



Università degli Studi di Cagliari

Corso di Laurea Magistrale in Ingegneria delle Tecnologie per
Internet

5G



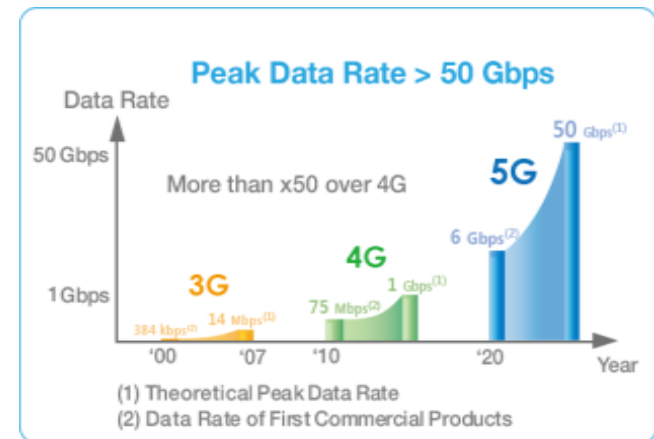
Contents

- ✓ What is 5G?
 - 5G for Vertical Industries
 - Standardisation of 5G in 3GPP
 - ITU-R IMT2020 and KPIs
 - 5G Spectrum Auctions and New Use Cases
- ✓ 5G Key Features
- ✓ Multicast/Broadcast for 5G
- ✓ Outlook



What is 5G?

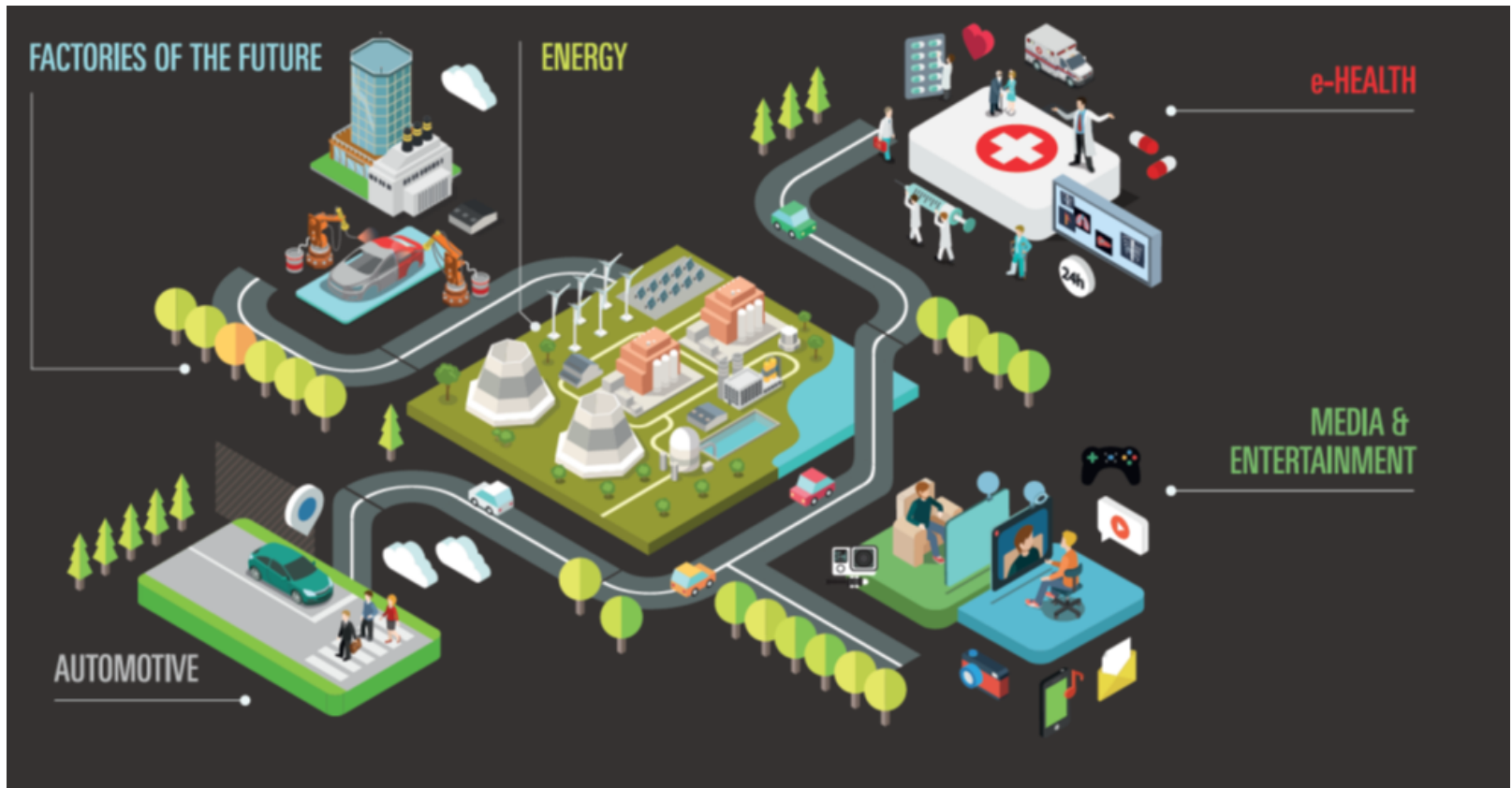
- ✓ **5G** is the next-generation of cellular networks (after **3G** and **4G**)
- ✓ It will **not only** provide **one order of magnitude increase in peak data rates**
- ✓ It is being designed to meet very challenging technical requirements to support **new use cases** derived from several **vertical industries**, **not just for mobile broadband**





5G Use Cases

- ✓ 5G Driven by New Use Cases and Designed for New Vertical Industries





5G – Beyond Mobile Broadband

10 000
x more
traffic

10-100
x more
devices

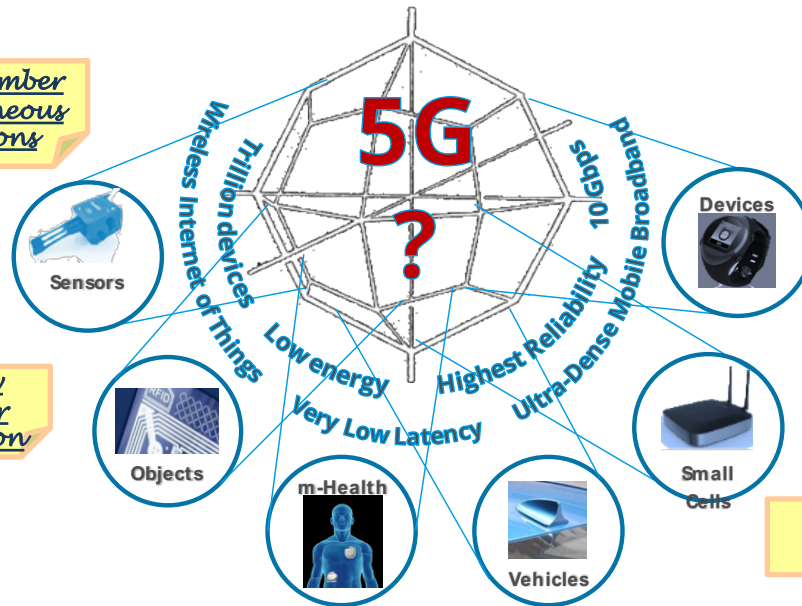
10 years
on battery

<1 ms
radio latency

*Massive number
of simultaneous
connections*

*Extremely
Low-power
consumption*

*Critical End-
to-End latency*



*Gbps
Throughput*

*Ultra
reliable*

>10 Gbps
peak data rates

100 Mbps
whenever needed

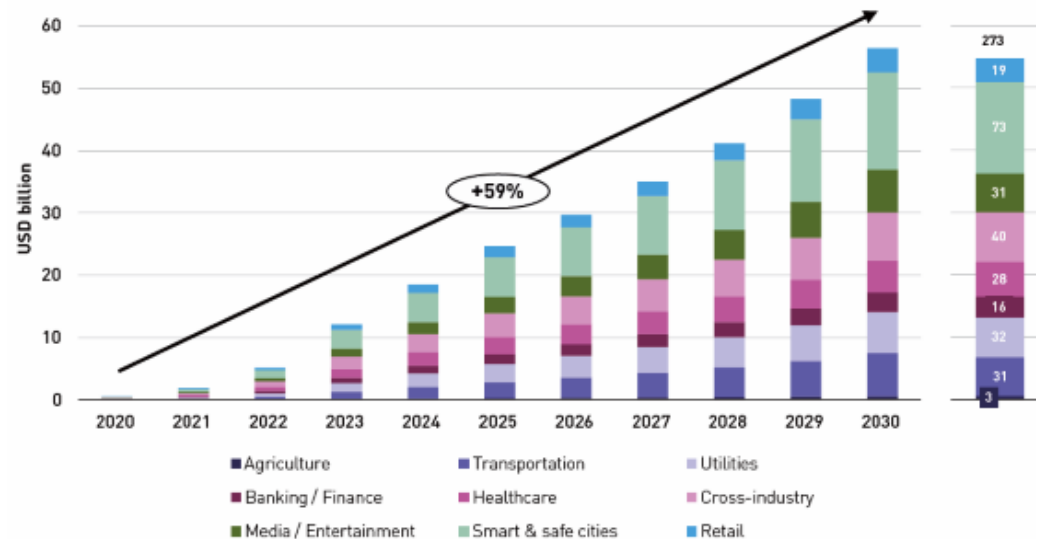


5G Business Models

✓ New digital industries embracing 5G infrastructure means

- new markets
- new customers
- new requirements
- new business arrangements
- Role of stakeholders likely to change
- **new opportunities!**
 - ❖ MNOs
 - ❖ Private networks
 - Licensed spectrum
 - Unlicensed spectrum

Source: Analysis Mason: Unlocking digital opportunities with 5G: a GCC outlook (13/02/2019)

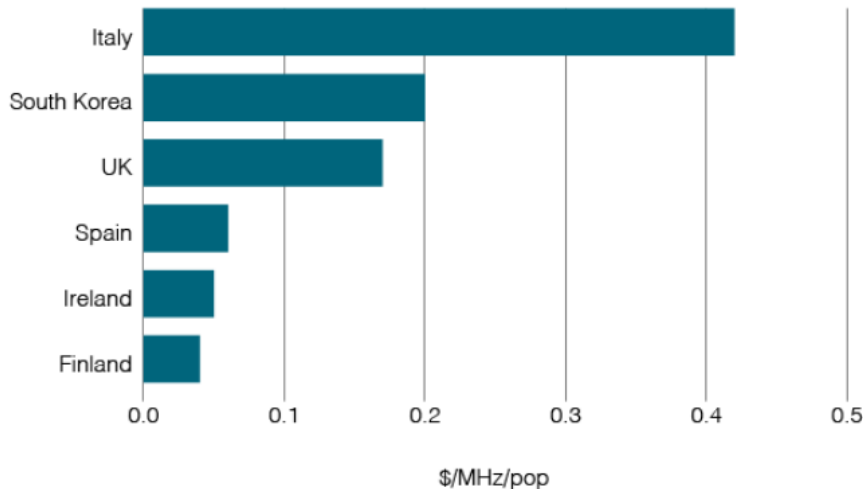




5G Spectrum Auction in Italy

✓ Over 6,5 billion euro for 1.275 MHz

- Band 700 MHz: 75 MHz
- Band 3.7 GHz: 200 MHz
- Band 26 GHz: 1 GHz



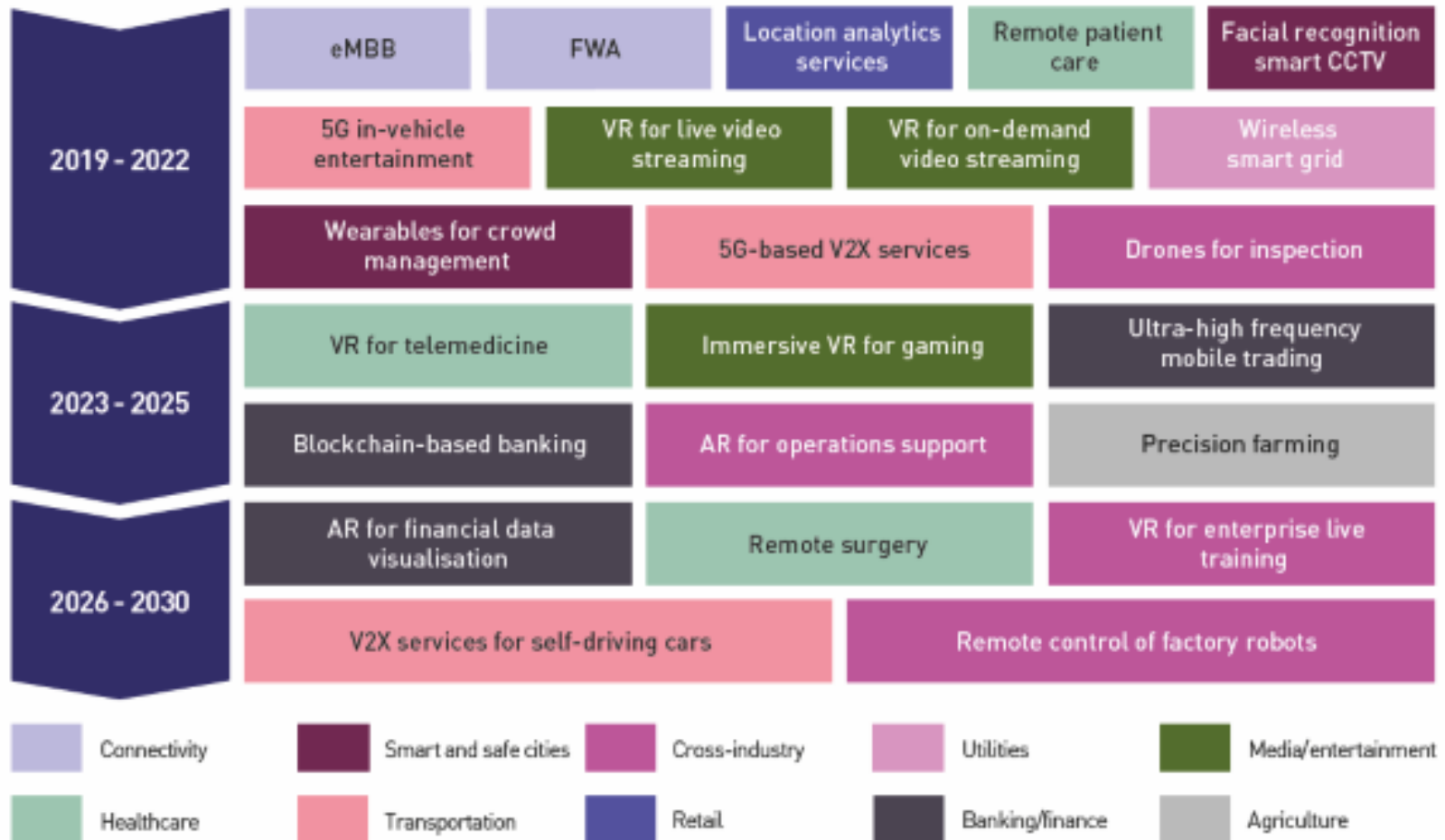
Band	Lot	Spectrum [MHz]	Winner	Price [€]	+% vs reserve price
700 MHz FDD	700_R	2x10	Iliad	676.472.792	0%
	700_FDD	2x5	Vodafone	345.000.000	2%
	700_FDD	2x5	Vodafone	338.236.396	0%
	700_FDD	2x5	TIM	340.100.000	0,6%
	700_FDD	2x5	TIM	340.100.000	0,6%
		2x30		2.039.909.188	0,52%
3.7 GHz	3700_C1	80	TIM	1.694.000.000	970%
	3700_C2	80	Vodafone	1.685.000.000	962%
	3700_C3	20	Wind Tre	483.920.000	1120%
	3700_C4	20	Iliad	483.900.000	1120%
			200		4.346.820.000
26 GHz	26G	200	TIM	33.020.000	1,3%
	26G	200	Iliad	32.900.000	1,0%
	26G	200	Fastweb	32.600.000	0,04%
	26G	200	Wind Tre	32.586.535	0%
	26G	200	Vodafone	32.586.535	0%
			1000		163.693.070
ALL		1260		6.550.422.258	162,0%

Source: <https://5gobservatory.eu/italian-5g-spectrum-auction-2/>

14 days of auction with 171 bidding rounds

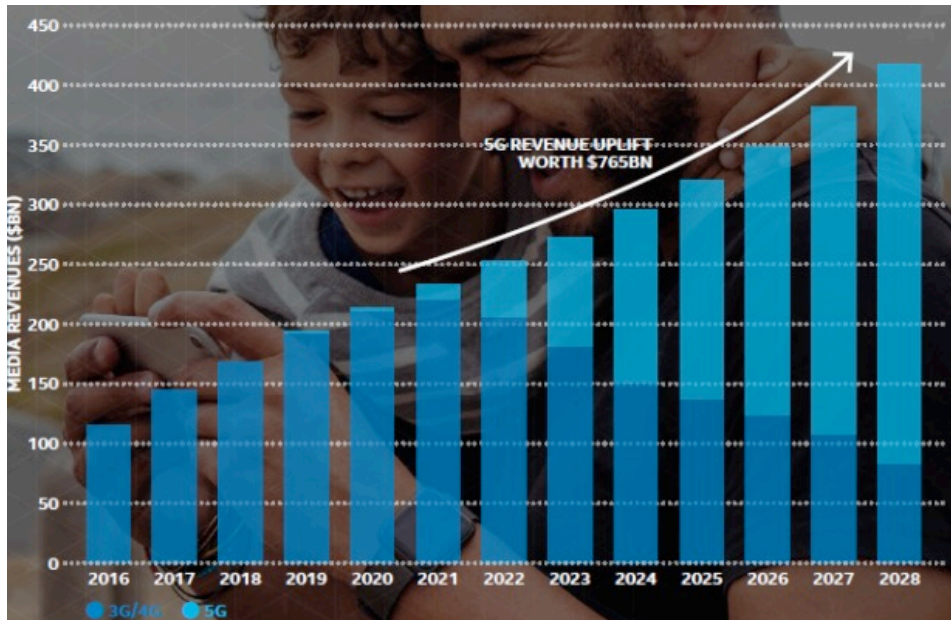


Potential New 5G Services

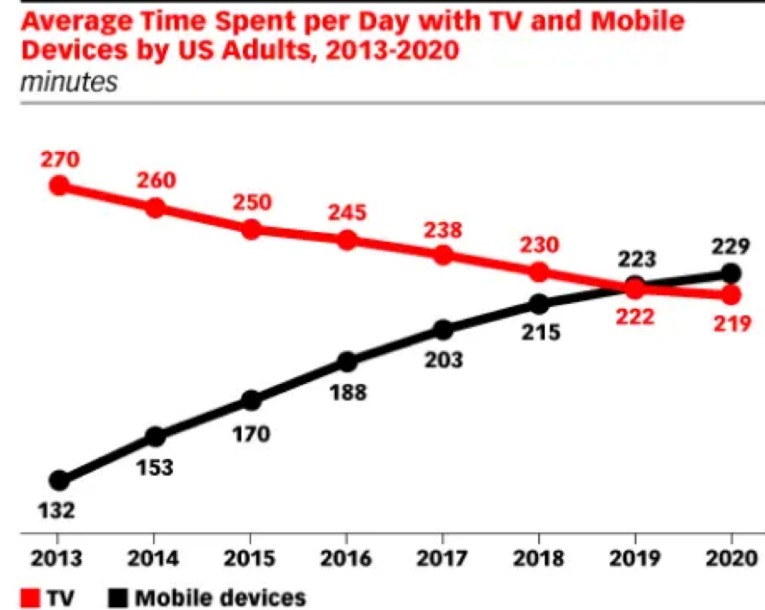


Impact of 5G in the Business of M&E

Total Global Media Revenues delivered over Wireless Networks



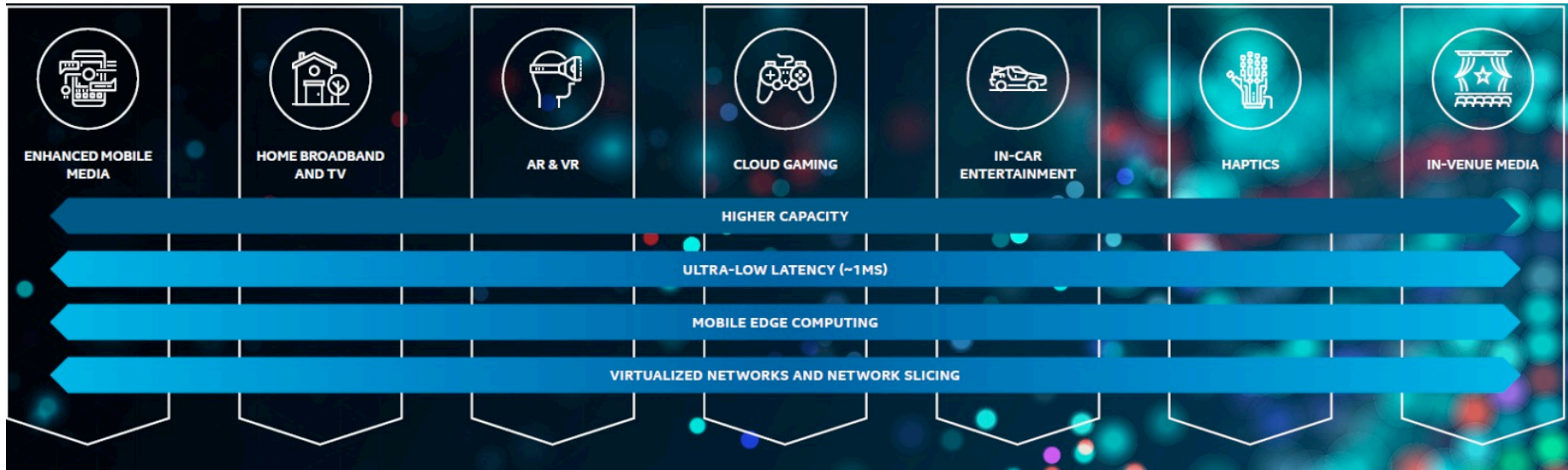
Source: Ovum



Mobile video traffic now accounts for more than half of all mobile data traffic



Main 5G M&E Applications

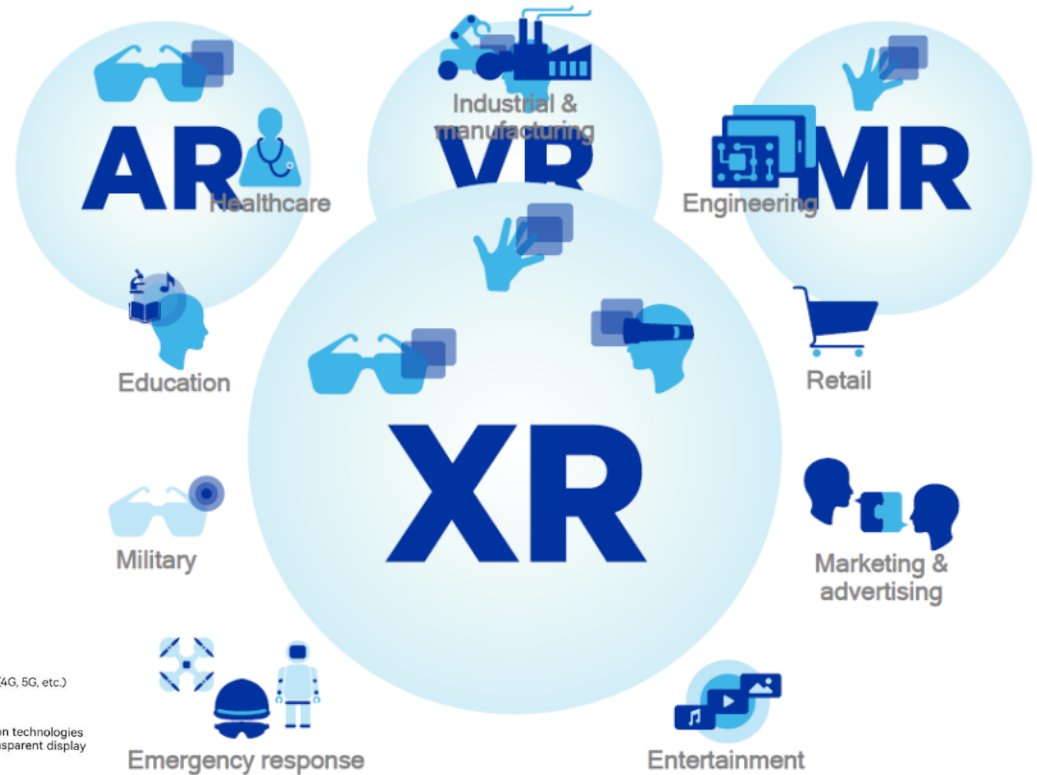
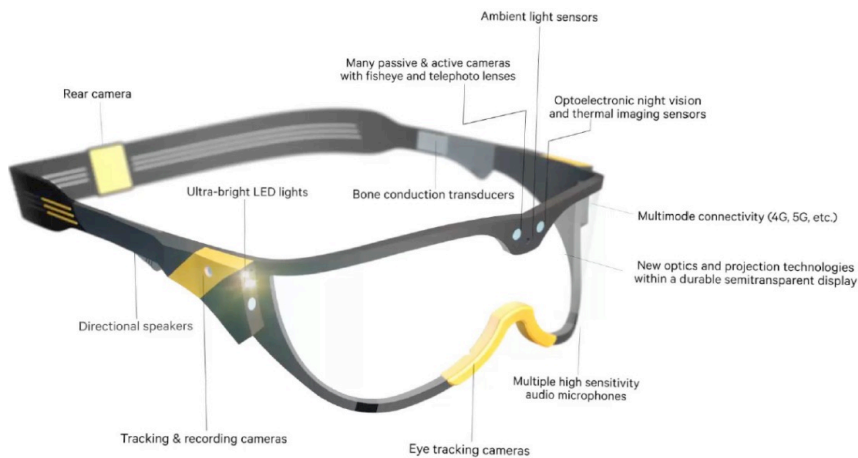


Source: Ovum



Extended Reality (XR)

The next Mobile Computing Platform





5G Wireless AR/VR Experiences

Current setup: fixed local networking



No processing

HDMI cable

High bitrate
Low latency



Powerful gaming laptop does processing for Social VR

Goal: exploit 5G mobile networking



Limited processing on mobile device

5G radio

High bitrate
Low latency



dynamically deployable virtual servers do most processing for Social VR

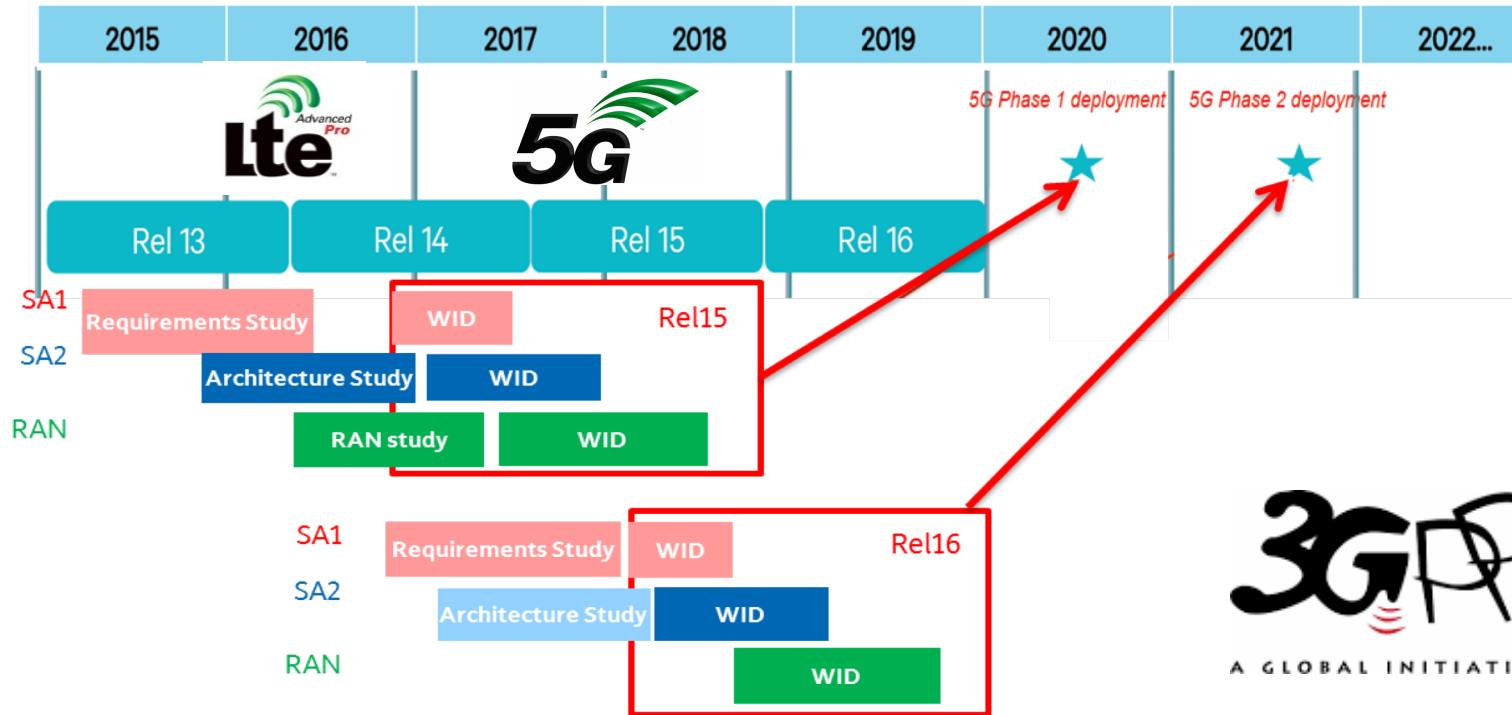


5G in 3GPP

- ✓ 3GPP started in March 2017 the normative work for 5G in **Release-15** (a.k.a. **New Radio NR**), while continue working in LTE-Advanced Pro
 - **Non-Stand Alone (NSA)** vs. **Stand-Alone (SA)**
- ✓ 3GPP Rel-15 aims the first phase of 5G deployments in 2019-2020
 - Foundation for 5G (enhanced Mobile Broadband **eMBB**)
- ✓ Second phase of 5G on-going (Rel-16)
 - Meet **IMT2020 requirements**
 - Ultra-Reliable and Low Latency Communications (**URLLC**)



5G in 3GPP

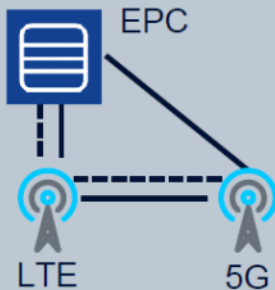




First 5G Commercial Networks: NSA

Why Dual Connectivity with NSA?

Option 3x | LTE+5G under EPC



- Available 6 months earlier than SA
- Existing EPC core used
- Existing LTE idle mode used
- Data rate aggregation LTE + 5G
- VoLTE in LTE

Source: Nokia

Fast 5G launch (2019)

Motivation

Simple use case

10x more capacity

Simple architecture

No new architecture

Simple deployment

No new sites

Simple baseband upgrade

AirScale for everything

Simple RF upgrade

AirScale RF ready for 5G at low bands

Simple core upgrade

No new core



Advanced 5G Commercial Networks: SA

Why Standalone SA?

Option 2 | SA 5G under 5GC



- 5G end-to-end for new services
- Lower latency without LTE leg
- Lower setup time in 5G
- No need for LTE network upgrades

Source: Nokia

Evolution (2020+)

Low latency, critical communication and IoT

Cloud optimized radio

Self powered, self optimized, self backhauled small cells

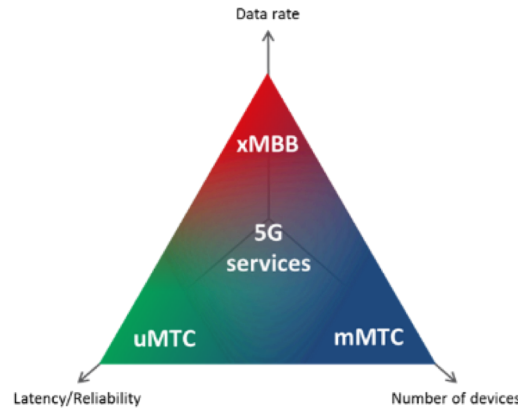
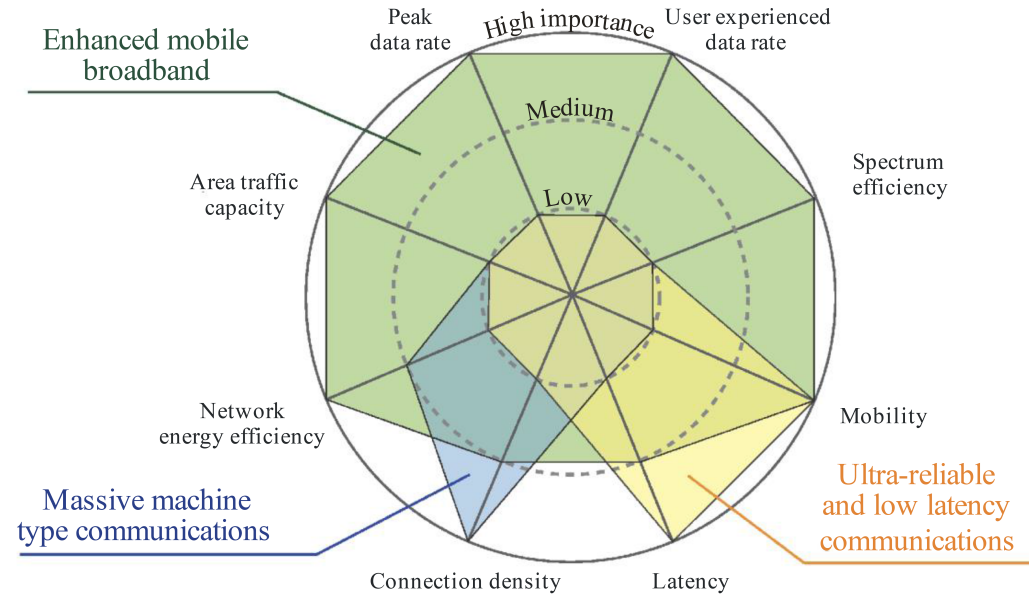
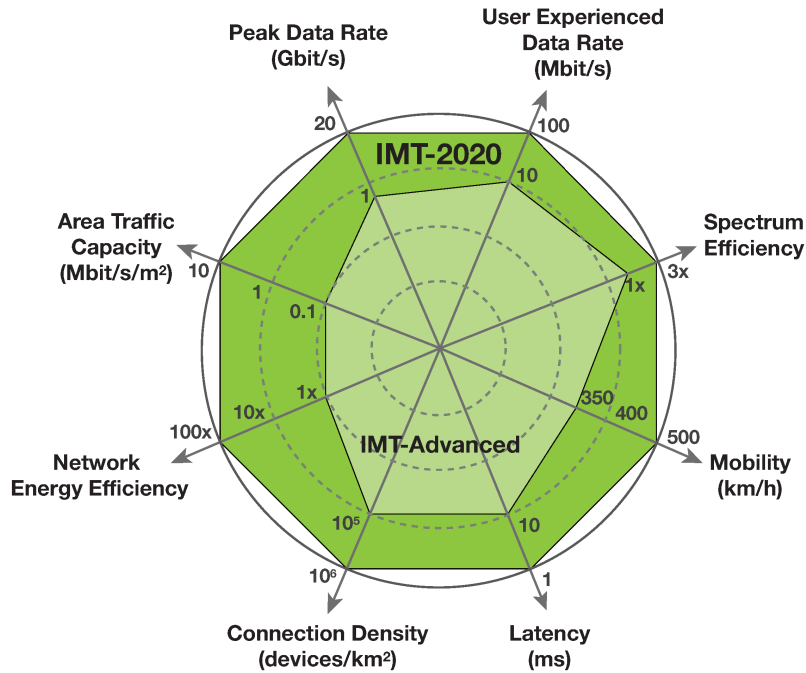
Small cells at mmW

mmW for extreme capacity and data rates

5G core for new use cases



ITU IMT-2020



M.2083-04



ITU IMT-2020

KPI	Minimum Requirement
Peak Data Rate (eMBB)	20 Gpbs DL 10 Gbps UL
Peak Spectral Efficiency (eMBB)	30 bps/Hz DL 15 bps/Hz UL
User experienced data rate (eMBB)	100 Mbps DL; 50 Mbps UL
5 th percentile user spectral efficiency (eMBB)	0.225 bps/Hz DL eMBB in dense urban (0.12 rural)
Average spectral efficiency (eMBB)	9/7.8/3.3 bit/s/Hz/TRxP for eMBB hotspot/urban/rural
Area traffic capacity (eMBB)	10 Mbit/s/m ² in the Indoor Hotspot for eMBB
Bandwidth (general/non-specific)	at least 100 MHz; 1 GHz above 6 GHz

Source: ITU Recommendation ITU-R M.2083-0, Sept. 2015



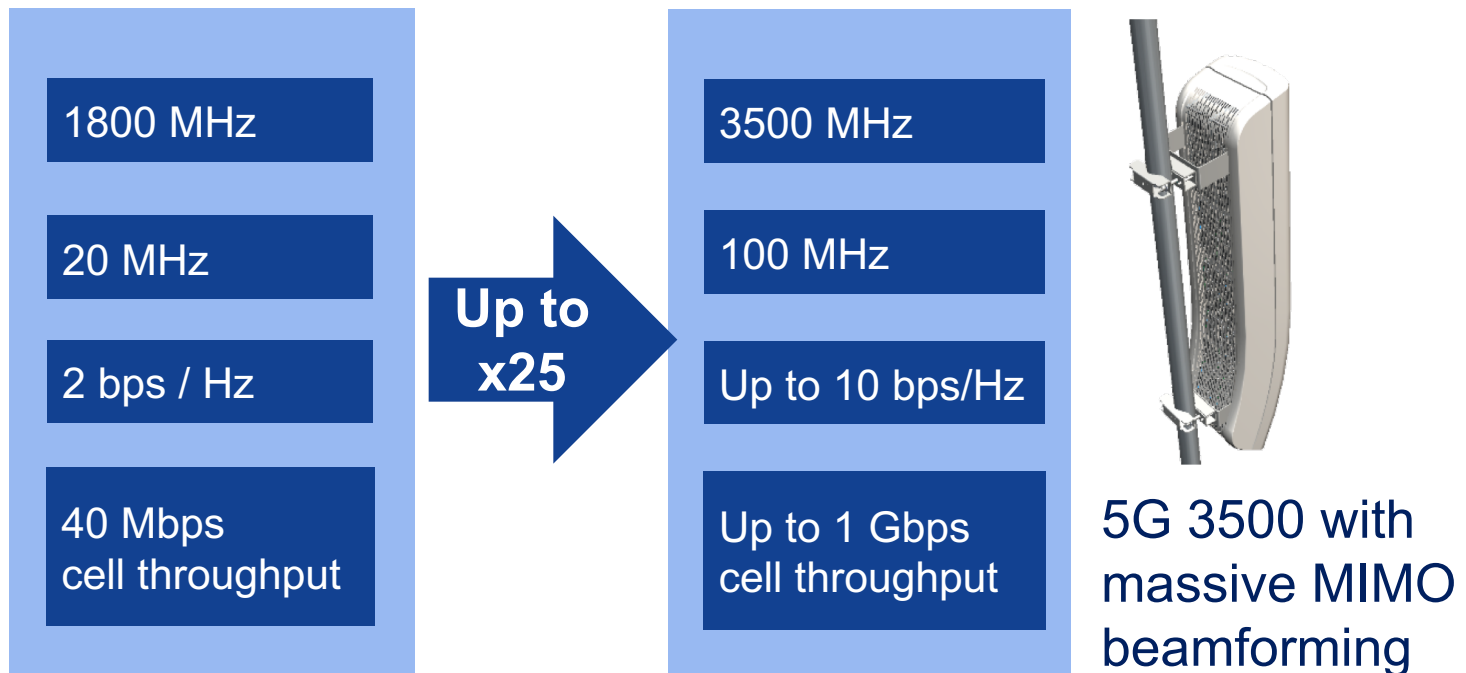
ITU IMT-2020

KPI	Minimum Requirement
Latency (eMBB, URLLC)	User plane latency: <ul style="list-style-type: none">4 ms for eMBB;1 ms for URLLC Control plane latency: <ul style="list-style-type: none">20 ms (10 ms encouraged)
Connection density (mMTC)	1.000.000 devices per km ²
Reliability (URLLC)	99.99999% success probability of transmitting a layer 2 PDU of 32 bytes within 1 ms in channel quality of coverage edge for URLLC
Mobility (eMBB)	Up to 500 km/h
Mobility interruption time (eMBB, URLLC)	0 ms
Energy efficiency (eMBB)	High sleep ratio and long sleep duration for eMBB



Example 5G Cell Capacity Boost

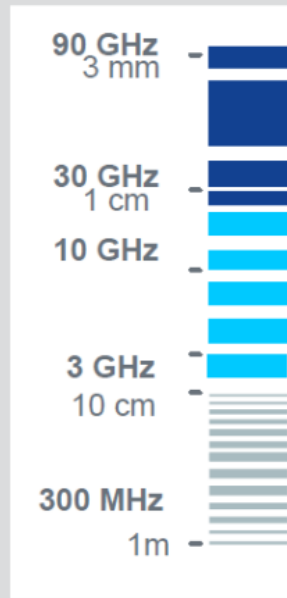
✓ x5 More Spectrum and x5 More Efficiency



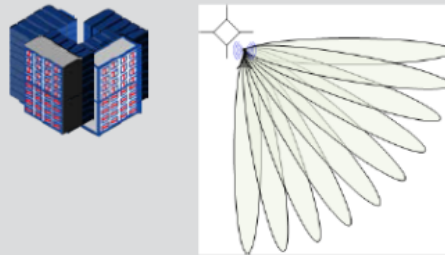


5G Key Technology Components

#1 New spectrum



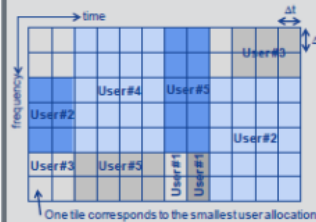
#2 Beamforming



#4 Dual-connectivity



#3 Slicing and flexibility



- Multi-service
- Flexibility
- Lean carrier

#5 Edge computing





5G Spectrum Bands

- ✓ Single radio interface for multiple frequency bands
- ✓ Main novelty: use of mmwave spectrum
 - Lower bands also needed for wide coverage

694-790 MHz
Wide area coverage
for mMTC* and URLLC*

700 MHz band targeted to become available latest 2020 in Europe
Re-use of existing 900/800 MHz grids allows for timely coverage
Pre-condition for new services like connected cars, smart sensors etc.

3.4-3.8 GHz
Urban coverage
for initial eMBB*

C-band is sparsely used in most parts Europe
Re-use of existing 1800/2100/2600 MHz grids
Carrier bandwidths of 100 MHz + allow for single Gbps data rates

24.25-27.5 GHz
Initially hot spots
of true eMBB*

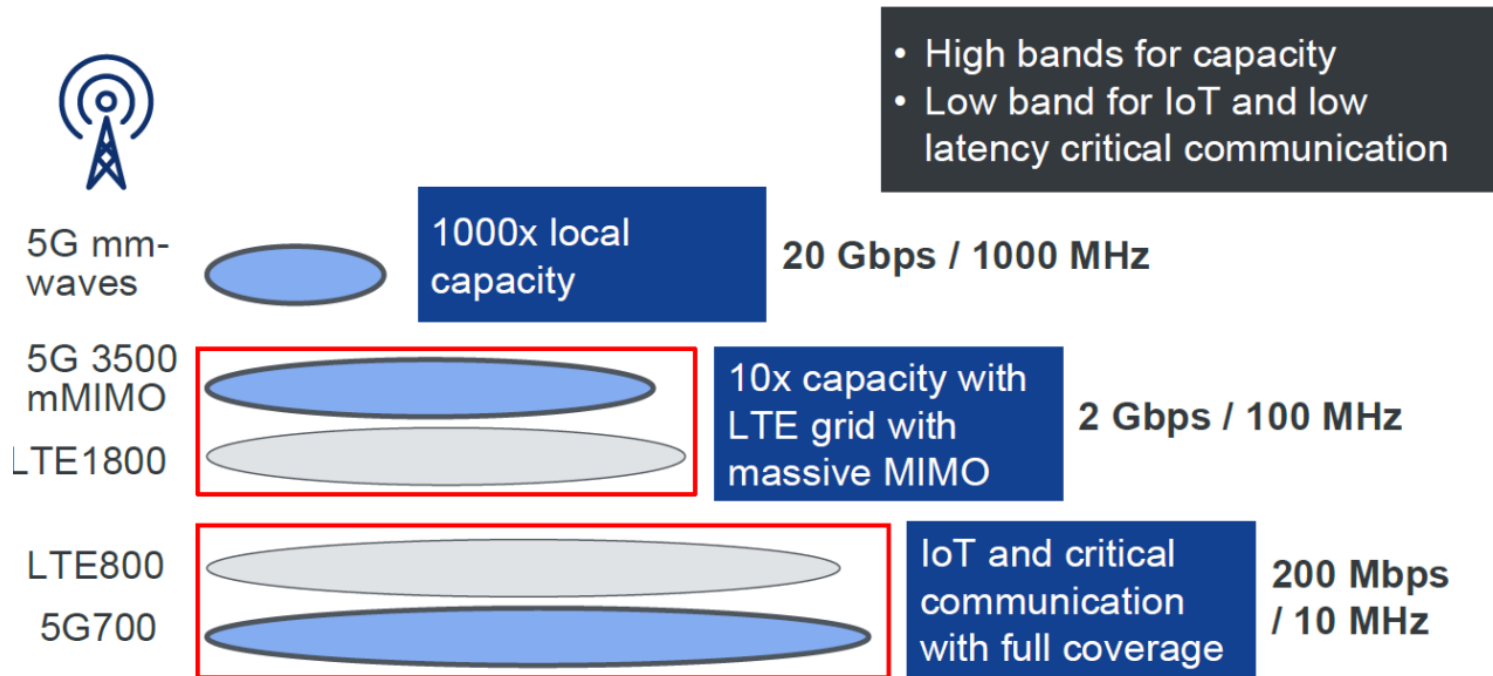
Common tuning range with 28 GHz range (US, Korea) is expected to allow for common economies of scale.
Carrier bandwidths of several 100 MHz allow double digit Gbps data rates

Source: Nokia, "5G for people and things - 700 MHz band as key to success for wide-area 5G services", 2017



5G Coverage Footprint

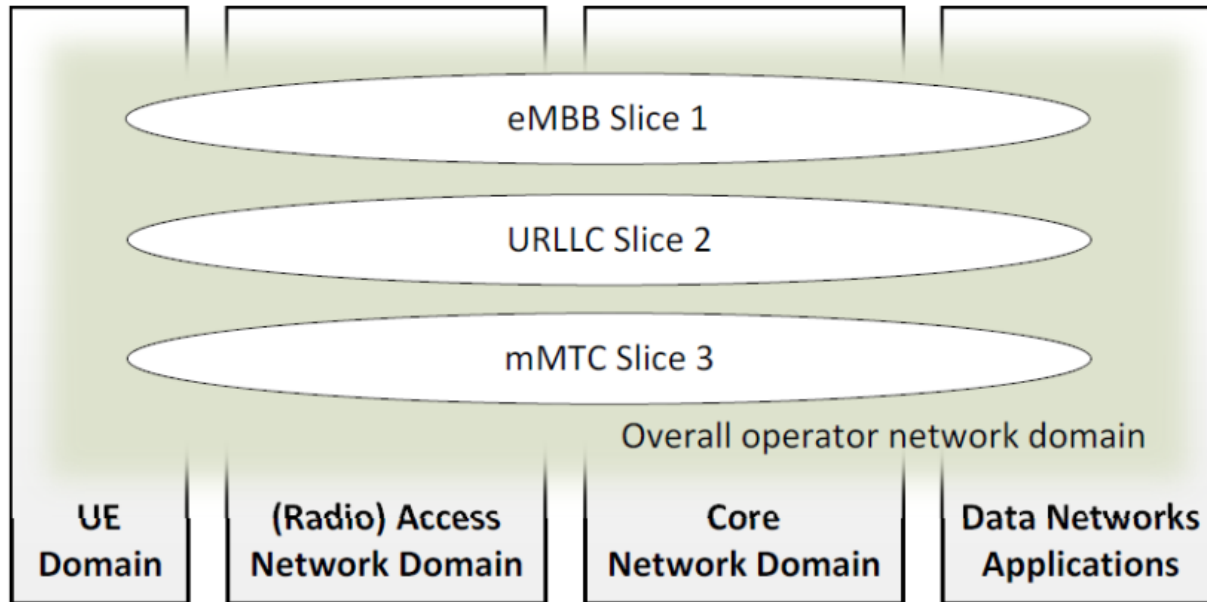
✓ Combination of Low and High Frequency Bands





5G Network Slicing

- ✓ Key feature to provide different types of services with the same infrastructure





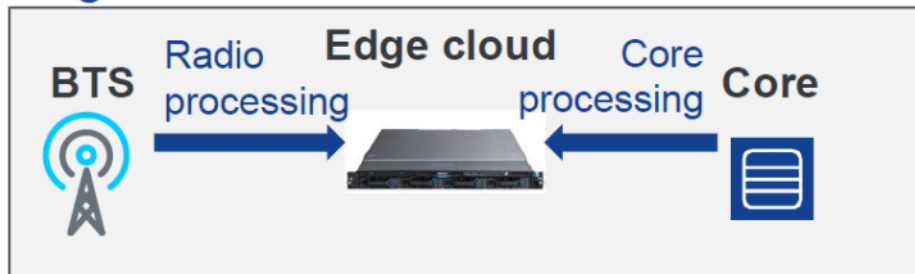
5G Architecture Towards Edge Cloud

- ✓ Mobile edge computing (MEC) brings network computing capabilities closer to the network edge. MEC can help enable lower latency and better distribution of network content



- Current radio is distributed
- Current core is centralized

Target

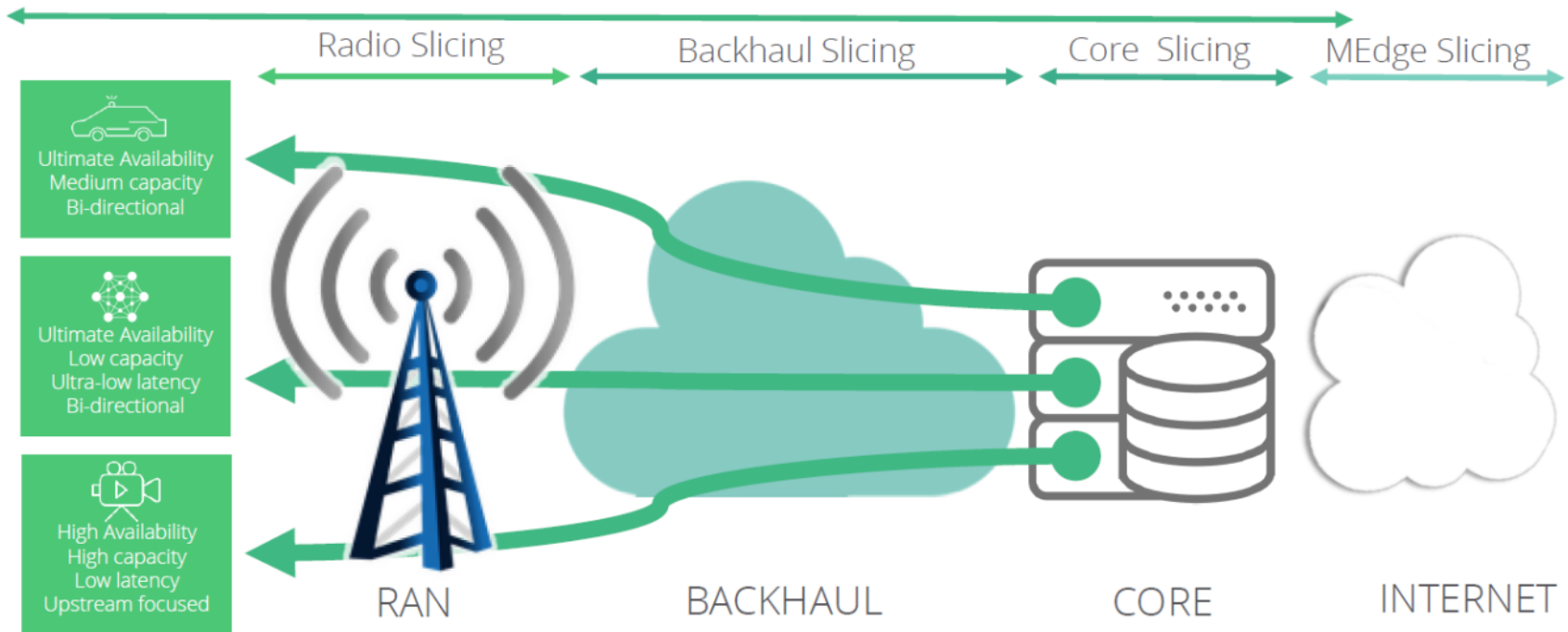


- Radio more centralized for faster scalability
- Core more distributed for low latency



5G End-to-End Network Slicing

✓ Many logical networks within one physical network



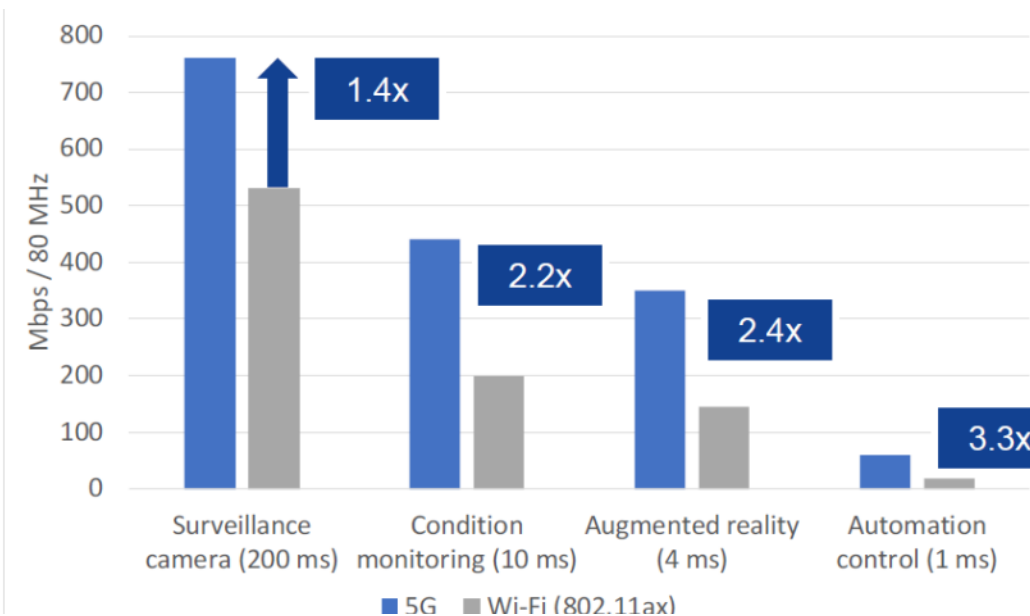
Source Cloudstreet



5G Private Networks

✓ 5G vs. Wi-Fi6 (802.11ax)

➤ NR-U(nlicensed) under standardisation in Rel-16



- 5G gives 1.4 – 3.3x higher efficiency than WiFi 802.11ax for Industry 4.0 use cases
- 5G benefit is largest compared to 802.11ax when the delay requirement gets tough (10 ms or less)

Assumptions: 80 MHz, TDD, 4x4 SU-MIMO, 2 streams, 1024QAM in Wi-Fi, 256QAM in 5G

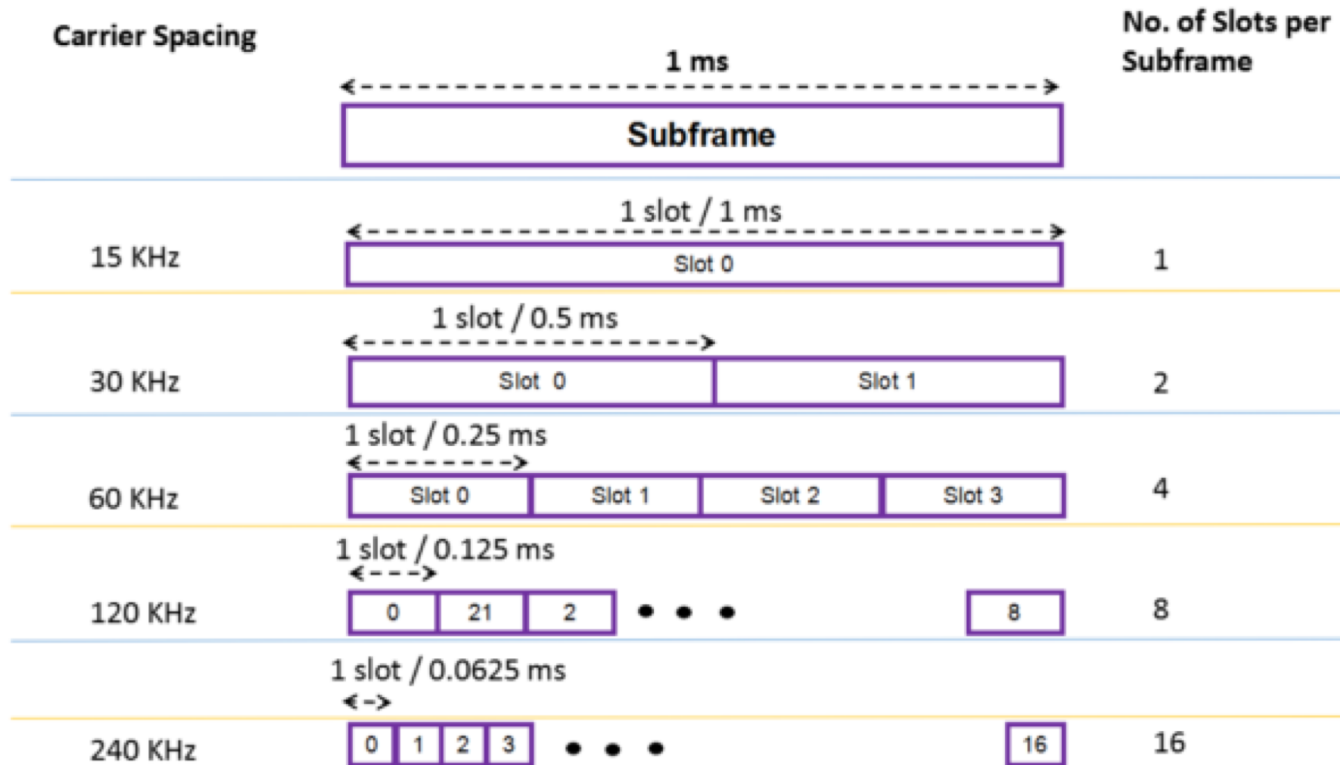


5G NR frame structures

- ✓ 5G NR introduces flexible numerology that scales the subcarrier spacing
- ✓ The scalable slot duration allows the subcarrier to be optimized for different types of service levels, balancing throughput, latency, and reliability
- ✓ Subcarrier spacing is governed by $2^{\mu} \times 15$ kHz subcarrier spacings
 - 15, 30, and 60 kHz subcarrier spacings are used for the lower frequency bands, and 60, 120, and 240 kHz subcarrier spacings are used for the higher frequency bands.
- ✓ as the frequency increases, slot duration is shorter in time, decreasing the TTI (transmit time interval) and optimizing the subcarrier spacing for the operating frequency band and channel characteristics

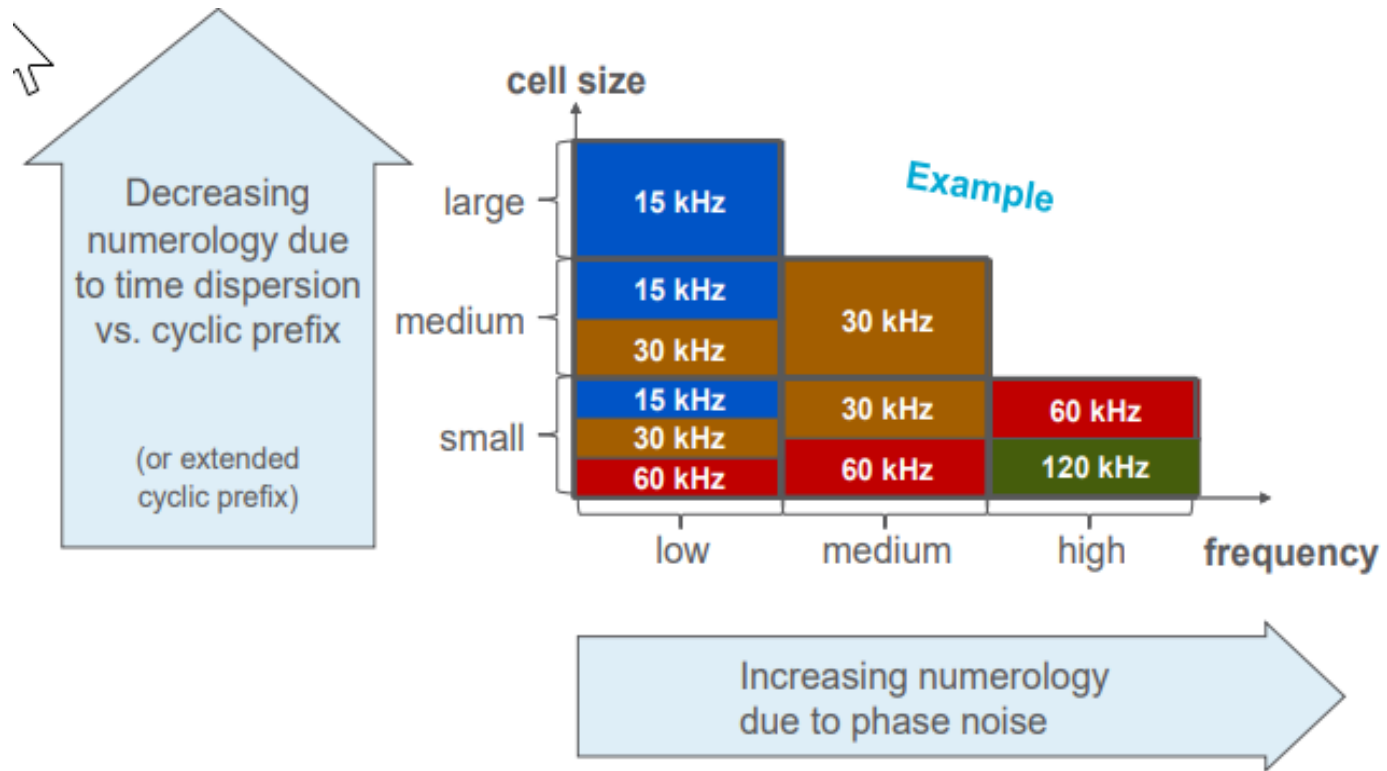


5G NR frame structures





5G NR frame structures





OFDM symbol

μ	0	1	2	3	4
Subcarrier spacing (KHz)	15	30	60	120	240
OFDM Symbol Duration (us)	66.67	33.33	16.67	8.33	4.17
Cyclic prefix duration (us)	4.69	2.34	1.17	0.57	0.29
OFDM including CP (us)	71.35	35.68	17.84	8.92	4.46



Resource Blocks

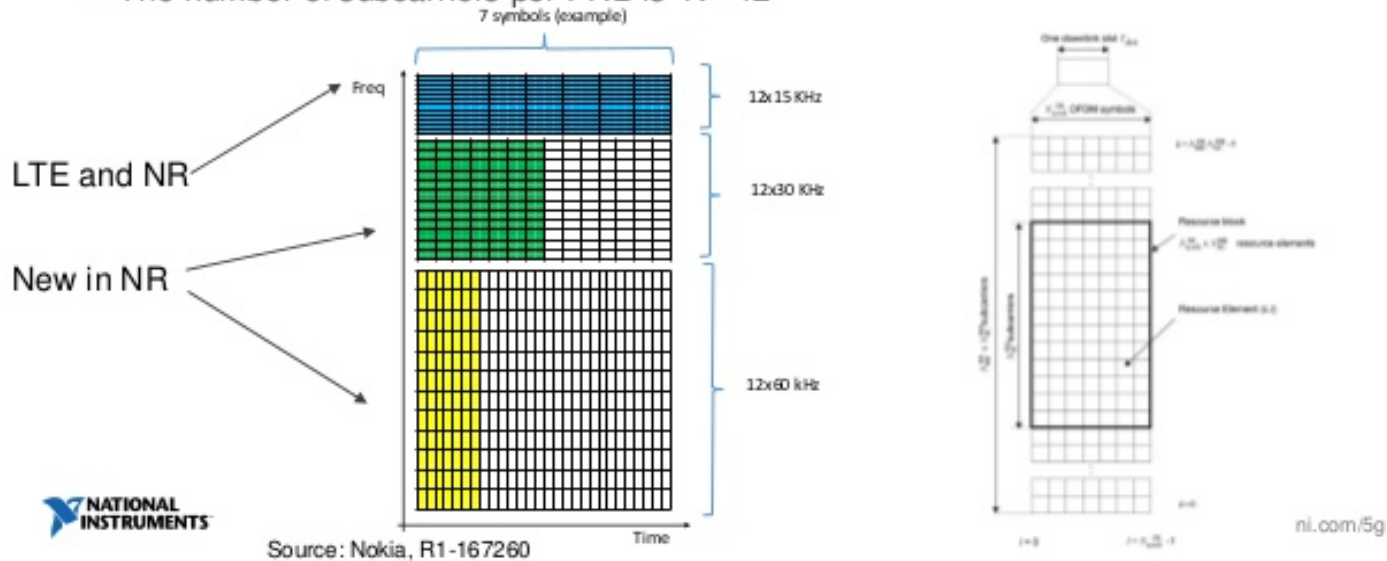
μ	RB_{\min} (DL/UL)	RB_{\max} (DL/UL)	f_{BW} (min)	f_{BW} (max)
0	24	275	4.32	49.5
1	24	275	8.64	99
2	24	275	17.28	198
3	24	275	34.56	396
4	24	138	69.12	397.44



RB in 5G NR

Resource Block in New Radio

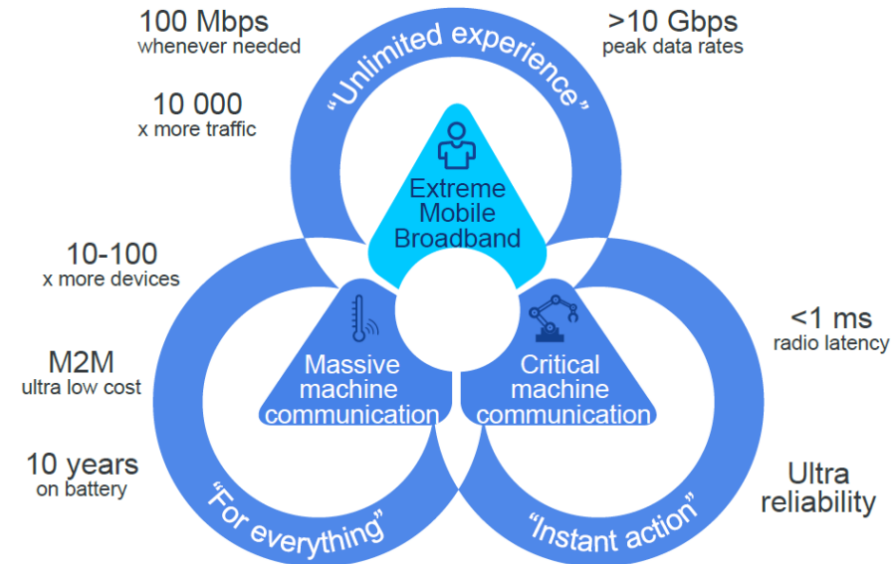
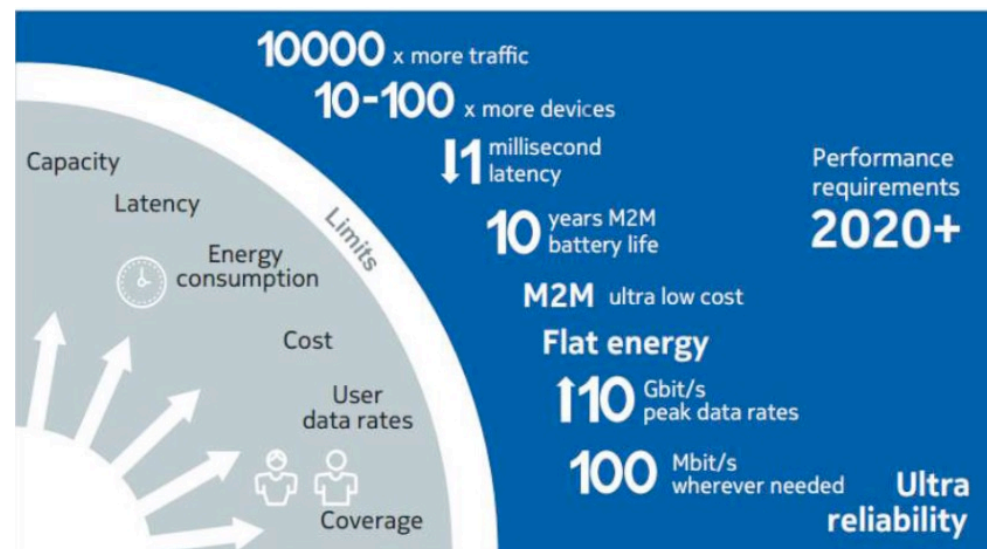
- NR defines physical resource block (PRB) where the number of subcarriers per PRB is the same for all numerologies.
 - The number of subcarriers per PRB is $N = 12$





The 5G Promise

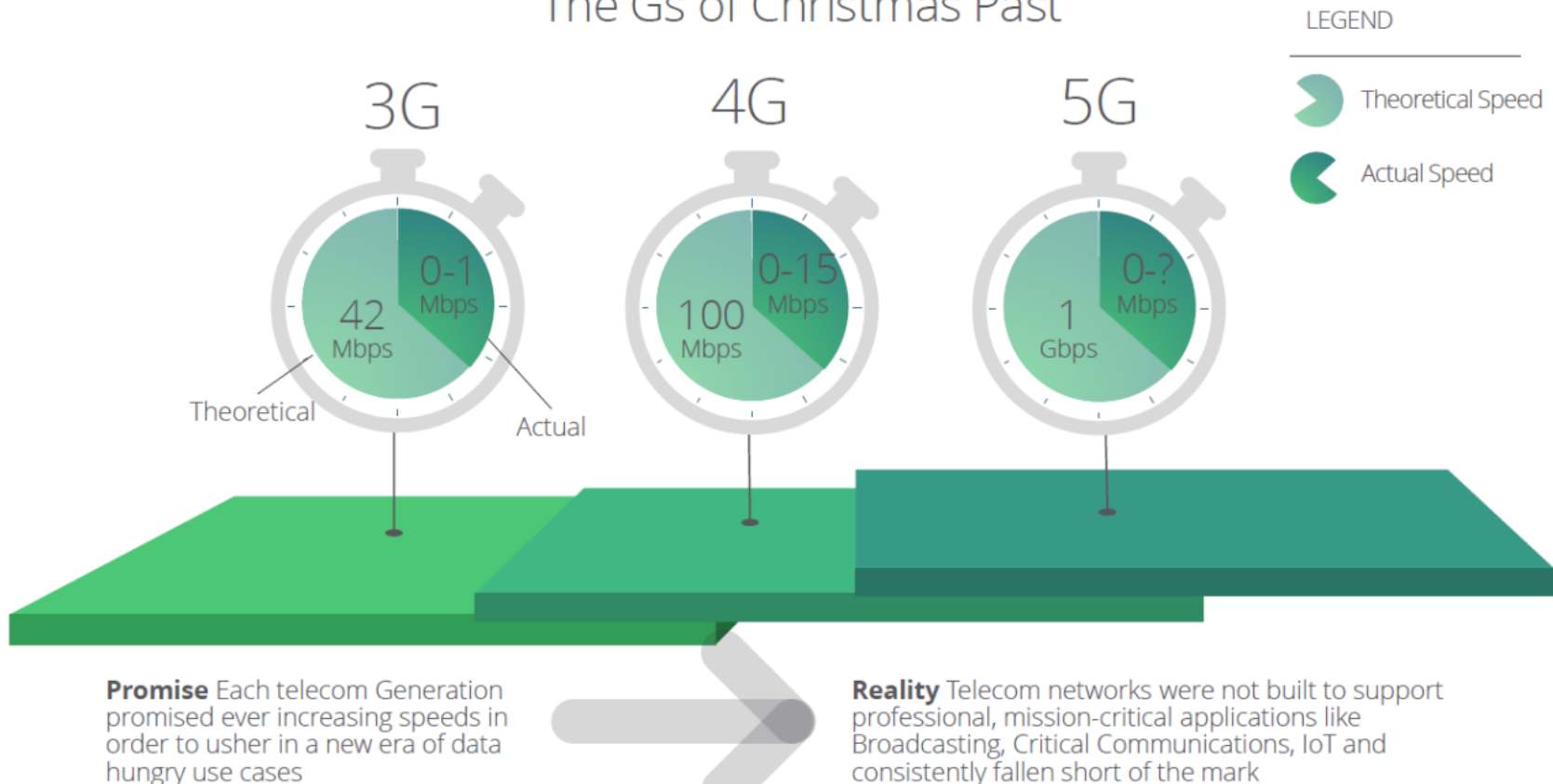
✓ 5G enables new capabilities beyond mobile broadband





The 5G Challenge

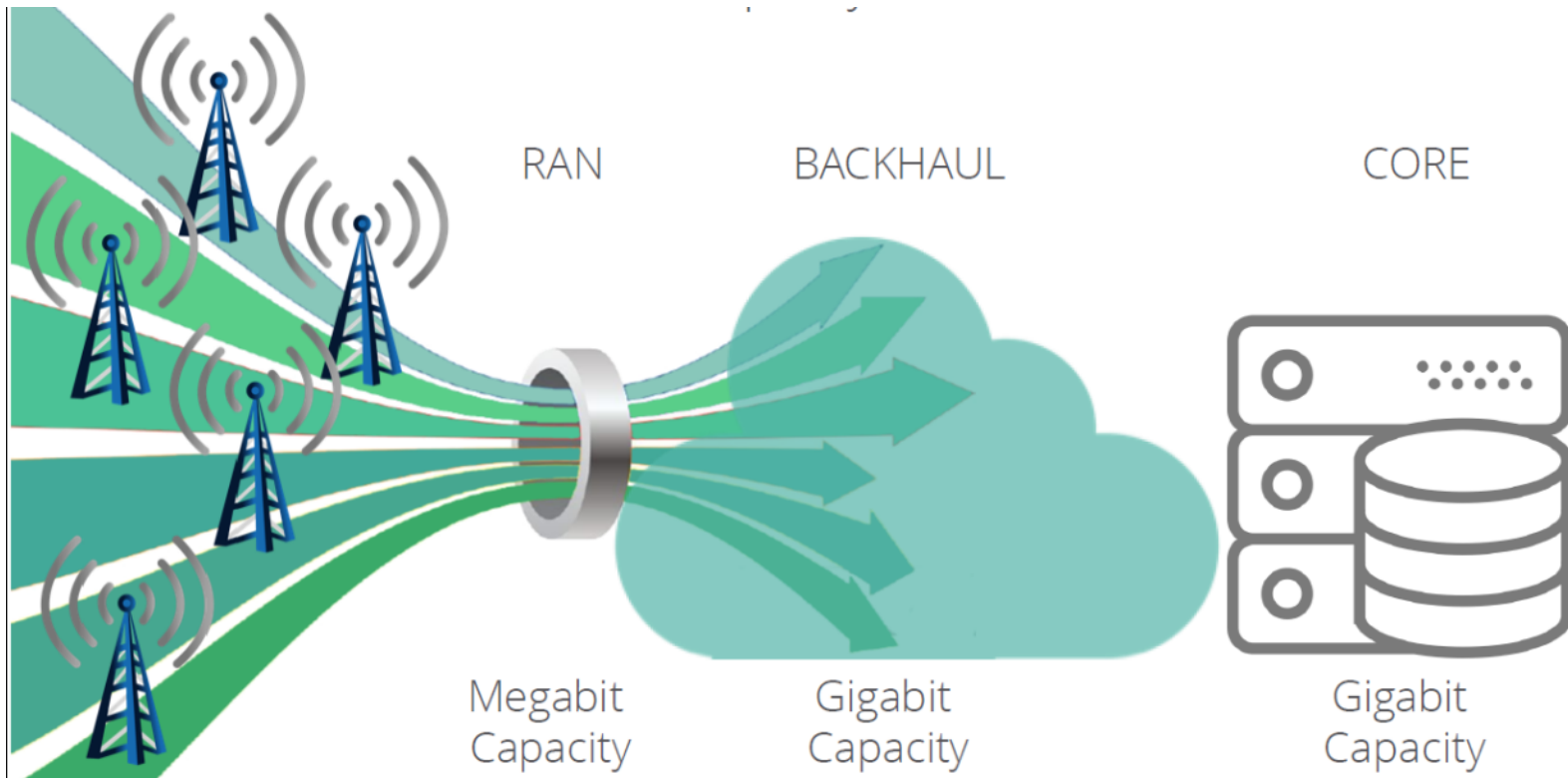
The Gs of Christmas Past



Source Cloudstreet



The Wireless Bottleneck Paradigm

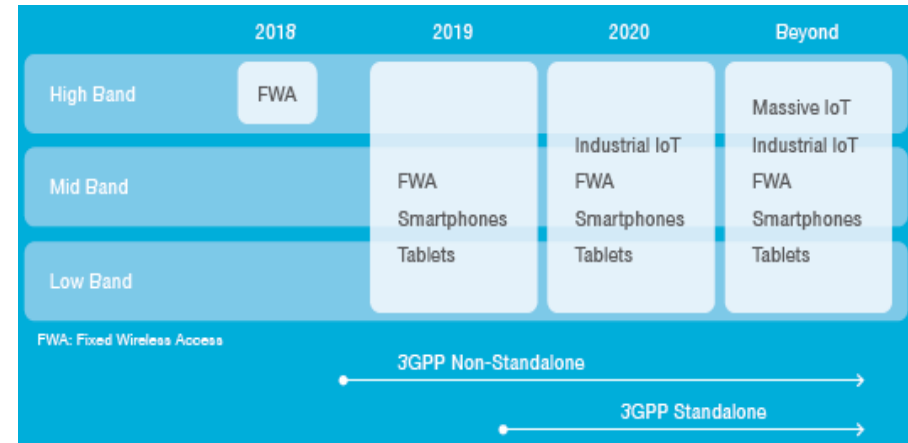


Source Cloudstreet



5G Evolution

- ✓ A lot of work still to do to fulfill the 5G vision in next 3GPP releases!
- ✓ First phase of 5G (Rel-15) completed
 - Foundation for 5G (enhanced Mobile Broadband **eMBB**)
- ✓ Second phase of 5G on-going (Rel-16)
 - Meet **IMT2020 requirements**
 - Ultra-Reliable and Low Latency Communications (**URLLC**)
- ✓ Future phases of 5G (Rel-17 and beyond)
 - Deliver new fundamental 5G NR technologies that expand and evolve the 5G ecosystem
 - massive Machine Type Communications (**mMTC**)



Ericsson white paper,
“5G deployment considerations”
Feb. 2018

