Technologies of 5G: An Introduction

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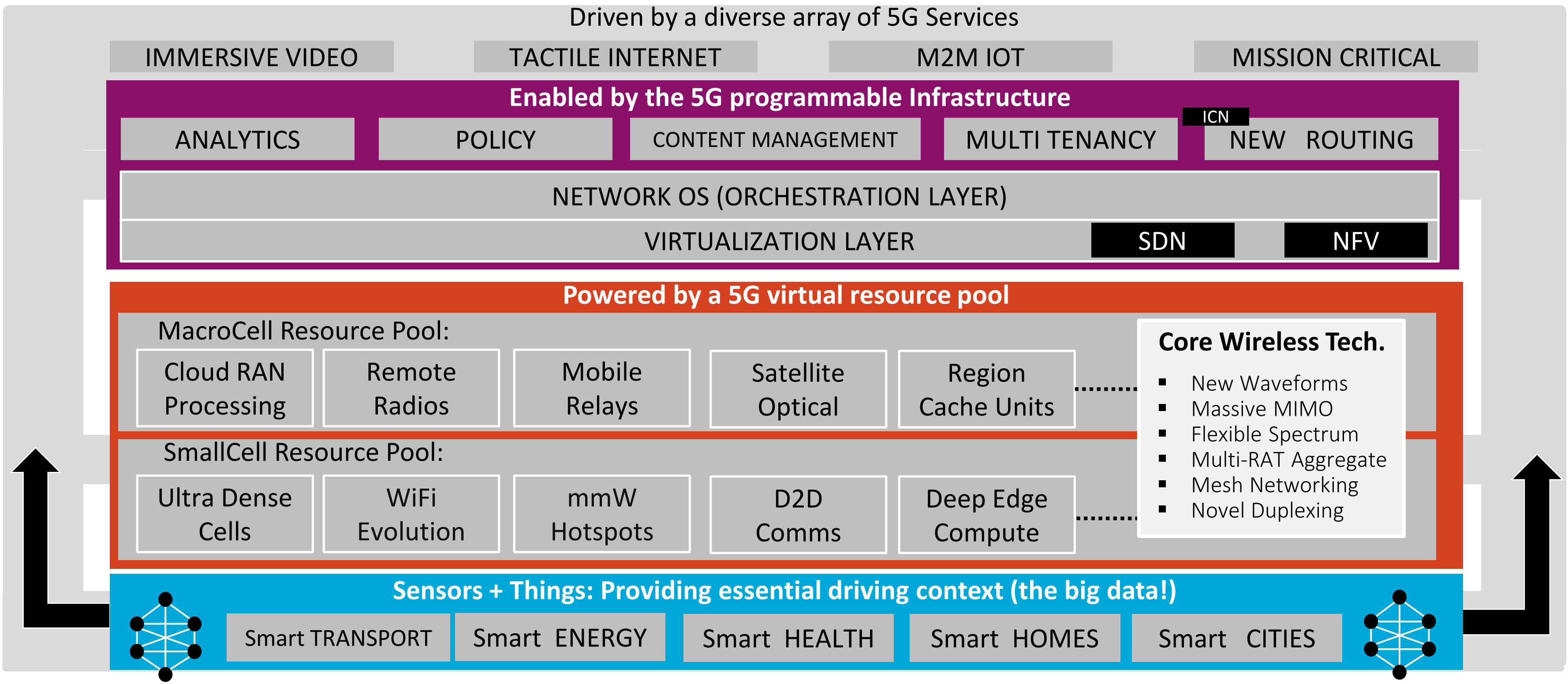
High Level Capabilities

Source: The EU 5G-PPP programme

- Providing **1000 times** higher wireless area capacity and more varied service capabilities compared to 2010
- Saving **up to 90%** of energy per service provided. The main focus will be in mobile communication networks where the dominating energy consumption comes from the radio access network
- Reducing the average service creation time cycle **from 90 hours to 90 minutes**
- Creating a secure, reliable and dependable Internet with a **"zero perceived"** downtime for services provision
- Facilitating very dense deployments of wireless communication links to connect **over 7 trillion wireless devices** serving over 7 billion people
- Enabling advanced User controlled **privacy**

Holistic Technology View

Source: InterDigital - The Living Network Vision



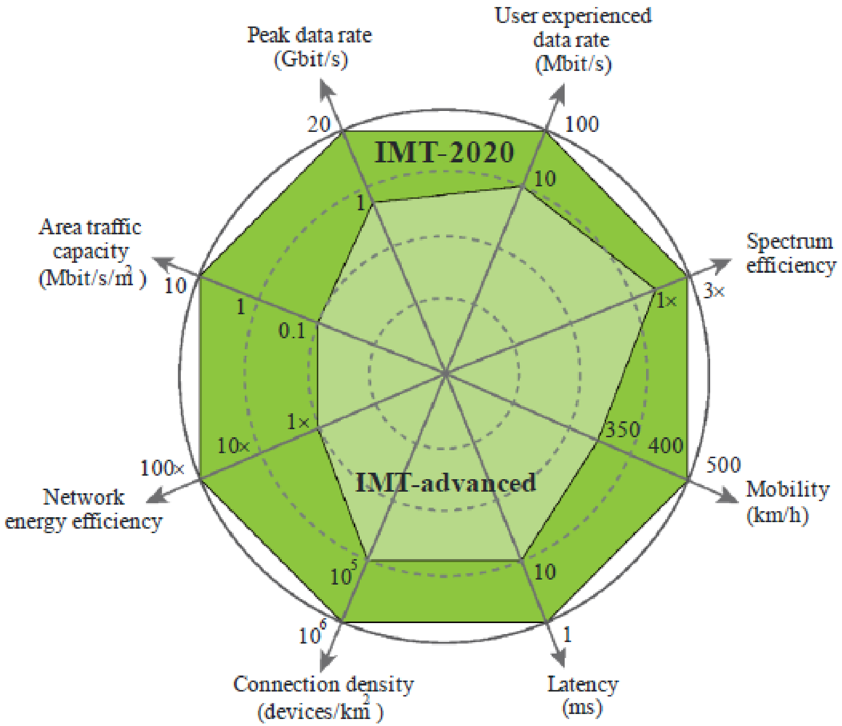
ICN=Information Centric Networking, SDN=Software Defined Networking, NFV=Network Function Virtualization, D2D=Device to Device Comms

Deep Dive into the 5G Radio Access Domain

A Tale of Two Spectrum Below and Above 6 GHz

5G Radio Access Capabilities

Source: ITU-R IMT for 2020 and beyond (M.2083-0)



Area traffic capacity	Peak data rate	User experienced data rate	Connection density
10 Mbps/m²	20 Gbps	100 Mbps	10^6 devices/km²

Latency	Spectrum Efficiency	Energy Efficiency	Mobility
1 ms	3x IMT-Adv.	100x IMT-Adv.	Up to 500 km/h

5G Radio Access – Enabling Technology (1)

100 Mbps	20 Gbps	10 Mbps/m^2	1 ms	3x IMT-Adv.	100x IMT-Adv.
User experienced data rate	Peak data rate	Area traffic capacity	Latency	Spectral efficiency	Energy efficiency

- Small cell densification
- Spectrum extension
- Multi-technology aggregation

- Ultra fast processing
- Ultra fast switching
- Ultra fast transmission

- Flexible spectrum sharing
- Massive multiplexing
- Interference mitigation

5G radio access – Enabling Technology (2)

Advanced waveforms and multiple access

- More flexible waveforms than pure OFDM (e.g. F-OFDM; FBMC; etc.)
- Non-orthogonal multiple access (NOMA)
- Broader set of modulation and coding schemes

Advanced antenna and multi-site technologies

- 3D-beamforming and MU-MIMO
- Active Antenna System (AAS)
- Massive MIMO
- Network MIMO (Adv. CoMP)

Novel duplexing schemes

- Joint TDD-FDD operation
- Dynamic TDD
- Single channel full duplexing

New and flexible spectrum usage

- New large spectrum at mmW frequencies
- Carrier Aggregation of discontinuous bands
- Dual band split user and control plane
- Joint multi-RATs management
- Cognitive techniques (Spectrum Sensing)

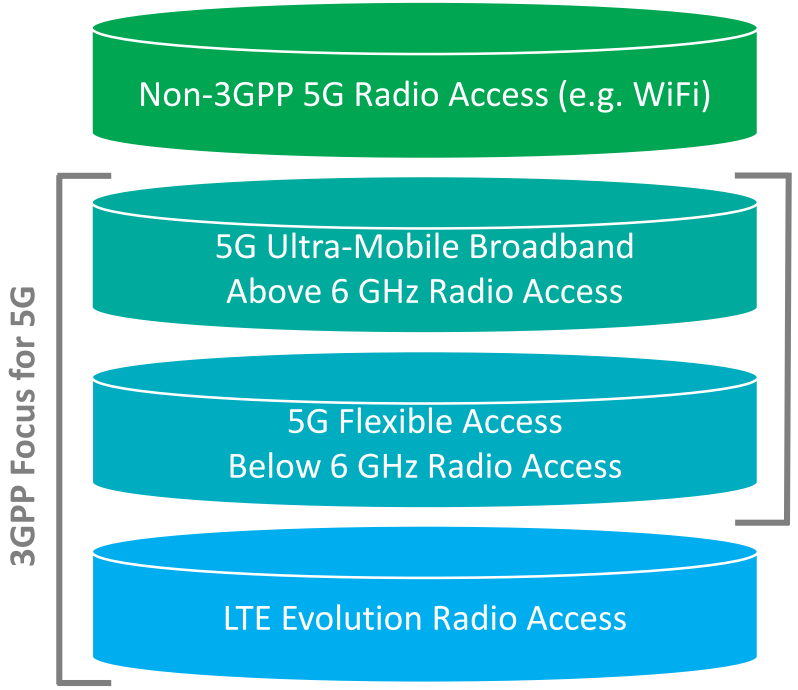
- Advanced interference coordination and cancellation techniques
- Flexible functional split (virtualization / cloudification)
- Flexible backhauling and joint optimization with access

5G Radio Access – Spectrum Outlook

f	What Spectrum should be considered?	What should it be used for?	How should it be used?
	New Spectrum above 6 GHz: ▪ Larger bandwidths available (cmWave & mmWave) ▪ Different propagation characteristics and hardware constraints	Ultra-Mobile Broadband for Indoor/Hotspot Access	New Radio: 5G Ultra-Mobile Broadband (Above 6 GHz)
6 GHz			
	New spectrum below 6 GHz: ▪ Opportunity to design a new non-backward compatible radio design **Existing spectrum below 6 GHz:** ▪ Leverage existing 4G deployments towards 5G	Enhanced Mobile Broadband Everywhere & Connected World Use Cases (diverging requirements)	New Radio: 5G Flexible Access (Below 6 GHz) & Existing Radio: LTE Evolution

5G – Multiple-Layers of Connectivity

5G should be designed with native support for connectivity across multiple radio layers



Common design framework while allowing for spectrum and/or use case specific design aspects

- Radio Layers could be deployed as “Standalone” or using multi-connectivity framework (e.g. R12 Dual-Connectivity)
- Framework should enable splitting of data and control paths
- 5G operators have flexibility to deploy radio layers based on their individual roll out plans for 5G services
- Mature 5G networks (i.e. 2025+) envisioned to include all radio layers working together
- LTE expected to evolve as a key component of 5G

5G Flexible Access Below 6 GHz

Air interface design must be flexible to support diverging requirements in the same spectrum

At least 3 Operating Modes identified so far (with potentially more):

Enhanced Mobile Broadband

- Macro and small cells
- 1 ms Latency (air interface)
- Up to 8Gbps of additional throughput in new spectrum
- Support for high mobility

Low Power & Complexity

- Low data rate (1~100kbps)
- High density of devices (up to 200,000/km^2)
- Latency: seconds to hours
- Low power: up to 15 years battery autonomy
- Asynchronous access

Ultra-High Reliability & Ultra-Low Latency

- Low to medium data rates (50kbps~10Mbps)
- <1 ms air interface latency
- 99.999% reliability and availability
- Low connection establishment latency
- 0-500 km/h mobility

5G Ultra-Mobile Broadband Above 6 GHz

New spectrum above 6 GHz provides opportunity for Ultra-Mobile Broadband for indoor and hotspots

- However, frequencies above 6 GHz suffer from much higher pathloss, lower diffraction and higher losses due to penetration and human/self-blockage
- Massive antenna arrays are feasible due to shorter wavelengths
  - Leads to compact antenna array structures
  - Provides beamforming gains required to overcome high pathloss

Free-Space Path Loss

Distance	2.4GHz	28GHz	60GHz
d = 1m	-40 dB	-62 dB	-68 dB
d = 100m	-80 dB	-102 dB	-108 dB

$\underbrace{\text{28GHz} \quad \text{60GHz}}_{\text{28 dB}}$

Key Requirements

- 20 Gbps (peak user throughput)
- 1 ms Latency (air interface)
- Standalone and/or macro-assisted access
- Joint access/backhaul

Key Enablers

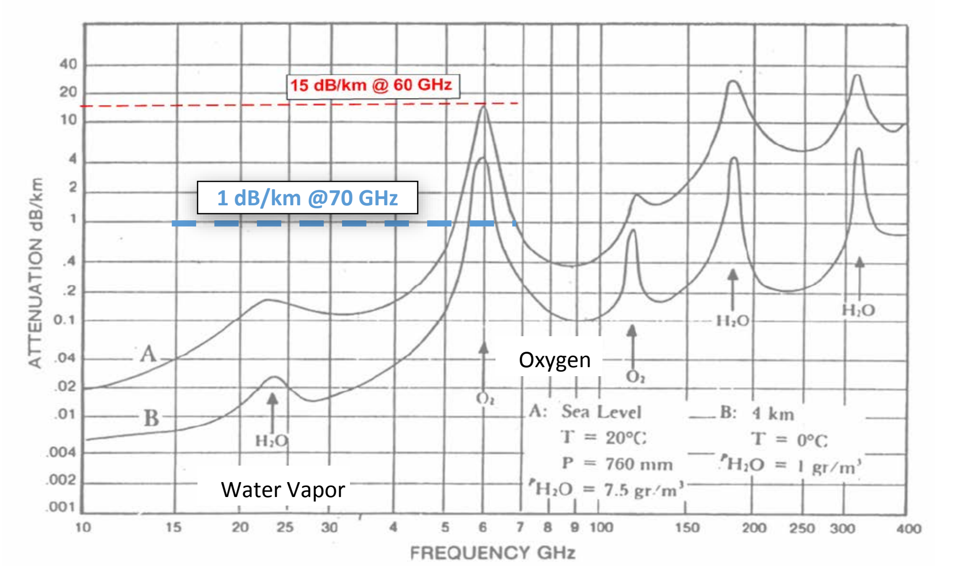
- Large amounts of spectrum
- Massive antenna arrays
- Cell densification

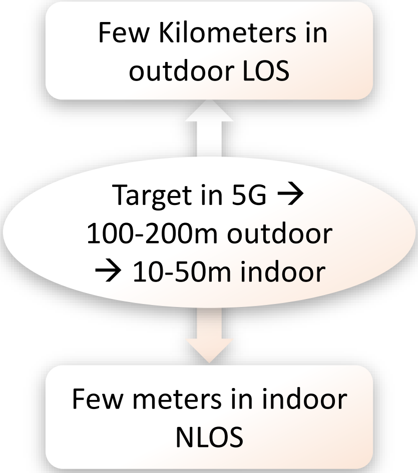
Key Challenges

- Timely availability of globally harmonized spectrum
- Low-cost and low-complexity implementations
- Discovery and initial access
- Frequent and abrupt loss of radio link(s)

5G UMB Above 6 GHz – The Range

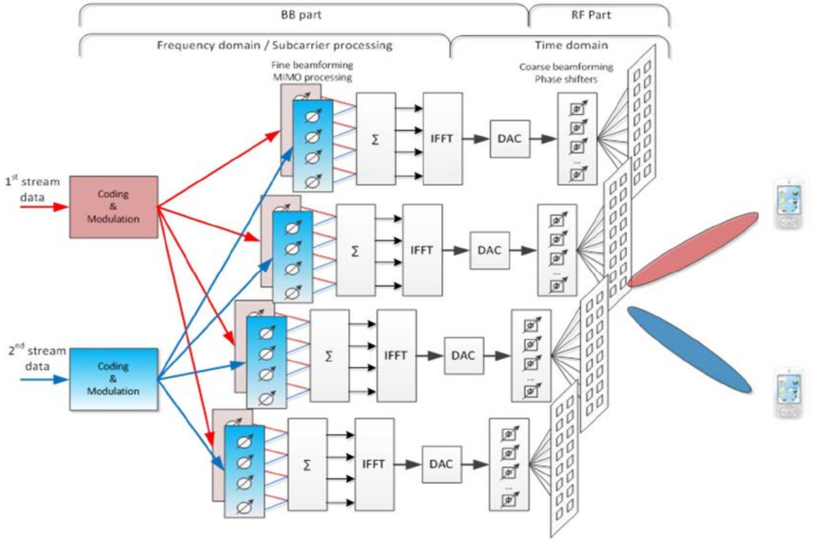
- ~ 20 dB free space path loss attenuation compared to below < 6 GHz + additional gaseous (Water Vapor / Oxygen) attenuation **→ Inherently short range → Enables X factor of densification**





5G UMB Above 6 GHz – The Beam

- 2-3 degrees beam width → array of antennas for wide angular coverage & multiple simultaneous beams/links @low interference → **Enables high multiplexing gain**



Electronically steerable phased array antennas to enable dynamic (re)configuration for guaranteed link reliability (in particular in mobile scenarios)

Small form factor (thanks to small antenna aperture and short inter-antenna distance) enabling the support of large number of antennas at the TX and RX

5G UMB Above 6 GHz – The Capacity

(20 x 10 x 5) = 1000x capacity increase

Wide contiguous bandwidth	X 20	Throughput gain
Short range and narrow beams	X 10	Densification gain
Multiple simultaneous links in the same band	X 5	Multiplexing gain

Few Take-Aways

- There is **much more in 5G** than just a new radio access interface
- A programmable E2E infrastructure leveraging **SDN, NFV and the (Central/Edge) Cloud** is at the core of the 5G system
- The 5G radio access domain is a tale of two spectrum, **below and above 6 GHz (mmWave)**, with multiple layers of connectivity
- The below 6 GHz is **primary** and needs to provide a flexible common framework for the support of various traffic/service profiles
- The above 6 GHz is a complementary **capacity booster** for ultra-mobile broadband in ultra-dense hotspots or indoor environments
- The success of the 5G radio access design lies in the **integration** of below and above 6 GHz technologies under a common framework

Thank You!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