-AN)

- One or more cells for each RAT
- Supports inter and intra RAT mobility and aggregation

* SDN = Software Defined Networking

Network Function Virtualization (NFV)

A more flexible platform to deploy functions to better suit service requirements



Service realization

- Defines the logical functions needed to support a service and where the they are located, e.g., edge or core
- Configured each specialized network function to enable the specific requirements for the service

Service hosting

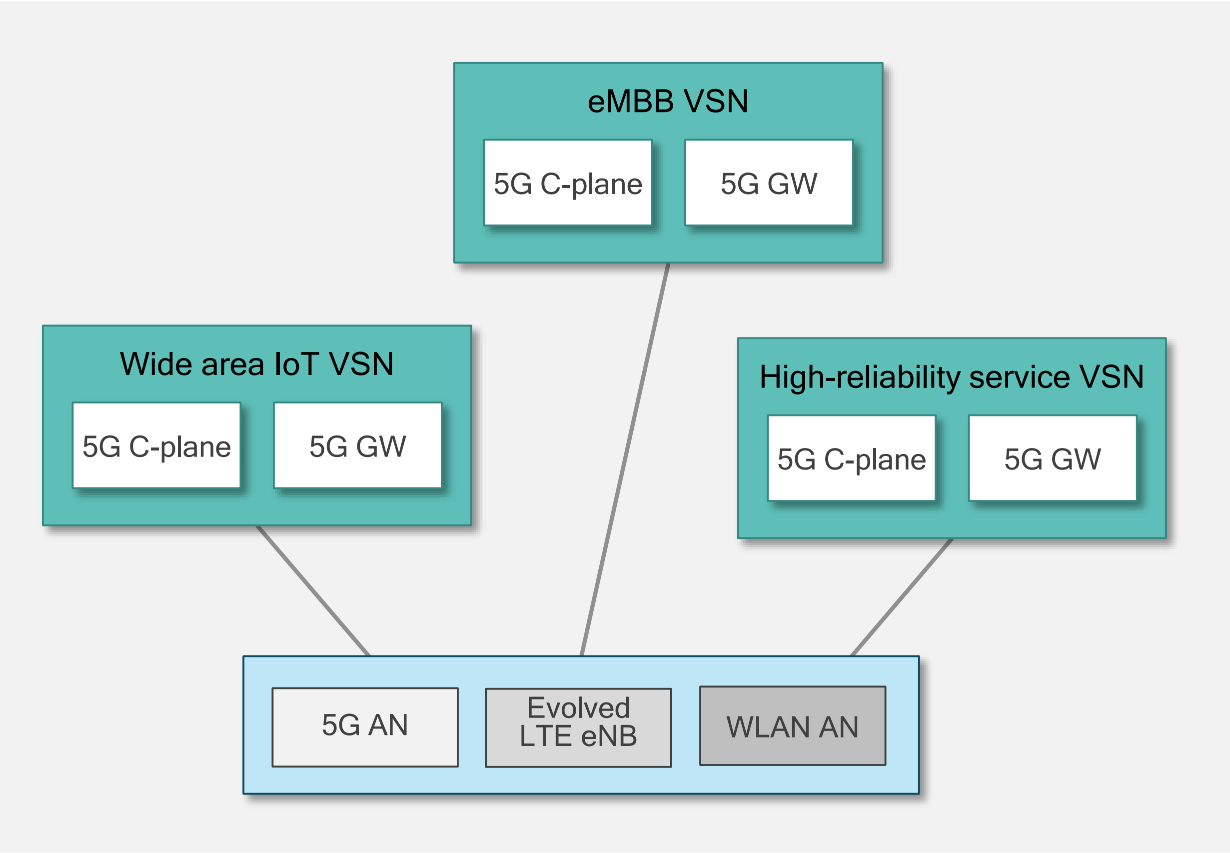
- Physical instantiation of the service on the NFV platform
- Hosts the logical functions and configurations at the best location for the service

* ANC = Access Network Controller, TRP = Transmission and Receiving Point, DU = Distributed Unit

Network slicing - an example

Network slicing based on NFV allows more flexible service enablement

Network slices - separate Virtual Service Networks (VSNs)



Network slicing

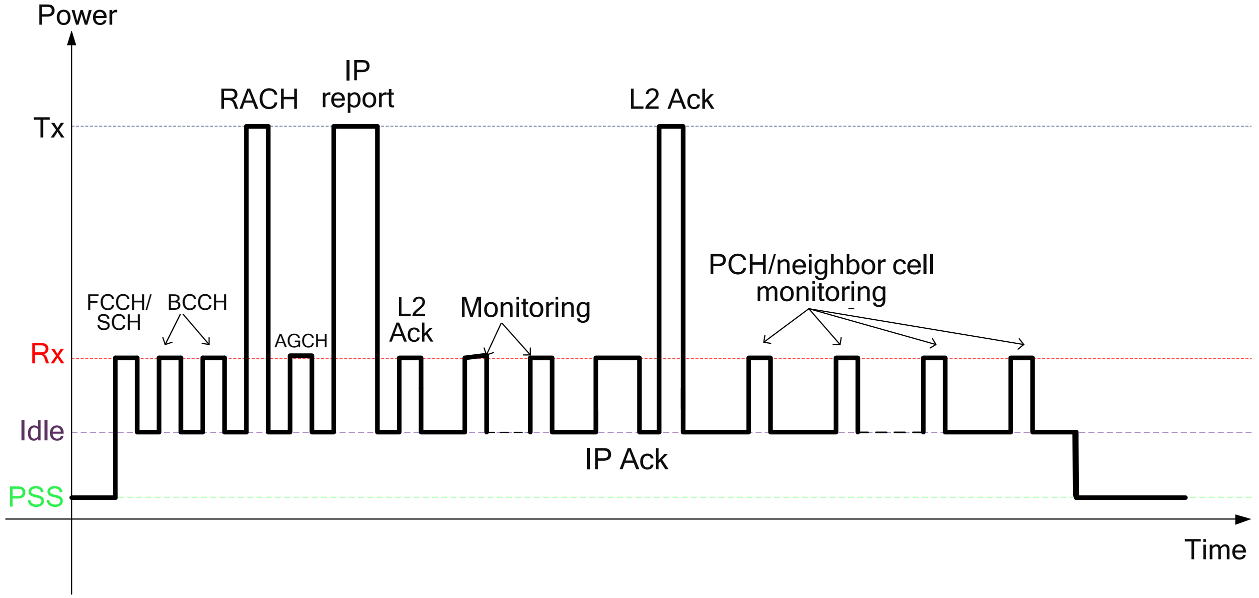
- More flexible configuration of the functions to better suit the needs of the service
- More modular use of different functions including making more functionality optional
- Also should allow for services hosted by operators and 3rd parties (RAN sharing)

mMTC and URLLC evaluation KPIs

	KPI	Descriptions
mMTC	Connection density	• Total number of devices fulfilling specific QoS per unit area (per km^2). • Target: 1 million/km^2 in urban
	UE battery life	• Battery life of the UE without recharge for given traffic and battery consumption models and battery capacity. • Target: 15 years
	Coverage	• "Maximum coupling loss" (MCL) in uplink and downlink between device and Base Station site for a given data rate • Target: 164dB
URLLC	User plane latency	• The time it takes to successfully deliver an application layer packet/message* • Target: 0.5ms (4ms for eMBB)
	Reliability	• Success probability of transmitting a given number of bytes within 1ms under a certain channel quality. • Target: $1\text{-}10^{-5}$ within 1ms

Example UE energy consumption model

Battery life is calculated based on energy consumption per day and total battery capacity



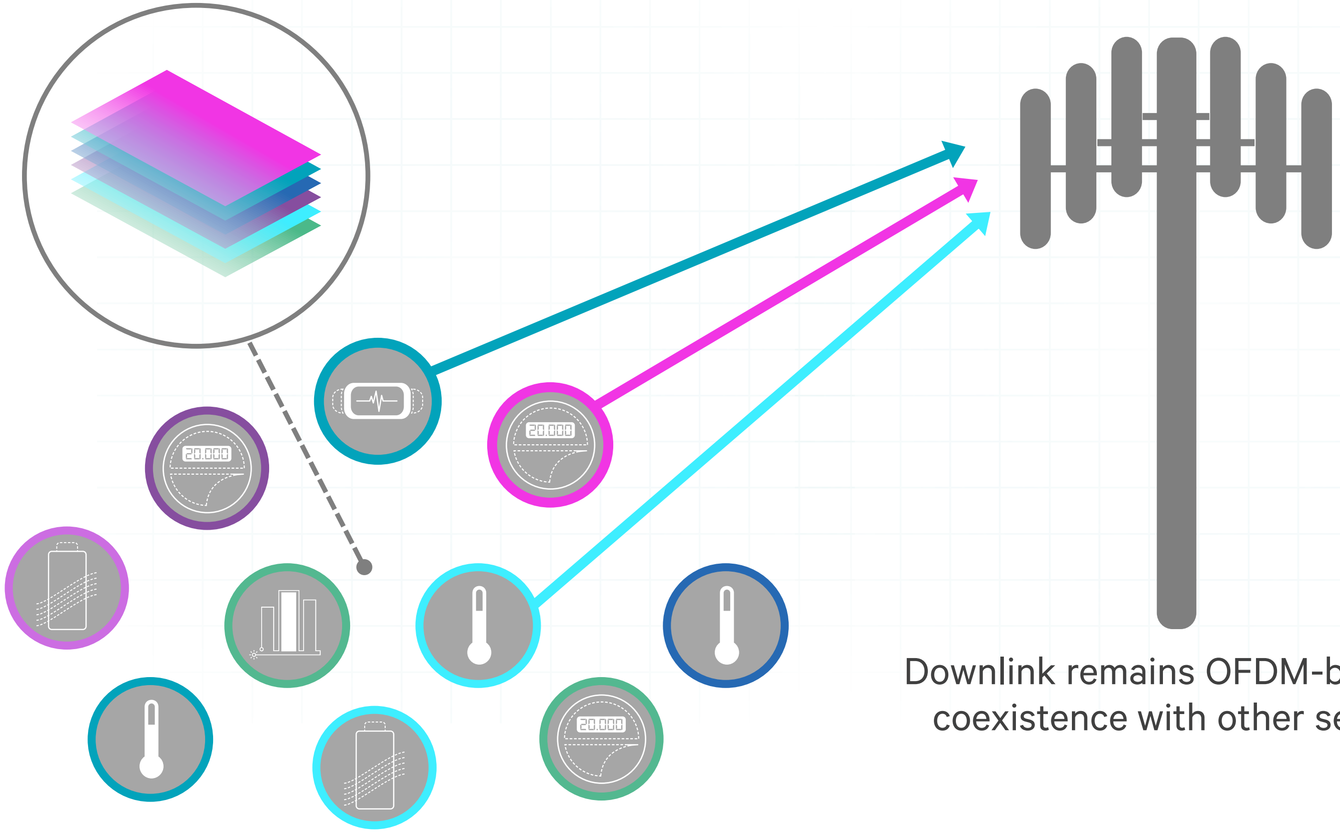
* From the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point via the radio interface in both uplink and downlink directions, where neither device nor Base Station reception is restricted by DRX

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[1]
- Allows devices to transmit data asynchronously
- Capable of supporting full mobility



Downlink remains OFDM-based for coexistence with other services

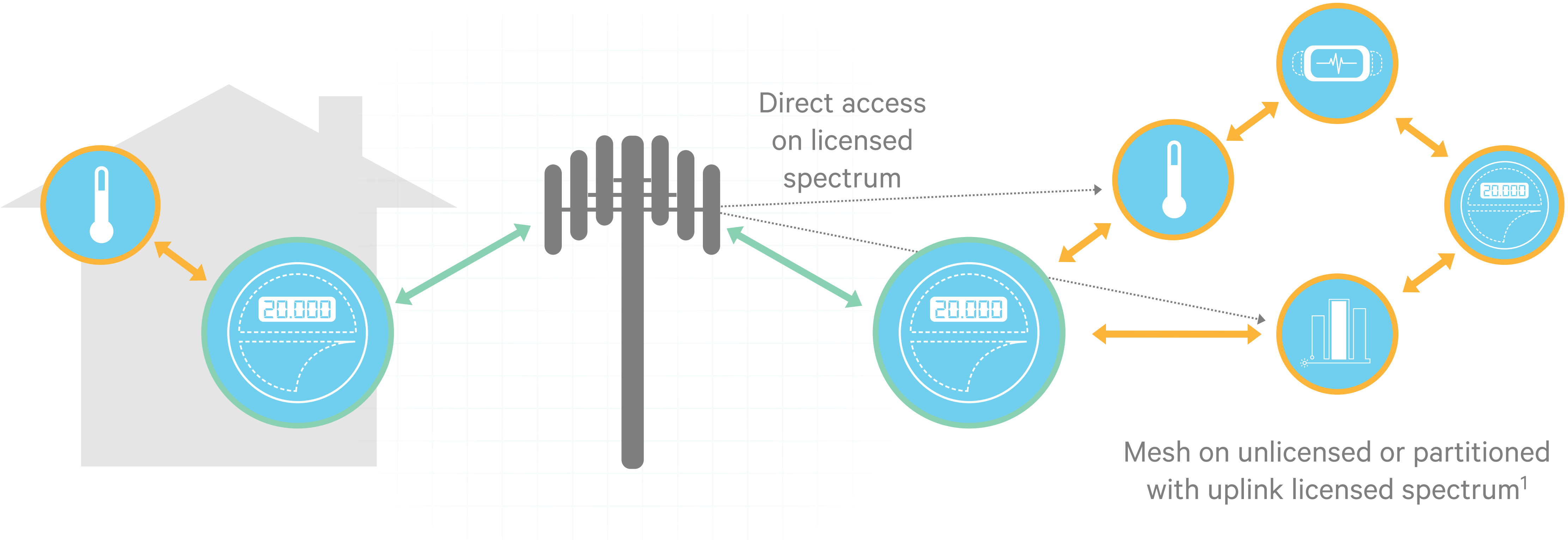
Increased battery life

Scalability to high device density

Better link budget

1. RSMA can utilize shared resource for small data burst transmissions

Support for multi-hop mesh with WAN management

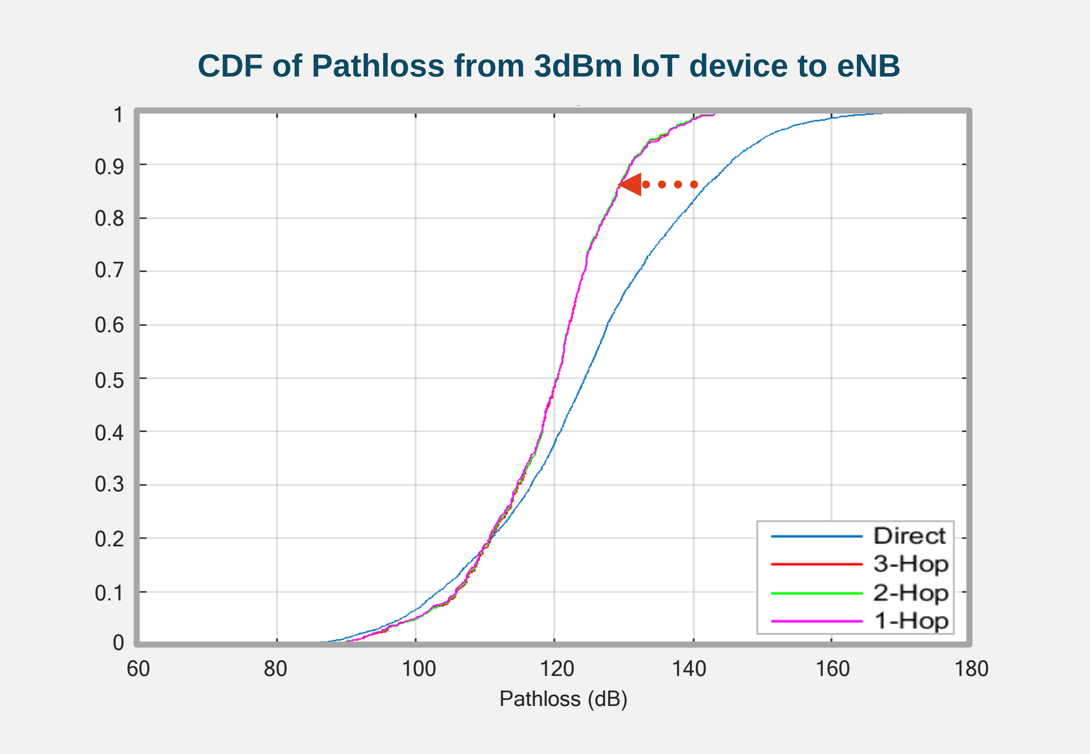


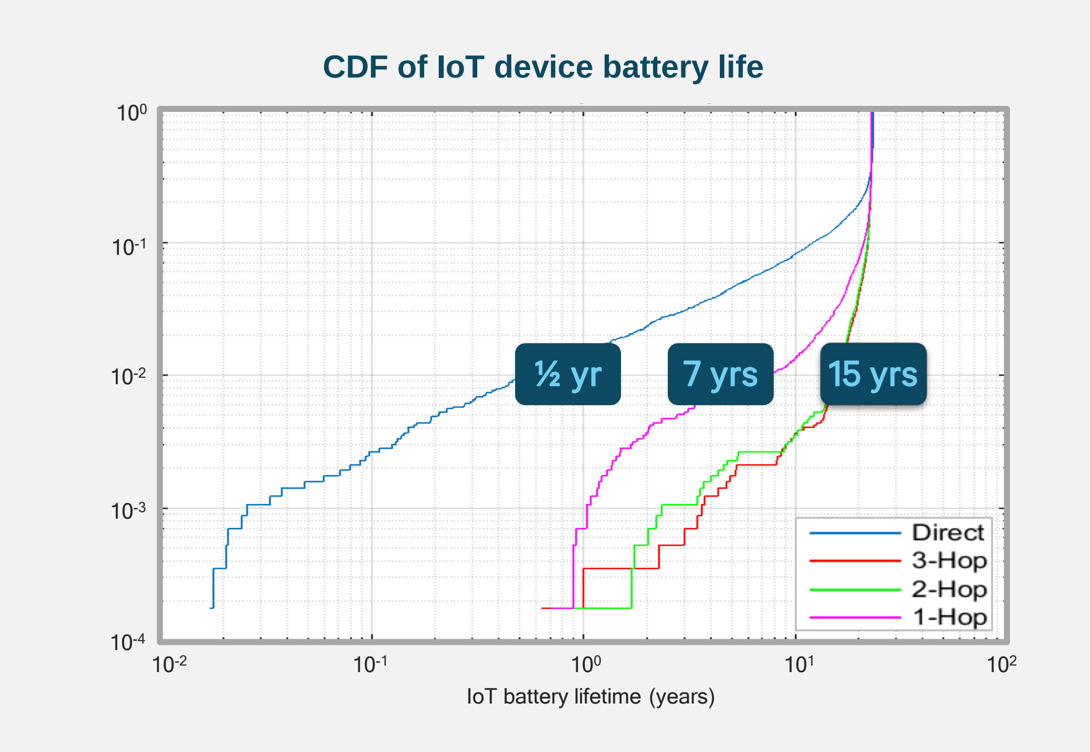
Problem: uplink coverage | Due to low power devices and challenging placements, e.g. in basement

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

Mesh improves coverage and battery life over uplink direct





- Based on one analysis, mesh increases 1-percentile battery lifetime from ½ yr (Direct) to 7 yrs (1-Hop) and 15 yrs (2-Hop)
- IoT devices can have significantly lower power budget: 3dBm instead of 23dBm for PA-less operation
- Some IoT devices have higher pathloss to eNodeB due to shadowing and device placement, e.g., basement
- These devices can take seconds to transfer small-payload using direct link leading to significantly reduced battery life

Thank you

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