5G for people and things
Key to the programmable world

Overview

5G Radio Interface

- Worldwide cm and mm bands to enable Gbps user rates. [Revolution]
- Massive MIMO technologies to help cm and mm wave technologies. [Revolution]
- Performance Results
- Dynamic TTI [Evolution]
- Multi-connectivity xRAT [Evolution]

5G IoT

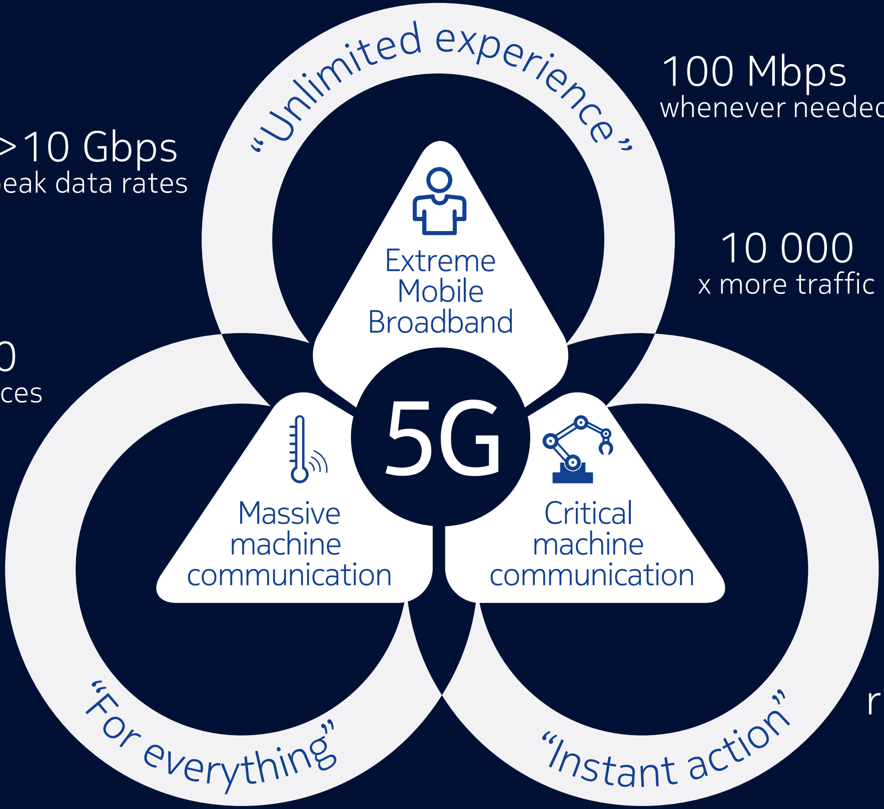
- Cat-M and NB-IOT [Evolution]
- New air inteface to optimize IOT? [Revolution]

5G Networking

- Network slicing [Evolution]
- Flexibility [Revolution]

5G involves two things: **what** we innovate on and **how** we do it.

Diverse requirements [MBB vs IoT]



>10 Gbps
peak data rates

100 Mbps
whenever needed

10 000
x more traffic

10-100
x more devices

M2M
ultra low cost

10 years
on battery

<1 ms
radio latency

Ultra reliability

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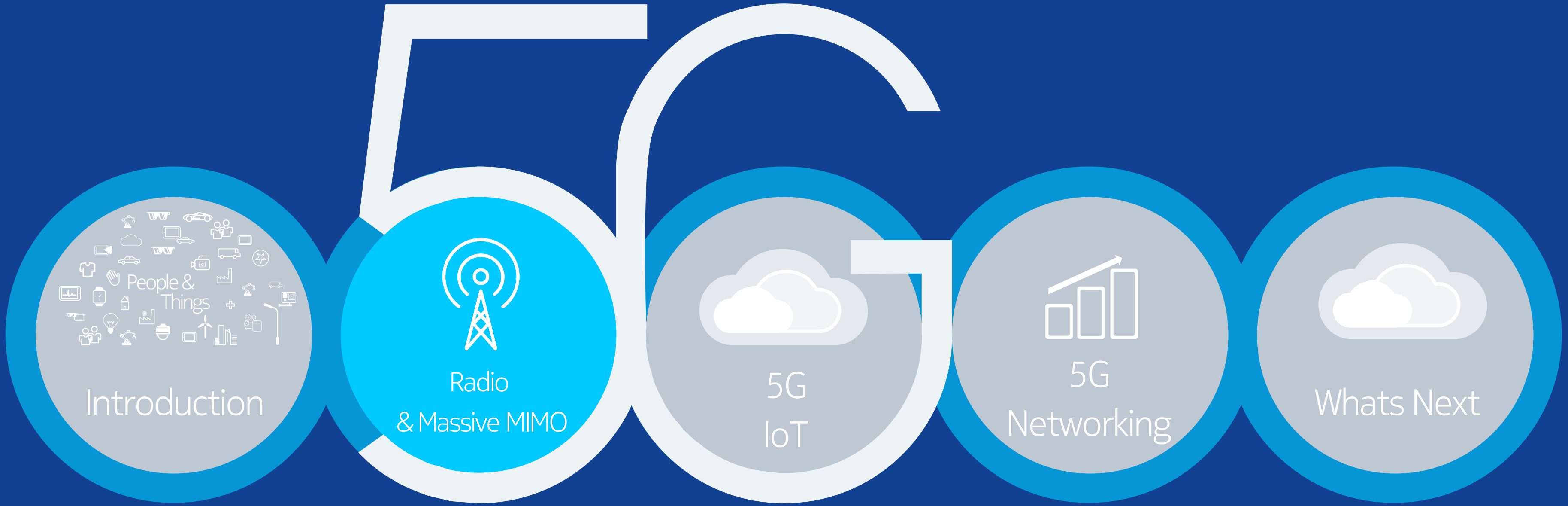

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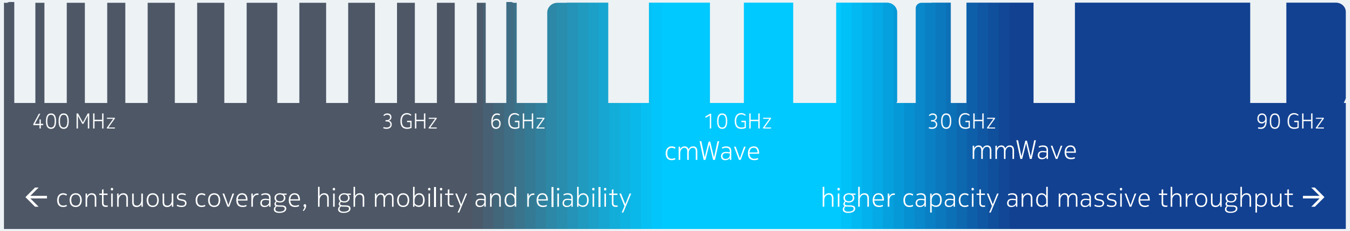
Unlocking new spectrum assets | Foundation for 5G

Leveraging all bands , ranging from ~400MHz - 100GHz



Different characteristics, licensing, sharing and usage schemes

Carrier BW	n * 20MHz	n * 100 MHz	1-2GHz
Duplexing	FDD		TDD
Cell size	Macro	Small	Ultra small
Coverage	← →		Capacity

10,000 x | >10 Gbps | 100 Mbps | <1 ms | 10-100 x | ultra low | 10 years

Leading METIS I & II spectrum work package

Leading modeling know-how
Channel measurements from 3-73GHz

World's 1st trials
on shared spectrum access

public

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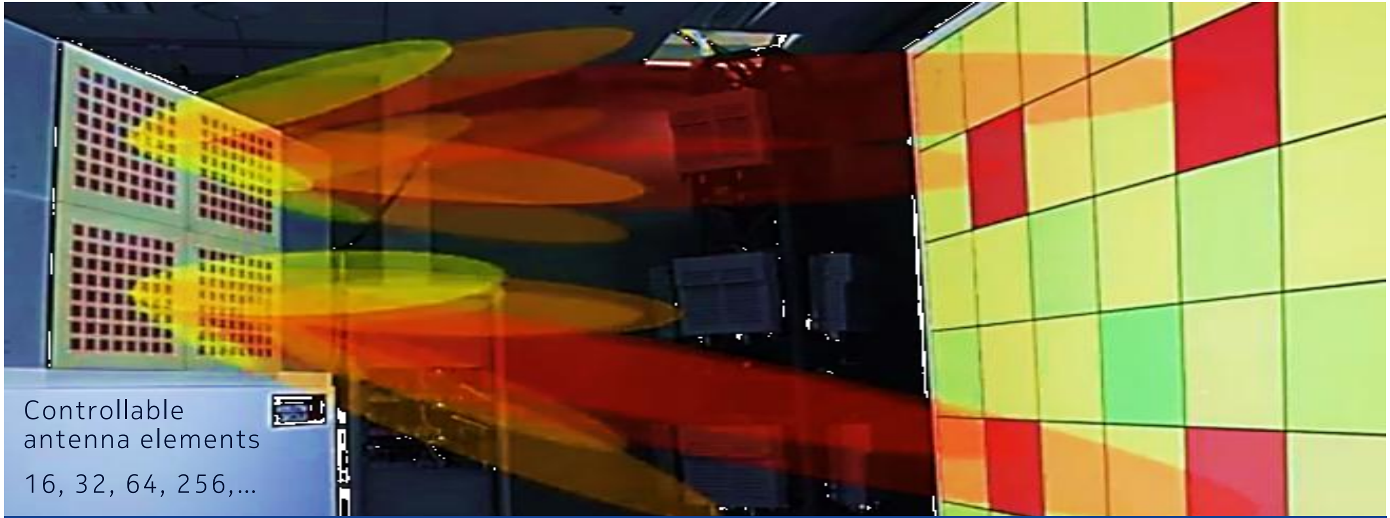
Native massive MIMO | Let the capacity follow the demand

Chip-scale antennas, high beamforming & multiplexing gain



Exploiting high frequency bands with chip scale antenna array research
→ Compensating path loss with high antenna gain

10,000 x | >10 Gbps | 100 Mbps | <1 ms | 10-100 x | ultra low | 10 years

700%
Cell edge gain

+80%
Spectral efficiency

Cooperation with top notch industry and university partners

mmWave trials
with DOCOMO

10Gbps speed record
w. National Instruments

  public

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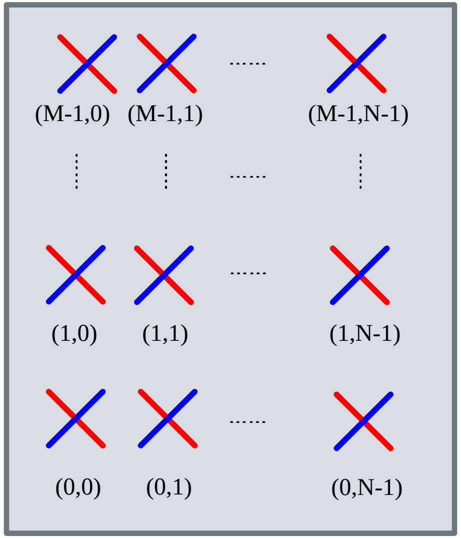
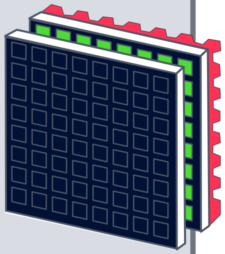
What is “Massive MIMO”?

- **Massive MIMO** is the **extension of traditional MIMO** technology to antenna arrays having a **large number** of **controllable antennas**



- MIMO = Multiple Input Multiple Output = **any transmission scheme involving multiple transmit and multiple receive antennas**
  - Encompasses all implementations:
    - RF/Baseband/Hybrid
  - Encompasses all TX/RX processing methodologies:
    - Diversity, Beamforming, Spatial multiplexing,
    - SU & MU, joint/coordinated transmission/reception, etc.
- **Massive ➔ Large number**: >> 8
- **Controllable antennas**: antennas (whether physical or otherwise) whose signals are adaptable by the PHY layer (e.g., via gain/phase control)



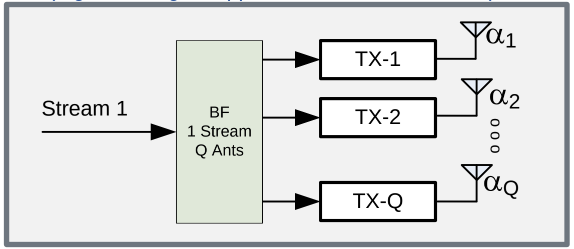
Why "Massive MIMO"

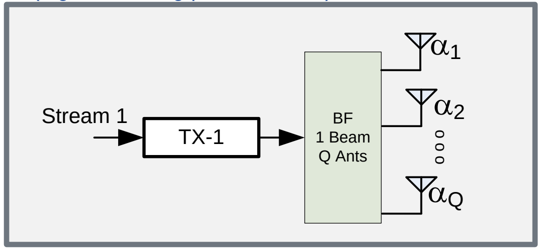
- Benefits:
  - **Enhance Coverage ➔** High gain adaptive beamforming
    - Focus energy more towards the user, increase SINR
  - **Enhance Capacity ➔** High order spatial multiplexing
    - Multiple parallel spatial streams to a single user (SU) or to multiple users (MU)
- Relevance to 5G:
  - Lower operating frequencies (e.g., <6GHz) are more interference limited
    - LTE already designed for high spectral efficiency (<8 Antenna ports)
    - **Capacity-enhancing solutions become essential**
  - Higher operating frequencies (e.g., >>6GHz) have poor path loss conditions
    - **Coverage-enhancing solutions become essential**

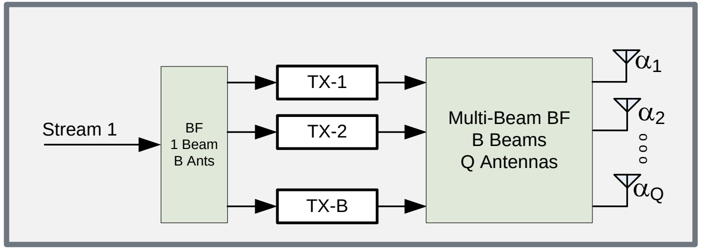
Signal Processing View: Fully Connected Arrays

	Baseband	**RF**	**Hybrid**
	Frequency selective weights applied at baseband (e.g., BF weights applied to OFDM subcarriers)	Frequency non-selective weights applied at RF (e.g., via analog phase shifters)	TX weights applied at both RF and baseband

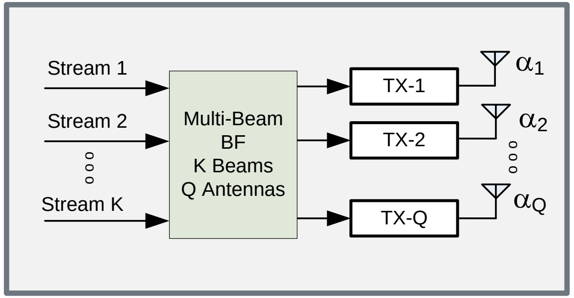
Single Stream

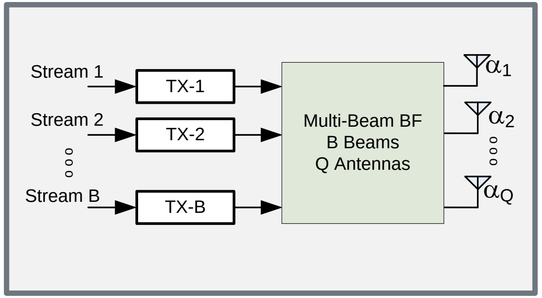


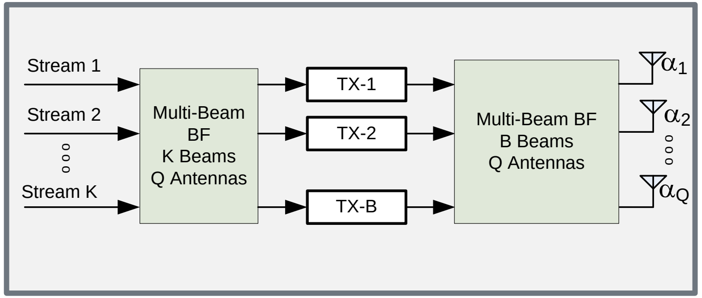




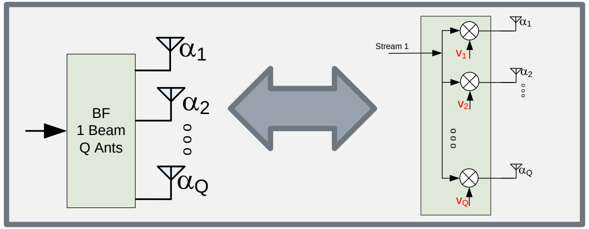
Multi-Stream

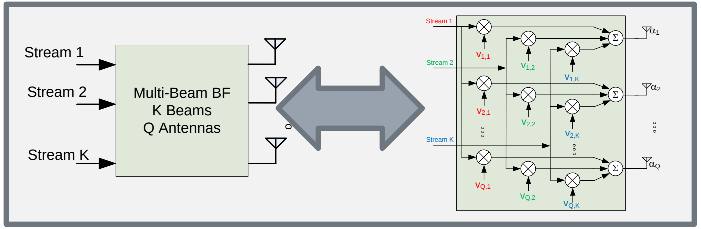






Legend:





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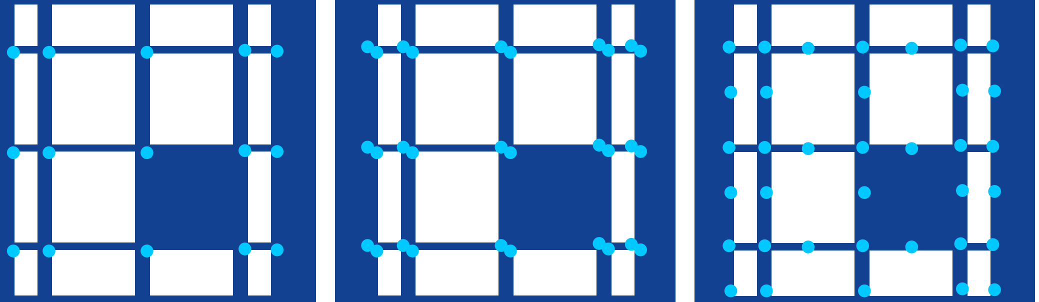
RF vs. Baseband vs. Hybrid Architectures

Baseband	RF	Hybrid
Adaptive TX/RX Weightings at Baseband	Adaptive TX/RX Weightings at RF	Adaptive TX/RX Weightings at both RF and Baseband
Single transceiver Per Antenna Port	Single transceiver per RF beam	Single transceiver per RF beam
“Frequency-Selective” Beamforming	“Frequency-Flat” Beamforming	Combination RF / Baseband
High Flexibility	Low Flexibility	Moderate Flexibility
High power consumption & cost characteristics	Better power consumption & cost characteristics	Good power consumption & cost characteristics

Performance of Massive MIMO @ mmWave
5G requirements can be met even in challenging environments



75 AP/km^2 — 150 AP/km^2 — 187 AP/km^2 →
AP density

75 AP/km^2	150 AP/km^2	187 AP/km^2
2.1 Gbps Average UE Throughput	4.1 Gbps Average UE Throughput	5.1 Gbps Average UE Throughput
<1 Mbps Edge Throughput	222 Mbps Edge Throughput	552 Mbps Edge Throughput
16.4% Outage Probability	3.2% Outage Probability	1% Outage Probability

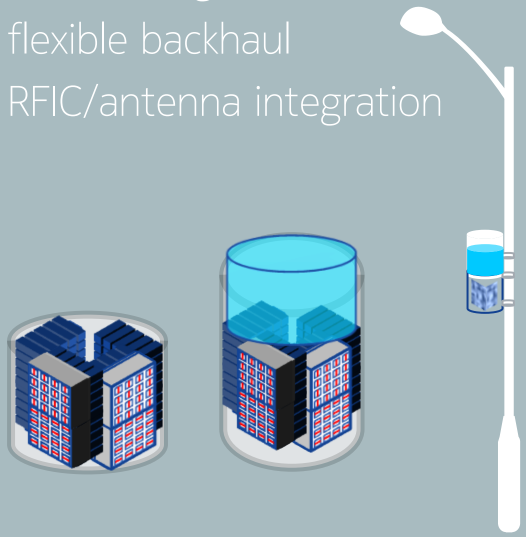
Network capacity →

Multi-connectivity (72GHz / 2GHz BW)

Performance in outdoor environments

Enabled through

- flexible backhaul
- RFIC/antenna integration



Outage = less than 100Mbps throughput

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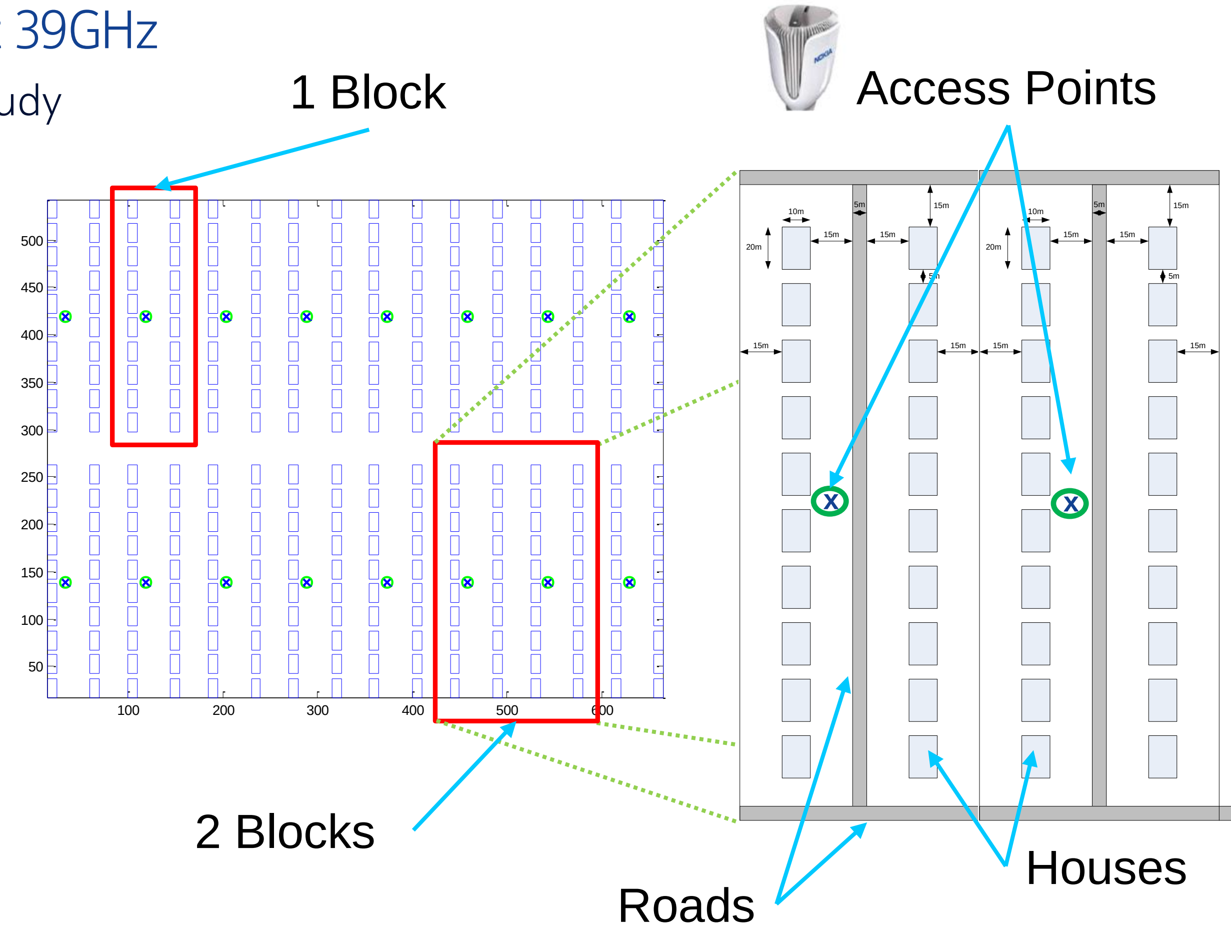
Wireless 5G to the Home at 39GHz

- Physical Layer Simulation Study



- Modified Detailed 3GPP/RAN1 physical layer system level simulator
- Suburban neighborhood layout of 320 houses, 16 blocks, 1 AP per block
- AP is either a single omni sector site or is a 3-sector site mounted on 6m high lamppost
- 10 active CPEs per AP site
- Indoor CPEs vs Outdoor CPEs
- Path Loss, Blockage, and Multipath Modeling appropriate for 39GHz
- Null Cyclic Prefix Single Carrier System with 800MHz Bandwidth

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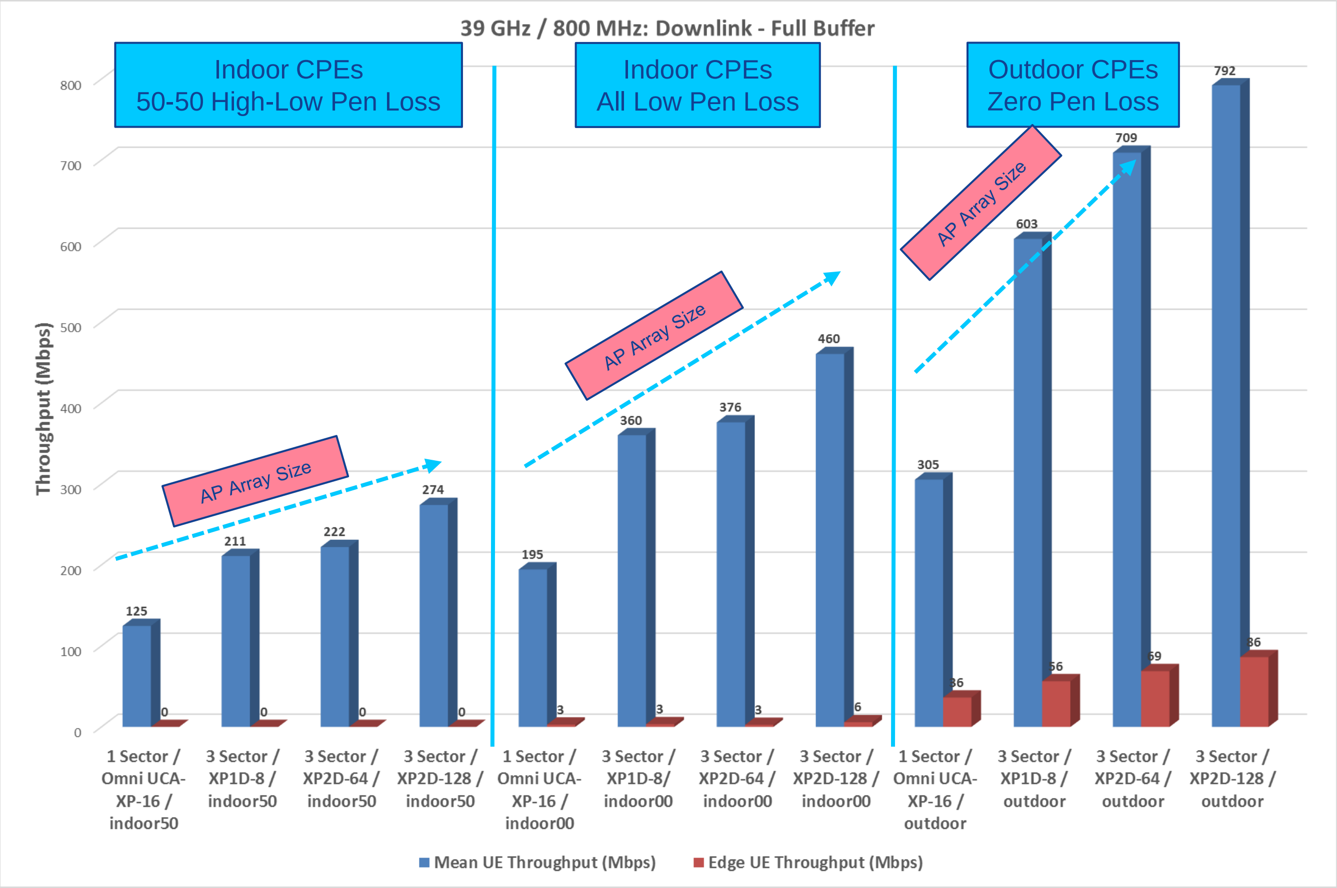
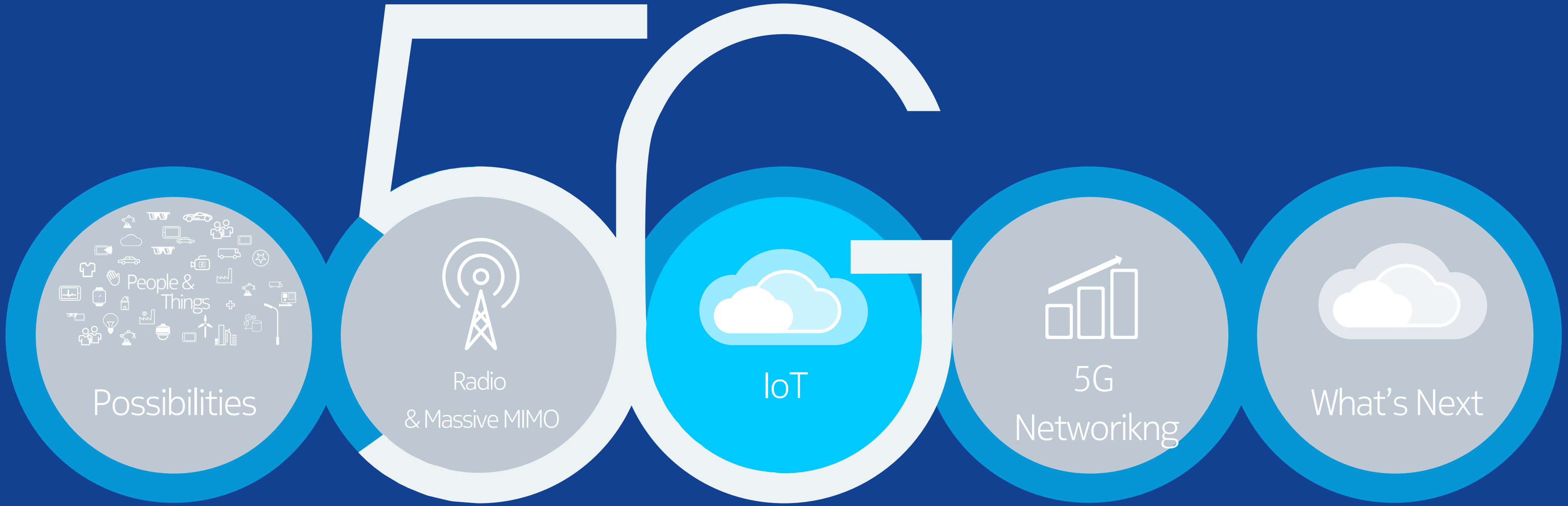
39 GHz NCP-SC, 800 MHz BW – Effect of Larger Antenna Arrays and Penetration Loss

- AP Arrays:
  - 1 Sector: Omni UCA-XP, **16** antennas
  - 3-Sector: XP1D, **8** antennas
  - 3-Sector: XP2D, **64** antennas
  - 3-Sector: XP2D, **128** antennas
- CPE: 2 antennas (omni)
- Antenna element gain:
  - For 1D arrays: antenna element gain = 14dBi
  - For 2D arrays: antenna element gain = 1dBi
- 10 CPEs per site on average





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IoT | Low cost & power for massive machine type communication

LTE-M for small, infrequent & low cost data transfer

Power saving

Longer sleeping cycles*

Less signaling for wakeup

Power Save Mode

Simplified modems

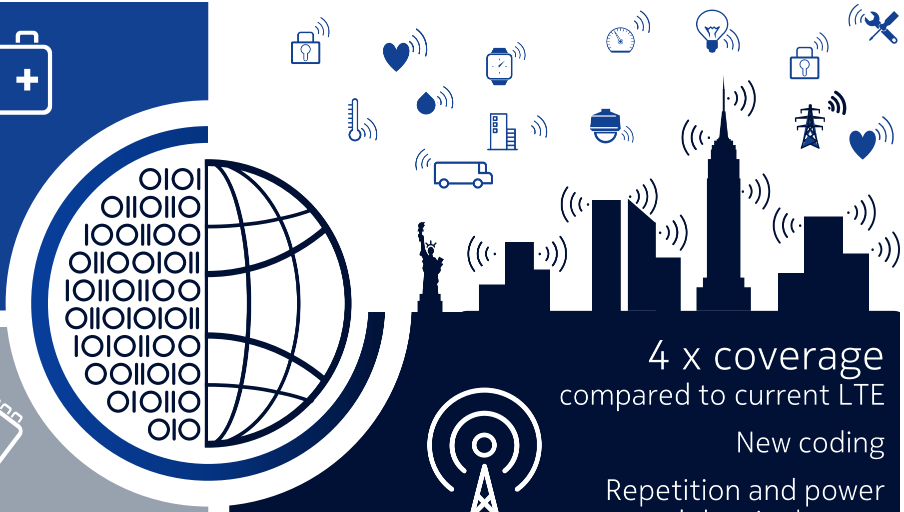
Narrowband transmission

Reduced transmit power

Limited downlink transmission modes

UE processing relaxations

...



4 x coverage

compared to current LTE

New coding

Repetition and power spectral density boosts

+15~20 dB coverage

>10 years

Battery life with two AA batteries

Very low device cost

Live trial with KT

MWC 2015

First live demo

on commercial Nokia FlexiZone and core

Driving for availability in 3GPP Rel.13, 2016

10,000 x | >10 Gbps | 100 Mbps | <1 ms | 10-100 x | ultra low | 10 years

*) Extended Discontinuous Reception (DRX)

Main LTE-M & NB-IoT features

- 3GPP specifications in Release 12 and 13

Release 12 introduced low complexity UE category ("Cat-0") with lower data rate, half duplex and single antenna.

Release 13 will further reduce UE device complexity with narrowband RF and lower peak data rates.

3GPP LTE	Release 8	Release 8	Release 12	Release 13	
UE characteristics	**Cat. 4**	**Cat. 1**	**Cat. 0**	**Cat. M**	**NB-IoT**
Downlink peak rate	**150 Mbps**	**10 Mbps**	**1 Mbps**	**1 Mbps**	**200 kbps**
Uplink peak rate	**50 Mbps**	**5 Mbps**	**1 Mbps**	**1 Mbps**	**144 kbps**
Number of antennas	2	2	1	1	1
Duplex mode	Full duplex	Full duplex	Half duplex	Half duplex	Half duplex
UE receive bandwidth	20 MHz	20 MHz	20 MHz	1.4 MHz	200 kHz
UE transmit power	23 dBm	23 dBm	23 dBm	20 dBm	23 dBm
Maximum signal loss	**<140 dB**	**<140 dB**	**<140dB**	**156 dB**	**164 dB**
Modem complexity	100%	80%	40%	20%	<15%

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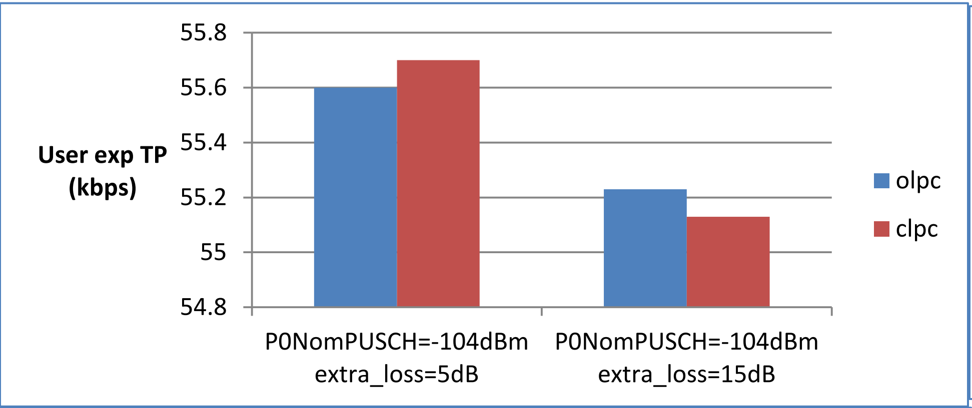
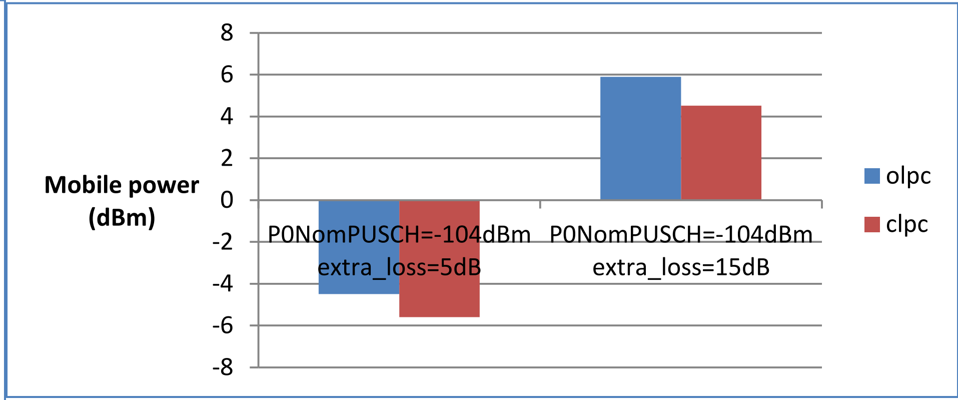
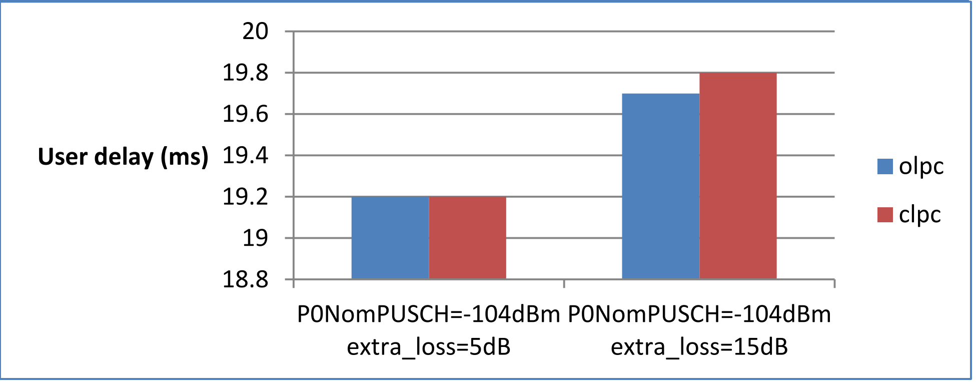
M-PUSCH Closed loop versus open loop (single cell)

- CLPC versus OLPC for a given P0NomPUSCH.





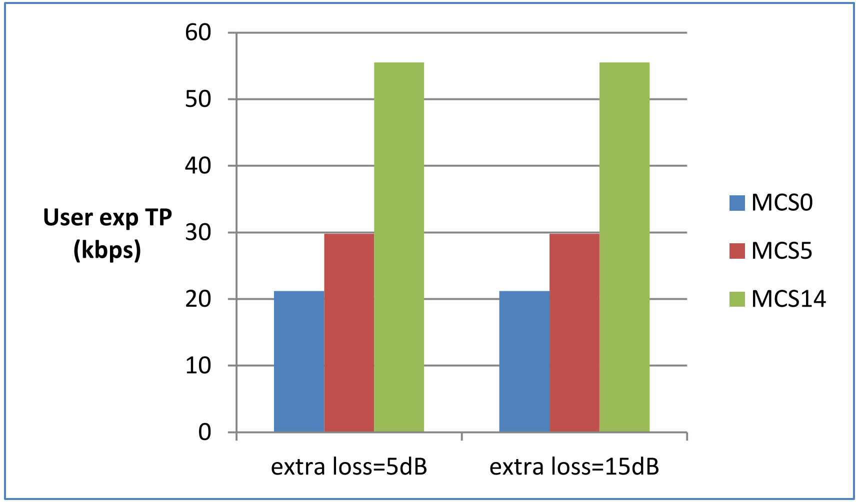


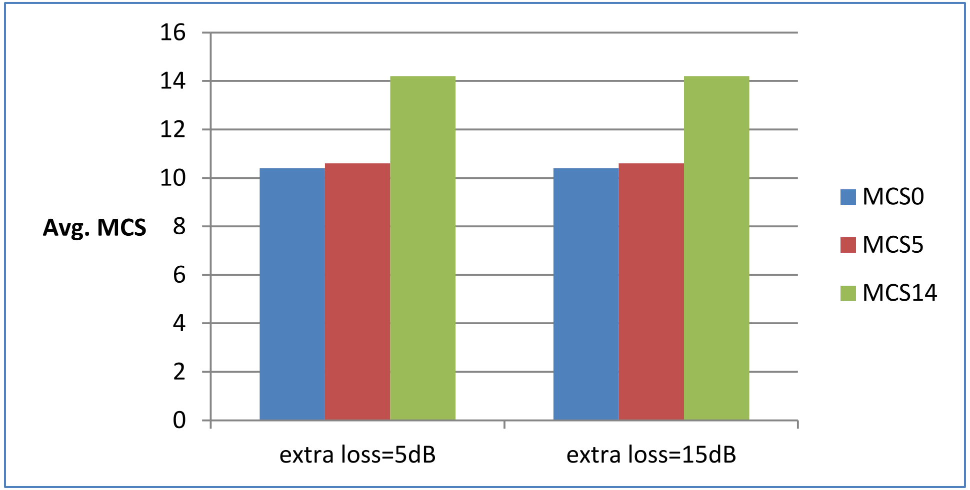
Performance is about the same between CLPC and OLPC. CLPC does seem to use lower transmission power.

OLPC has the about the same performance as CLPC in terms of throughput and delay but uses higher transmit power .

M-PUSCH - Impact of initial MCS(single cell)

- OLPC, PoNomPUSCH=-114dBm





- Performance is sensitive to the initial MCS.
- Note: msg3 is not modeled here which could serve as a M-PUSCH measurement.

Initial MCS impacts performance .

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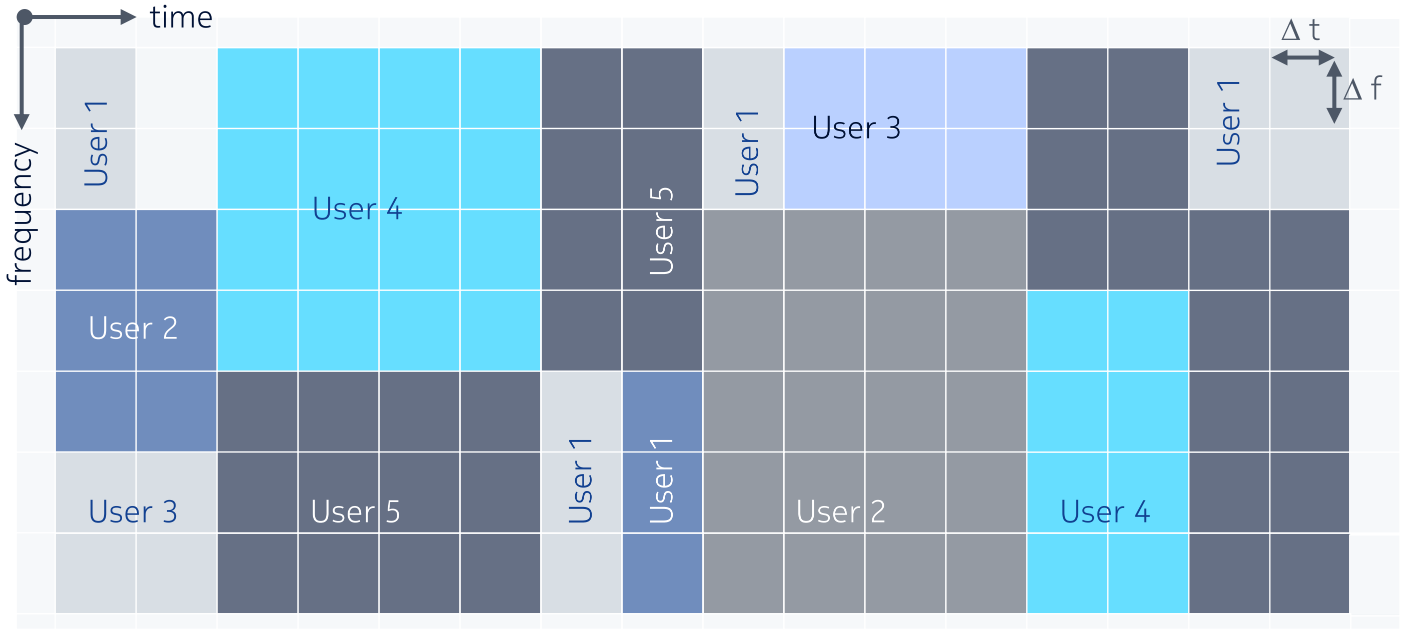
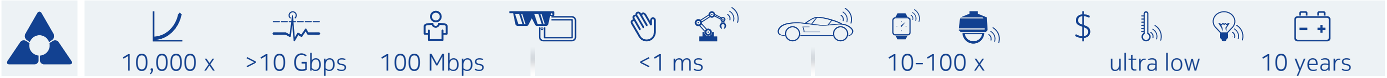
Dynamic TTI: Flexibility in supporting MBB and IoT





*) compared to static TD-LTE

50-100% capacity gain*

Smart local traffic routing e.g. D2D on top of local cellular

SC/UDN low cost deployment e.g. via self-backhauling

Dynamic TDD cmW and mmW air IF blue prints and PoC

Part of eLA concept adopted in METIS

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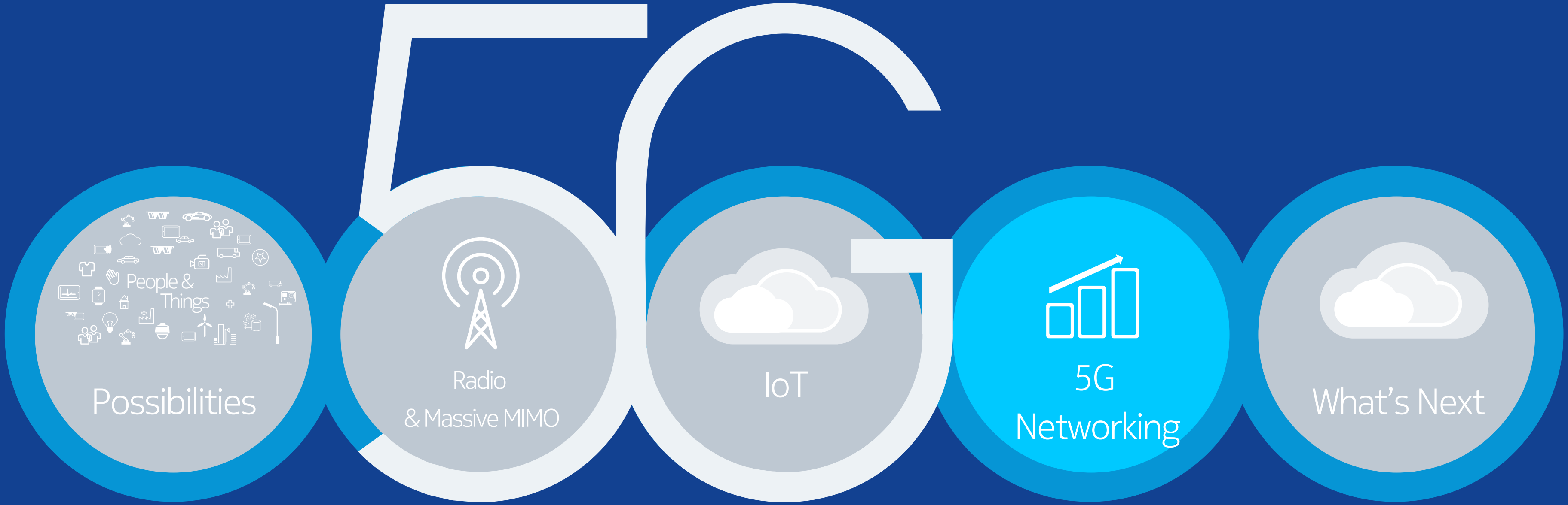

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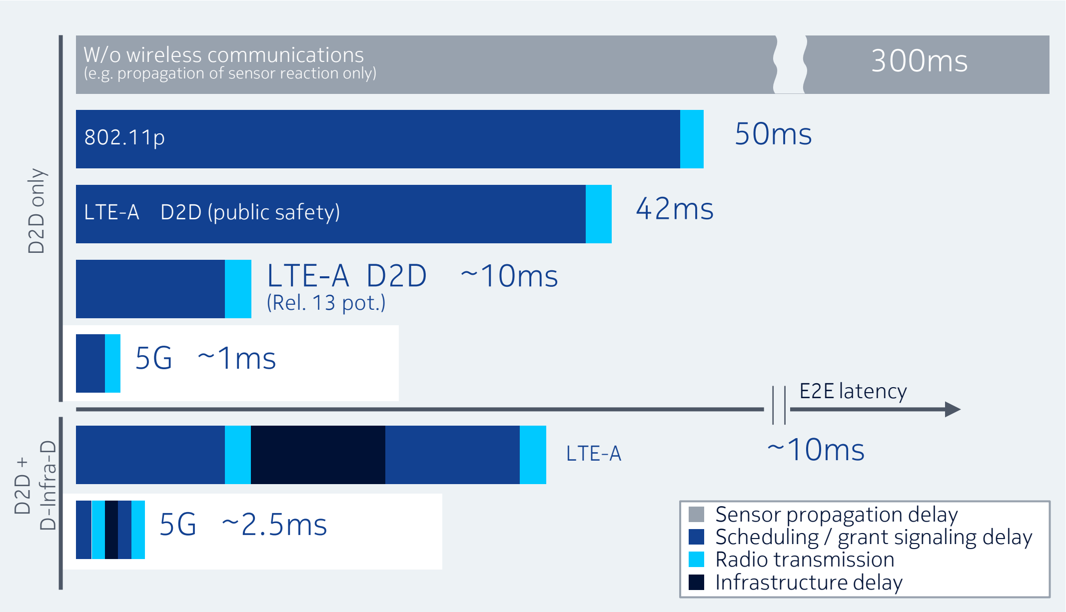
1ms Latency | Enabling a new generation of latency critical services

E2E latency aware scheduler

Latency optimized frame structure

Dynamic uplink-downlink

Pipeline processing



Autonomous driving and production

Tactile internet services

mmWave demo with NTT DoCoMo

10,000 x | >10 Gbps | 100 Mbps | <1 ms | 10-100 x | ultra low | 10 years

DMRS = Demodulation Reference Signal; GP = Guard Period

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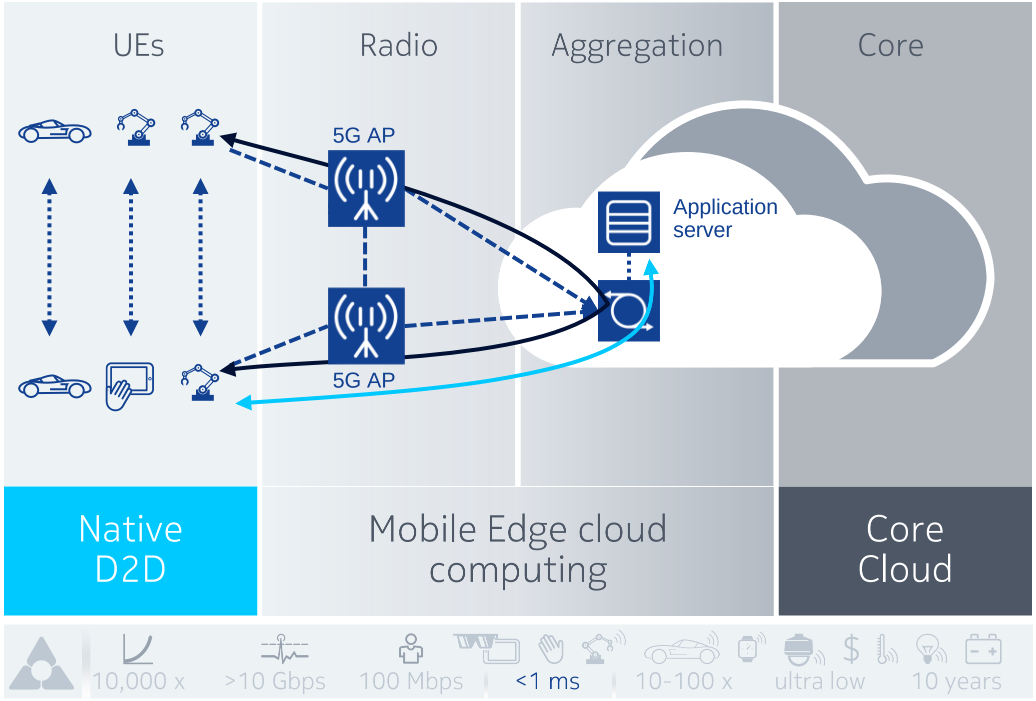
Fast traffic forwarding | Enabling a new generation of latency critical services

Lowest latency packet forwarding to UEs



Moving
virtual networks

Mission-critical
services, e.g. in V2X or industrial applications

Central cloud based	> 50 ms latency
Mobile Edge LTE	≈ 10 ms
5G Edge	≈ 2,5 ms
5G D2D	≈ 1 ms

Vehicle2Infra trial
on German motorway

Pioneer in Mobile Edge Computing

Vehicle2Infra live demos

ETSI ISG Chair

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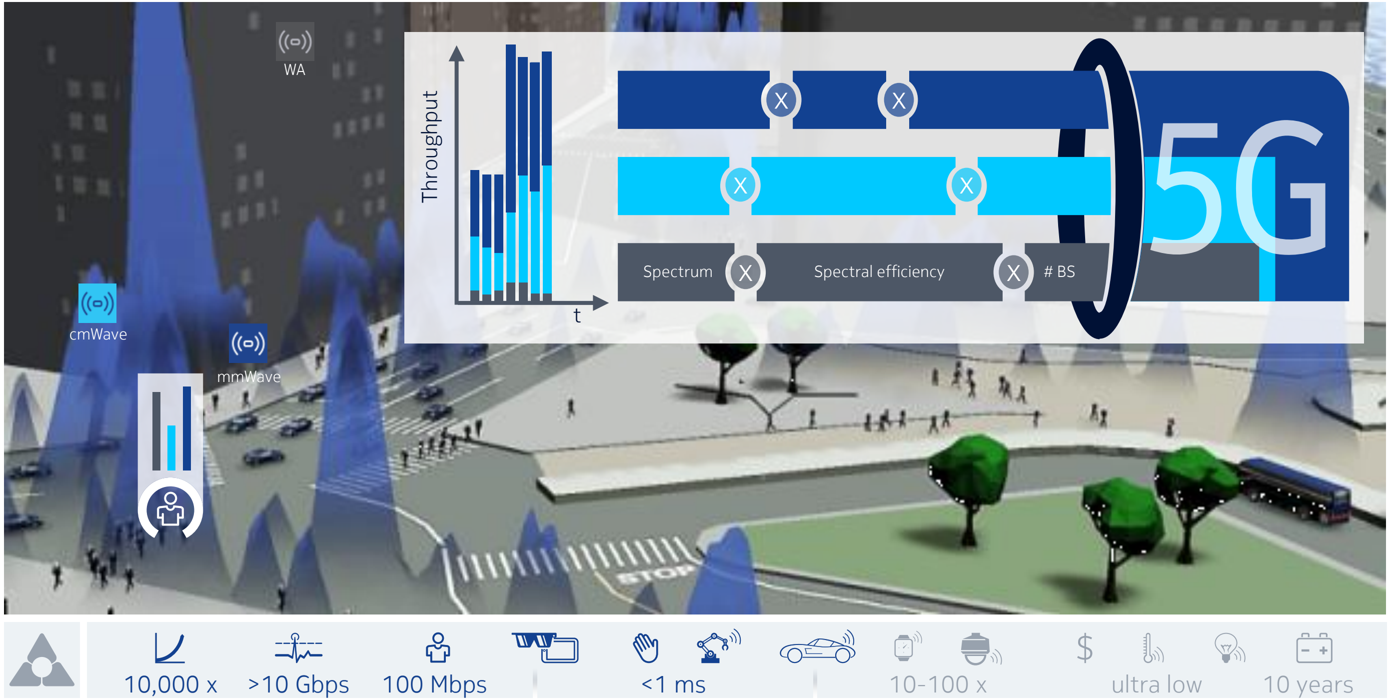
Multi-Connectivity | Perception of infinite capacity

Multiple radio technologies collaborating as one system



Extreme mobility robustness and ultra reliability

>100 Mbps anywhere

~ 3X burst throughput*

4G/5G real-time radio resource management know how built on demonstrator

*in example area, 50% load

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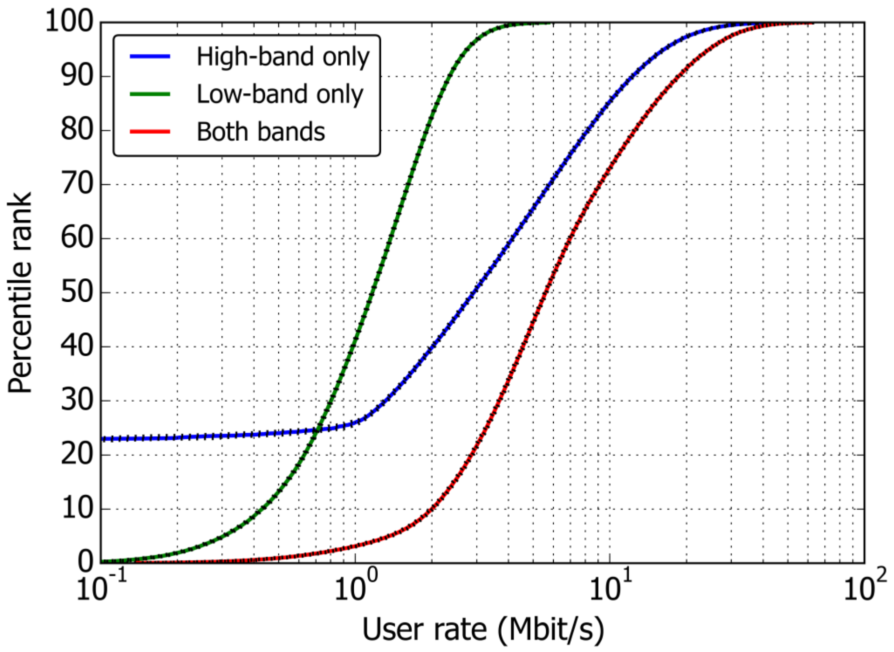
Multi-connectivity Gains

Opportunistically allowing mmwave to complement low band transmissions.



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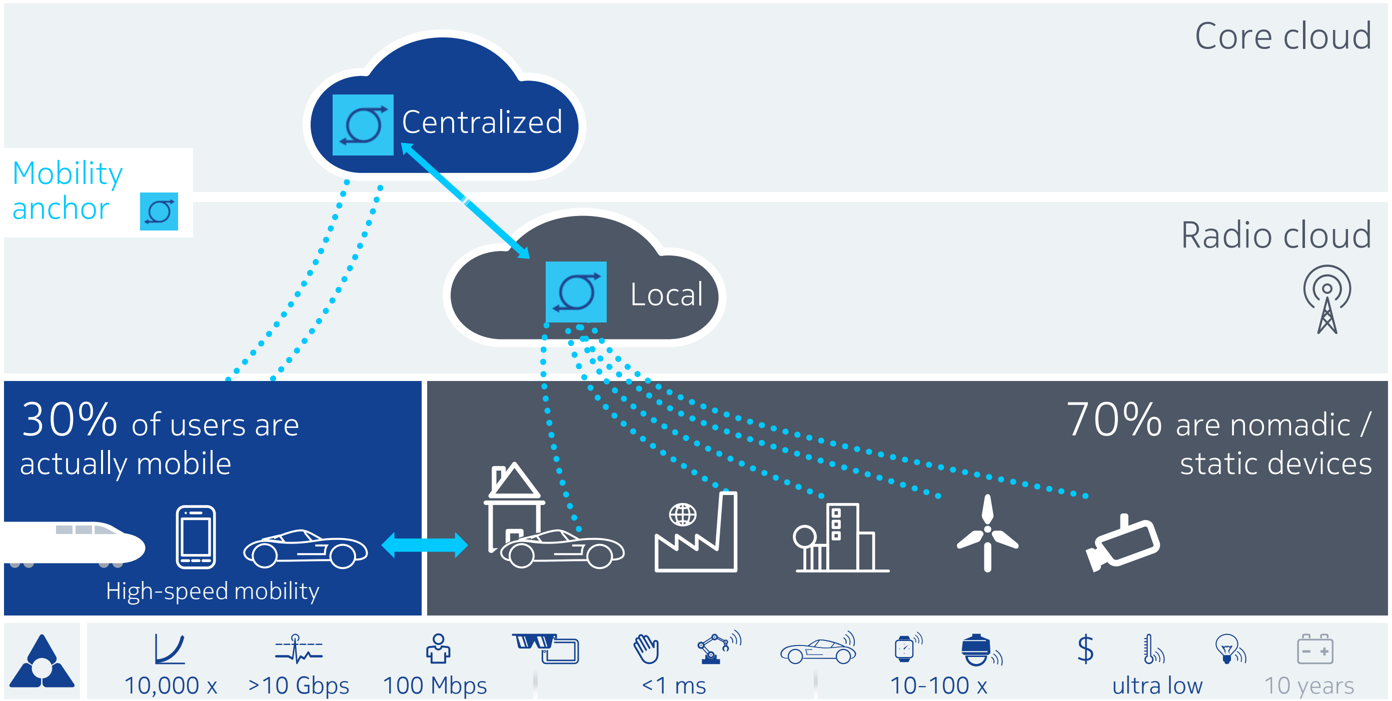
Mobility on demand | Highly efficient resource utilization

TCO optimized use of network resources



Less traffic backhauling to centralized cloud

TCO optimization

Best per service flexibility

Reduce core network resources

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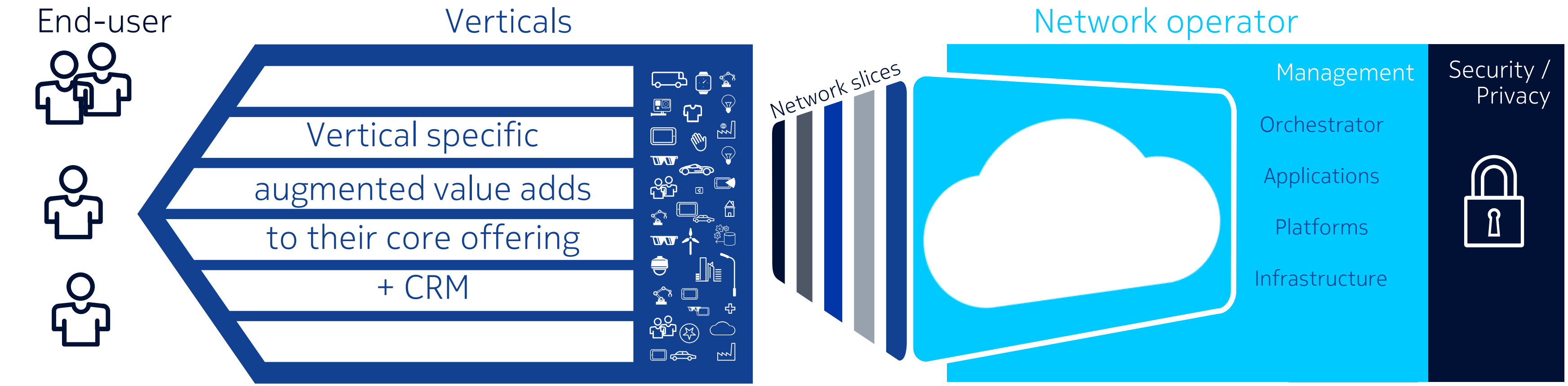
Network slicing

Help different industries to transform



KEY ENABLERS

- Slicing
- Dynamic Experience Management
- Any-to-any connectivity
- Low latency
- Slim radio for IoT

Network as a Service

Safety & Security	Mobile living	Utility & Energy	Traffic Mgmt.	Auto-motive	Health	Communi-cation	Logistics

Tailored vertical XaaS solutions

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Key milestones on the road to 5G – What's next?

2014

1st Brooklyn 5G Summit

- First 5G MWC showcase
- NTT DoCoMo cooperation
- MoU with CMCC/CMRI

2015

5G Radio demos

- 5G PPP projects started
- Positive outcome at WRC2015
- 3GPP standardization kicked off for 5G

2016

5G System demos

- 5G PPP projects in full swing
- 5G standardization on channel model, requirements and technology option selection

2017

Single RAN 5G System

- 3GPP 5G work in full progress
- IMT2020 evaluation process in ITU-R

2018

Pre standardized trials

- 5G phase 1 specs ready
- WRC2019 preparation underway
- Technology trials with key customers

2019

Pre commercial trials

- WRC19 outcome clear with new bands for IMT
- 5G phase 2 specs ready
- ITU-R process nearing completion

2020

Commercial network opened DOCOMO

- Research on "6G" starts

+ Details

public

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