What is 5G?

Robert A. Soni, Ph.D.

October 26, 2020

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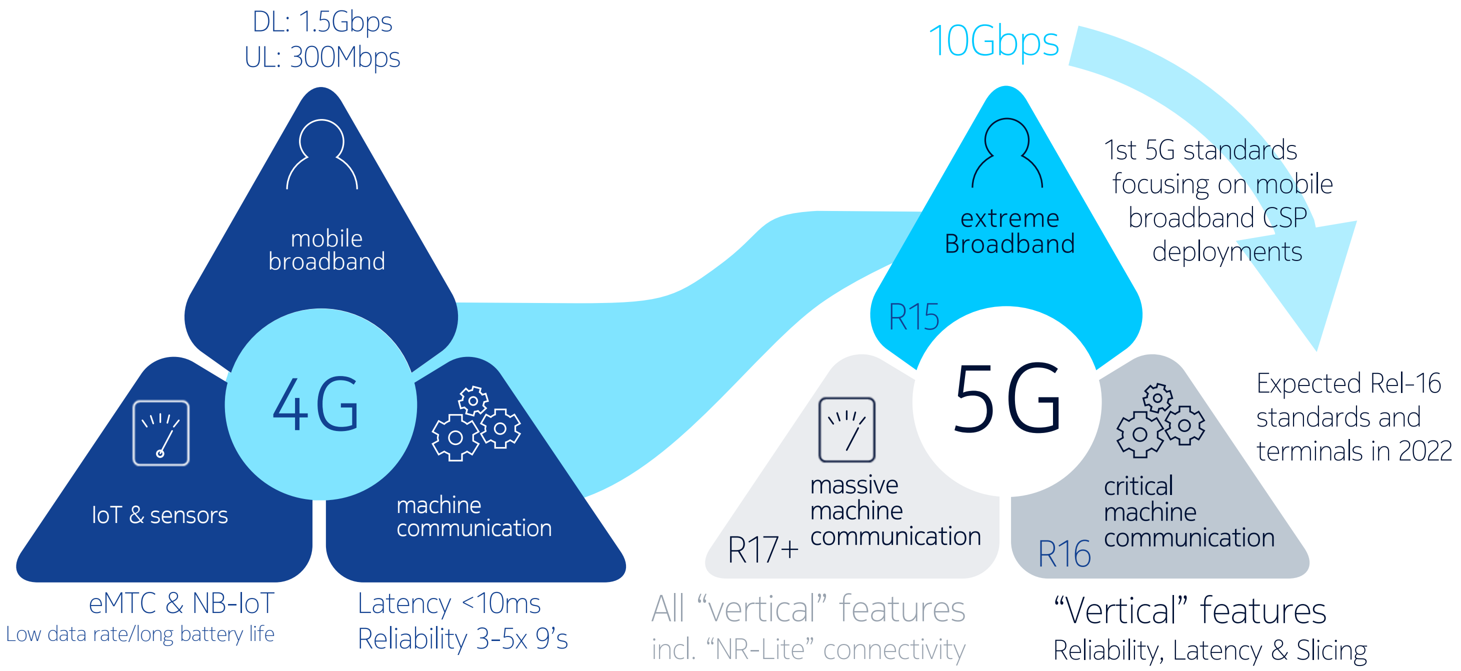
Realizing the full promise of 5G through 3GPP evolution

5G connectivity fabric builds on existing LTE deployments



End-to-end 5G will redefine the human condition and industrial productivity paradigm

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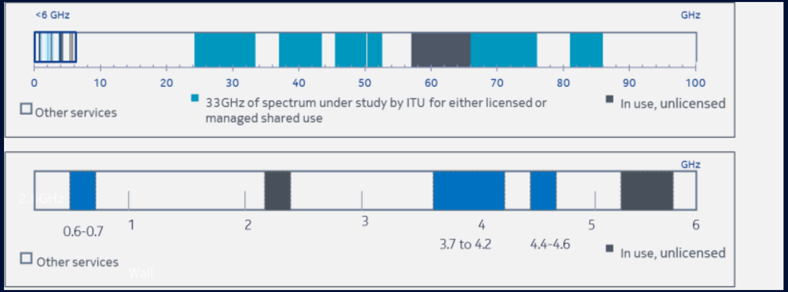
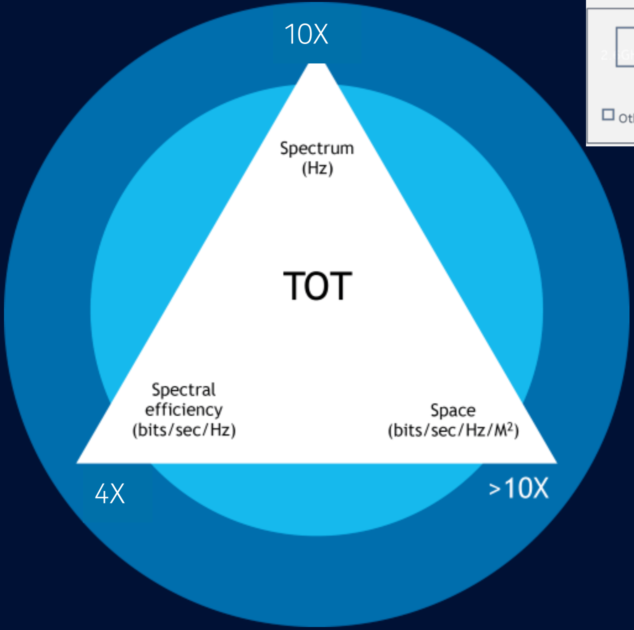
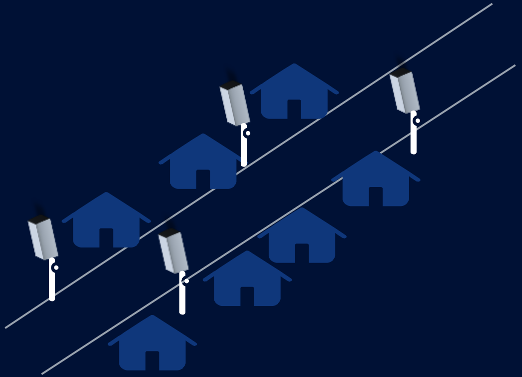
The Path to Hyper Capacity
Wireless Triangle of Truth

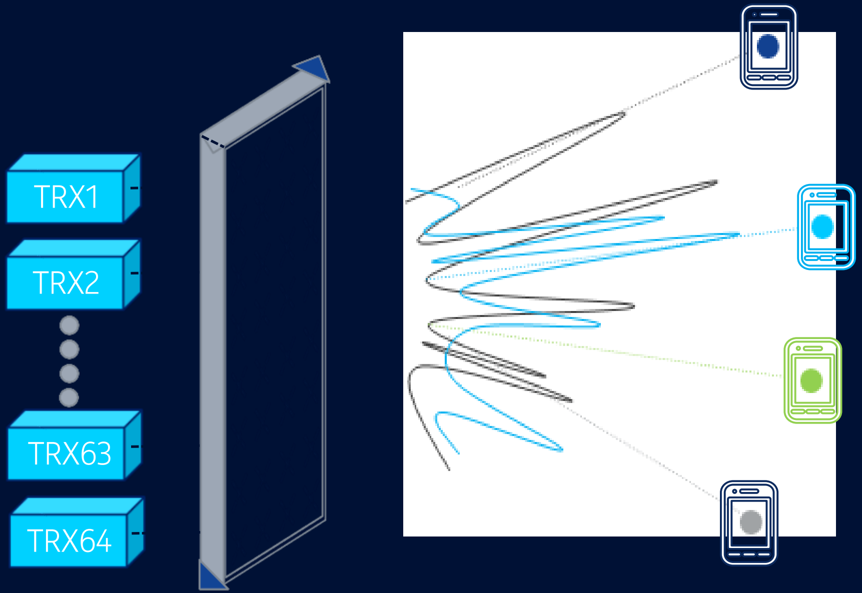




Massive MIMO



Massive MIMO
Key Challenges

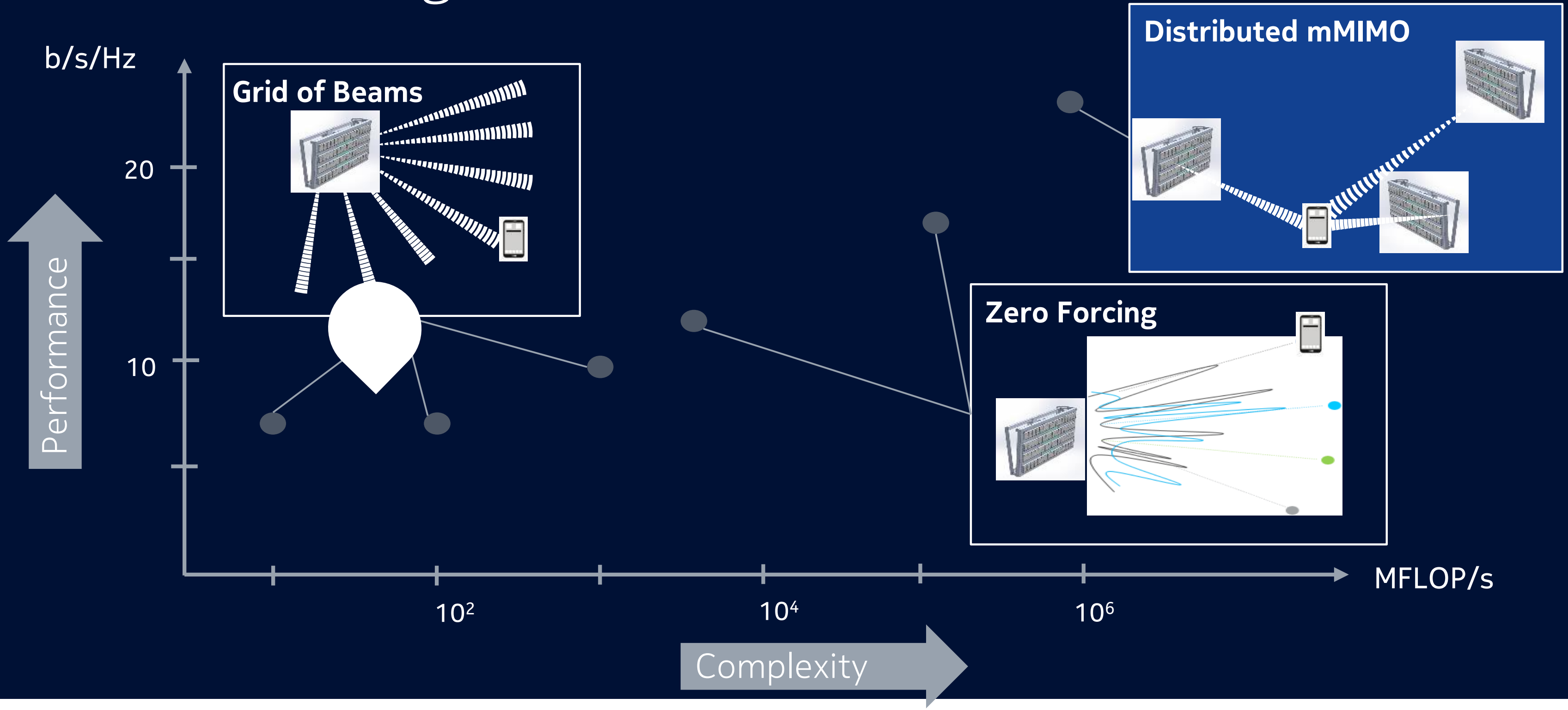


- Massive MIMO works by using many more antennas than devices simultaneously served to create beams that explicitly form nulls in the direction of other users not served by beam
- For given number of elements array size increases with wavelength
- Size of the array dictates beamforming gain to the user served
- 2x to 4x capacity gain

5G substantially increases spectral efficiency

NOKIA Bell Labs

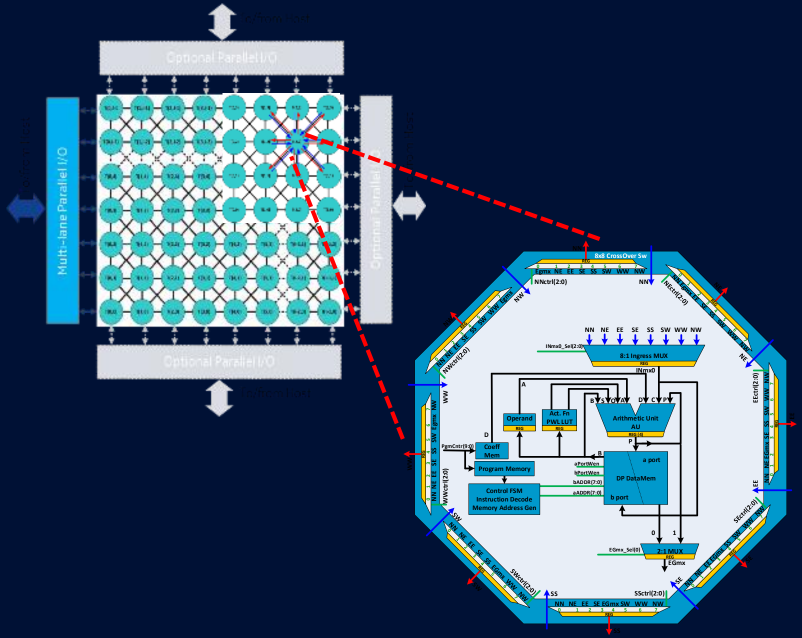
Massive MIMO algorithm innovation



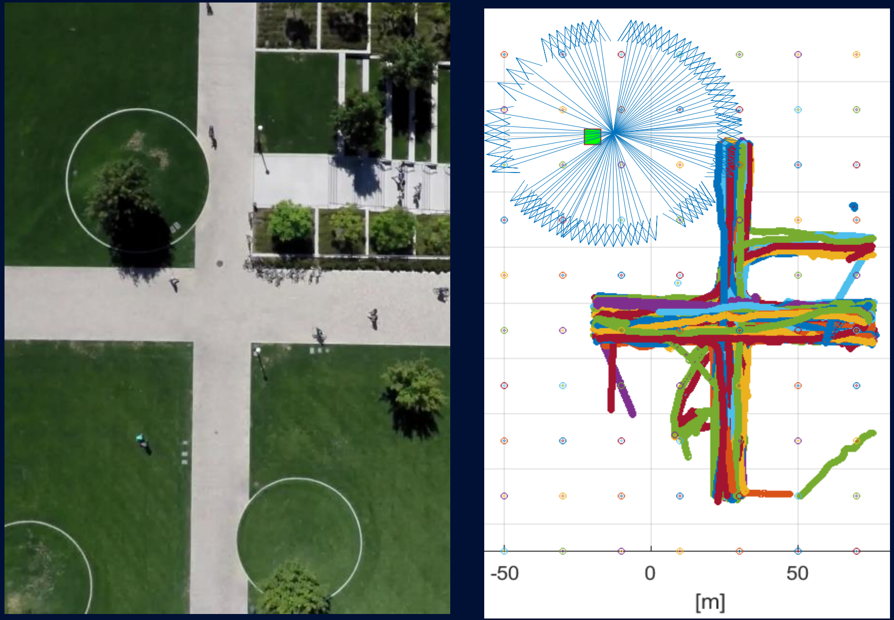
Advanced processing enabled through SoC for maximum mMIMO cost performance

NOKIA Bell Labs

Wireless networks with high IQ and high EQ



Bell Labs highly efficient AI/ML Chip



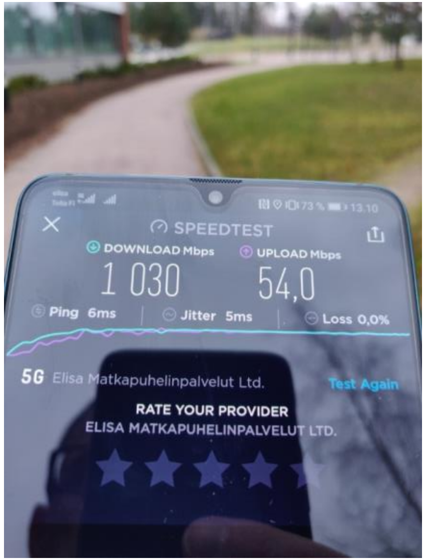
Bell Labs AI/ML algorithms for Radio (e.g. Beam Forming)

NOKIA Bell Labs

A Personal 5G Experience (live Elisa and Telia) in Espoo & Helsinki

Commercial 5G Network and 5G Device

Downlink over 1 Gbps



Latency below 10 ms

Uplink over 100 Mbps

First phase 5G is about better mobile broadband – higher data rates and more capacity

5G Boosts Cell Capacity by 20x

4x More Spectrum and 5x More Spectral Efficiency with New Antenna

LTE-FDD

4G/LTE

- 1800 MHz
- 20 MHz
- 2 bps / Hz
- 40 Mbps cell throughput

Up to 20 x

5G

- 3500 MHz
- 100 MHz[1]
- Up to 10 bps/Hz
- 800 Mbps cell throughput

5G 3500 with massive MIMO beamforming

[1]TDD with 80% downlink

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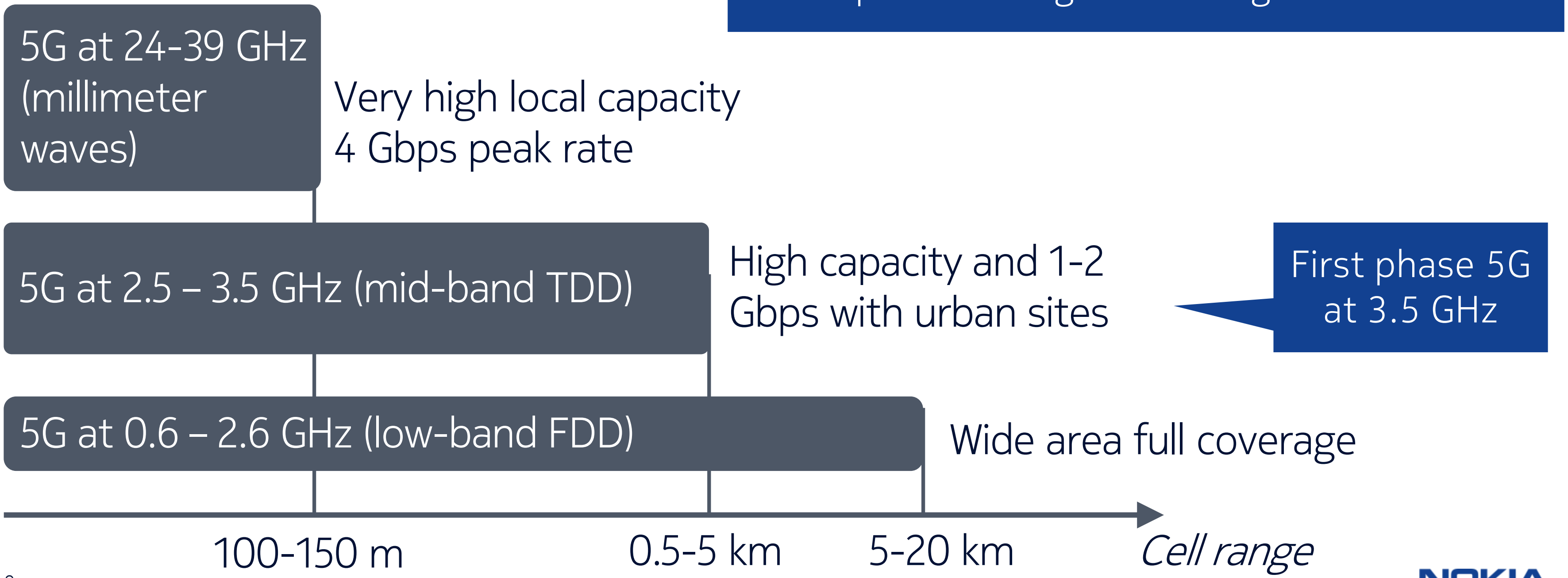
5G Frequencies – Combination of Low and High Bands

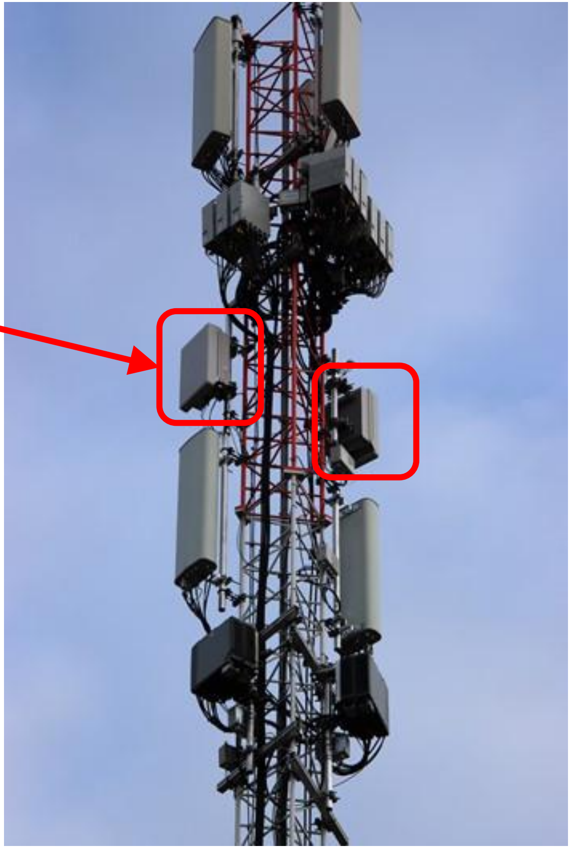
- 5G can use spectrum from 400 MHz to 100 GHz
- High spectrum for high data rate
- Low spectrum for great coverage



Massive MIMO – ”Small in Size, Massive in Performance”

mMIMO antenna
= antenna + RF +
beamforming

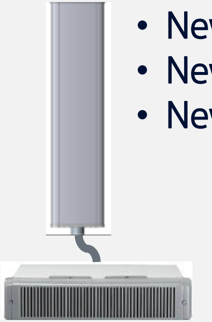
Nokia massive MIMO antenna in Helsinki



mMIMO is simple for installations: no RF cables, just antenna + power cable + fibers.

Dynamic Spectrum Sharing for Fast 5G Rollout on Low Bands

Traditional radio network rollout



- New spectrum
- New antenna
- New RF

LTE

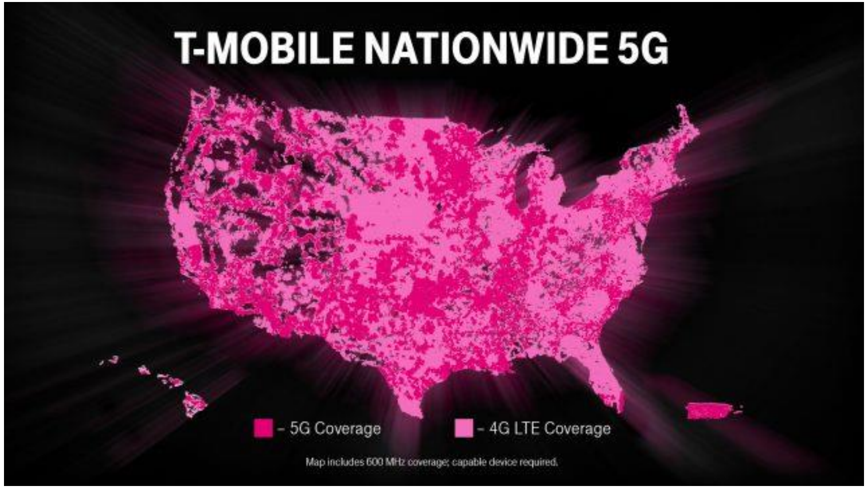
5G

Dynamic spectrum sharing rollout

- Reuse existing spectrum
- Reuse existing antenna
- Reuse existing RF
- Resources shared dynamically between LTE and 5G

LTE+5G

Example Low Band 5G: T-Mobile USA Launched Nationwide December 2019



600 MHz spectrum and RF shared between LTE and 5G

5G Use Cases and Phasing – Broadband Followed by New Services

	5G Phase 1 = Mobile broadband	5G Phase 2 = Critical services
Solution	• 4G core network • Non-standalone (NSA) • Existing base station sites • 3.5 GHz band	• 5G core network • Standalone (SA) • Distributed edge • Low band 5G or mmWave
Benefits	• 5-10x capacity • 5-10x data rate	• Low millisecond latency • High reliability 99.999%

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5G Enables Ultra Reliable Low Latency Communication (URLLC)

Option 1: Public networks with slicing

- Guaranteed quality with slicing
- Slice allows different security levels
- Example cases: public safety, remote control of machinery

09.04.2020 14:00
Elisa chosen as the sole radio network supplier to Finland's new public safety network for 10 years due to quality and coverage

Option 2: Dedicated local network

- Dedicated local network
- Customized security
- Example case: private LTE at Helsinki airport or Rio Tinto mine

Konecranes, Nokia and Ukkoverkot to operate - smart cranes depart on the 5G journey

Expected 5G Device Penetration based on LTE History

LTE

LTE penetration hits 50%

- iPhone5 with LTE September 2012
- Korea Sep 2013
- AUS Dec 2014
- USA March 2015
- UK Dec 2015
- **Finland 2016**

2012	2013	2014	2015	2016

5G

- iPhone with 5G
- 5G penetration hits 50%

2020	2021	2022	2023	2024

5G device penetration will hit 50% in advanced markets during 2022-2024 if we follow LTE history with 8 year difference between 5G and LTE

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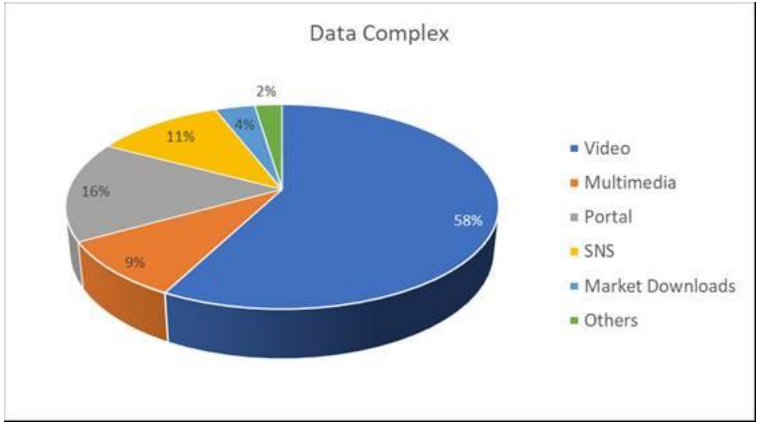
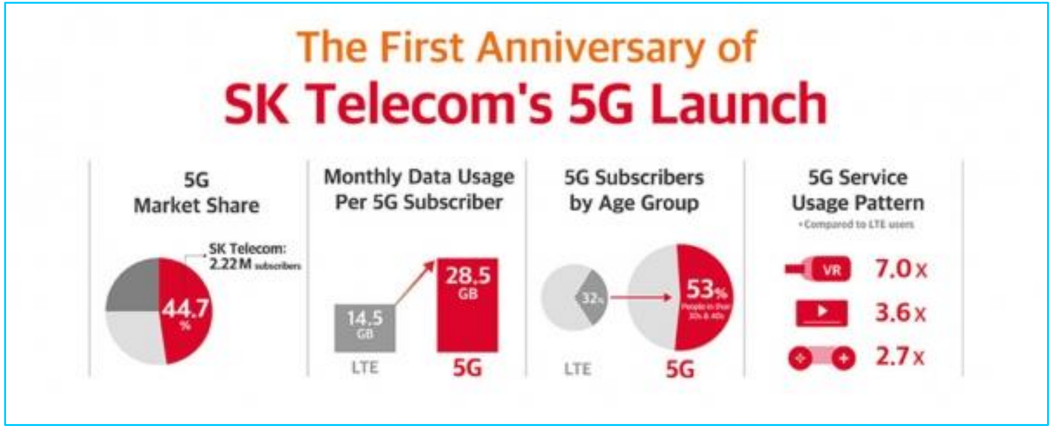
5G Application Usage in Korea





- High quality video
- Multimedia including augmented reality
- Cloud gaming

- Virtual Reality (VR) usage 7x higher than with LTE
- Video usage 3.6x higher
- Gaming usage 2.7x higher
- Data consumption 2x higher

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O-RAN & vRAN

Open-ness and virtualization

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Fusion of two global forces created the mobile internet

Telco

1969 – Bell Labs creates Unix: source code made publicly available

1986 – Open standard organization; home of the Internet protocol suite (TCP/IP)

1998 – Standards organization for mobile telecommunications protocols; 4G LTE was the first global mobile standard

2012- Virtualization of network functions to leverage the scale of cloud infra

2014 - Intersection of mobility and cloud to deliver edge cloud services

2017 – Open source telco automation project from merger of ECOMP and Open-O

2017 – E2E architecture for zero touch network and service management

2018 – Open RAN interfaces, disaggregation and programmability from merger of xRAN & C-RAN

Webscale/IT

1991 – Linux kernel is the foundation for numerous OS and embedded systems: PCs, Android handsets, routers, smart TVs, …

1995 – WWW suite and Web server software powers around 40% of websites around the world

1995 – Relational database management system; SQL = Structured Query Language

2008 – Best selling smartphone operating system

2010 – Cloud computing platform

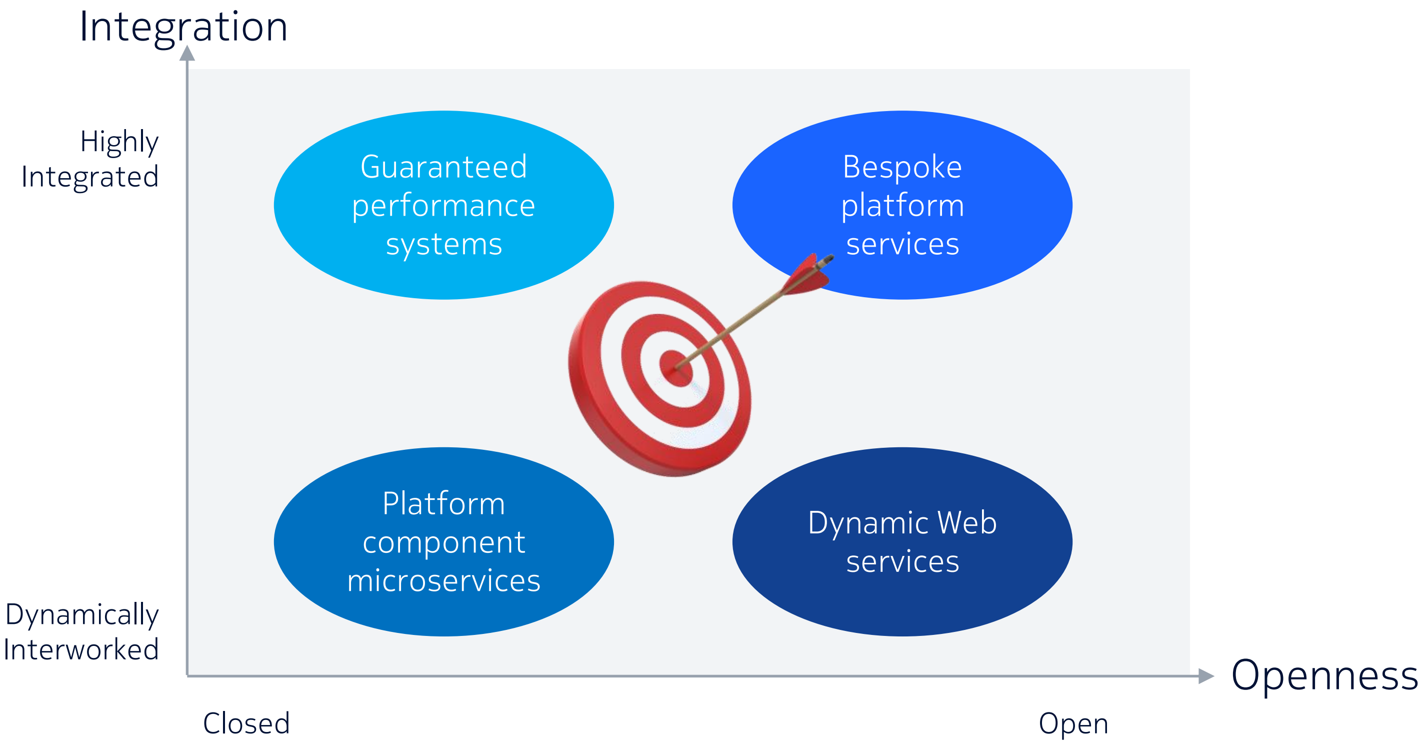
2014 – Container-orchestration system for automating application deployment, scaling, and management

2015 – Symbolic math library used for machine learning applications such as neural networks

Select examples shown only

… driven by openness via open industry standards and open source

Integrated vs Open : Integrated & Open



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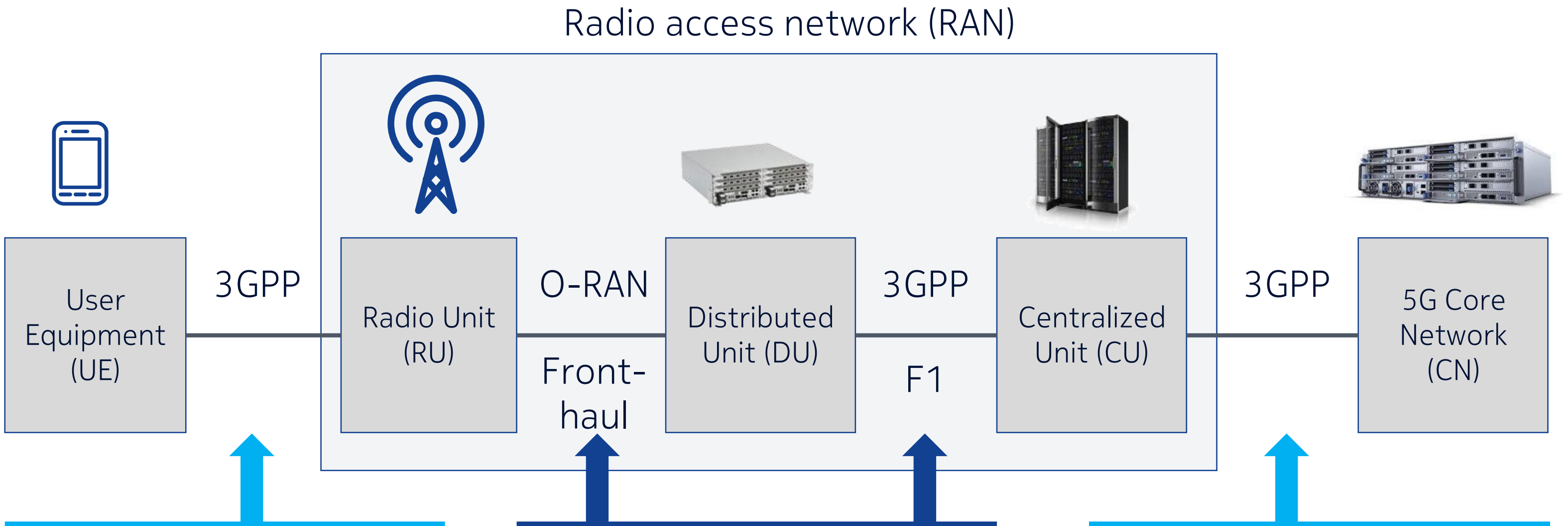
Open Interfaces in Mobile Networks



Open air interface led to the success of mobile networks since GSM times

5G now brings opens interfaces inside radio access network by 3GPP and O-RAN specs

Open interface between radio and core networks has been true in commercial networks

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A Brief History of O-RAN

O-RAN ALLIANCE

140+ contributors

- Launched June 2018
- Merging of the xRAN Forum with the C-RAN Alliance
- O-RAN Alliance announced collaboration with TIP in February 2020
- 9 key working groups led by operators with vendors co-chairing

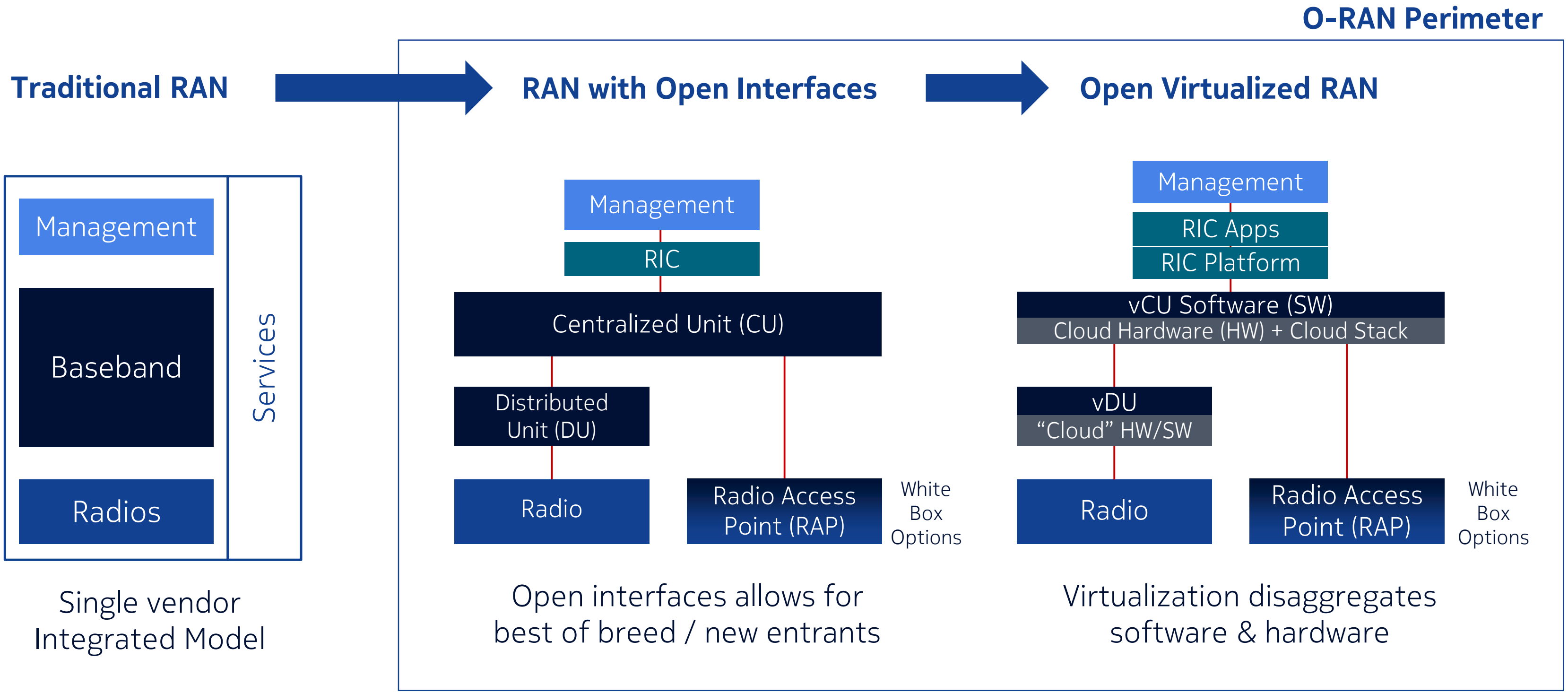
24 operators

Founders

Objectives

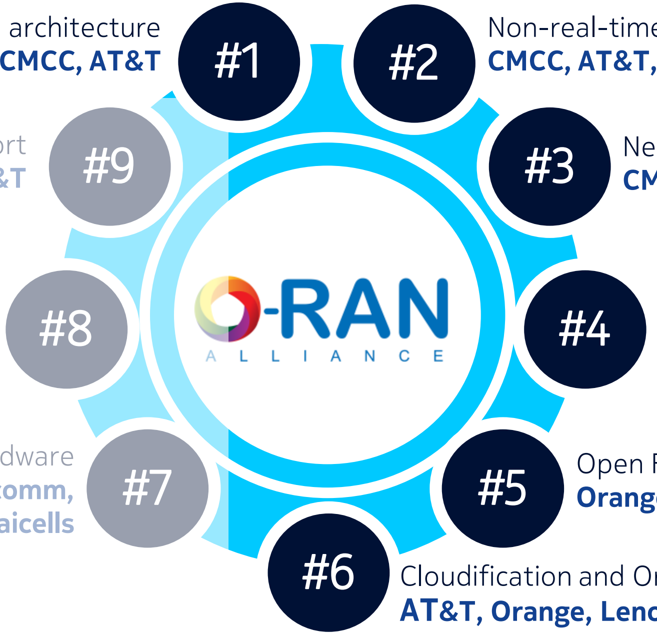
1. Adopt **open RAN interfaces and infrastructure** to allow multi-vendor combinations
2. Achieve **faster time-to-market** and **easier innovation leverage**
3. **Decrease TCO** by increased competition and **white box approach**
4. Rapid and broad industry promotion and adoption of **open standards, interfaces and APIs**
5. **RAN programmability** and service optimization through leverage of AI and Machine Learning

O-RAN disaggregates the whole RAN architecture



RIC = Radio Intelligent Controller

Nokia active in all O-RAN working groups & leading fronthaul & RIC groups



#1 Use cases & overall architecture
CMCC, AT&T

#2 Non-real-time RIC and A1
CMCC, AT&T, Ericsson

#3 Near-real-time RIC and E2
CMCC, DT, Nokia

#4 Open Fronthaul
DoCoMo, Verizon, Nokia

#5 Open F1/W1/E1/X2/Xn
Orange, DoCoMo, Ericsson

#6 Cloudification and Orchestration
AT&T, Orange, Lenovo, Ciena

#7 White-Box hardware
CMCC, AT&T, Qualcomm, Baicells

#8 Stack Reference Design
CMCC, AT&T, Radisys, Intel

#9 Open X-haul Transport
CMCC, AT&T

Nokia active contribution / co-leading

Our priorities

- **Global adoption** of O-RAN with **no market fragmentation**
- **Avoid overlap** with 3GPP and ONAP
- Continued progress and consolidation of **Fronthaul specification**
- **RAN Intelligent Controller**

  Public

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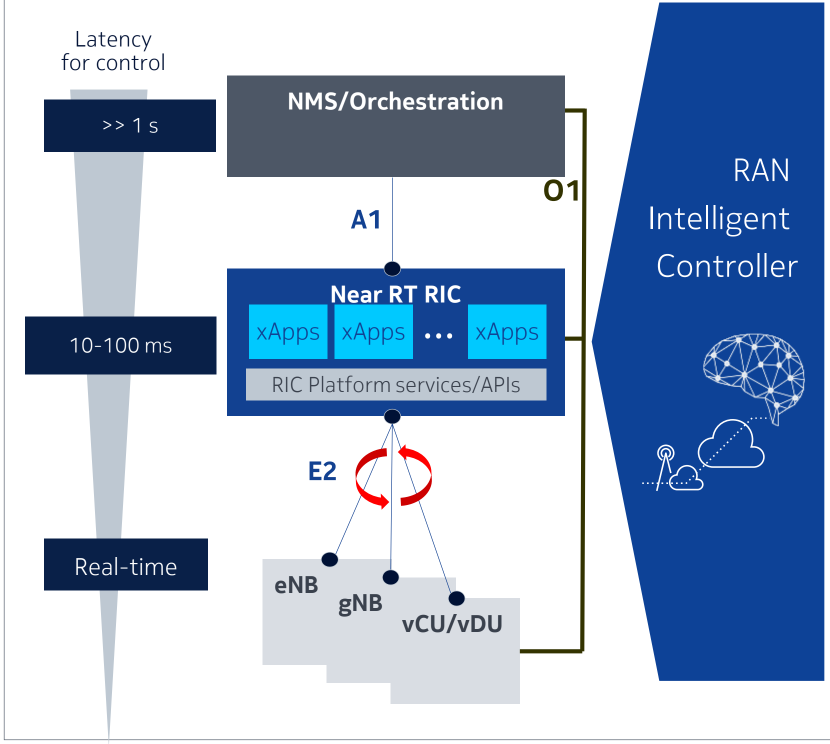
Deeper dive: RAN Intelligent Controller (RIC)



Use cases	
Network intelligence	Policy Enforcement
	Handover Optimisation
Resource assurance	Radio-Link Management
	Advanced SON
Resource control	Load Balancing
	Slicing Policy

- AI/ML for programmability
- Platform based on Open Source from O-RAN Software Community
- Services provided by xApps

- A1: Declarative policy
- E2: RAN optimization
- O1: Data collection and Control

- RAN optimization and automation from **AI/ML**
- Fast **closed loop** to deliver **real-time SON** benefits
- Leverage **AI/ML Cloud capabilities**
- Supports LTE and 5G, **Classical RAN and vRAN**
- Open API towards **3rd party Applications** (xApp) which need to be integrated with the RAN

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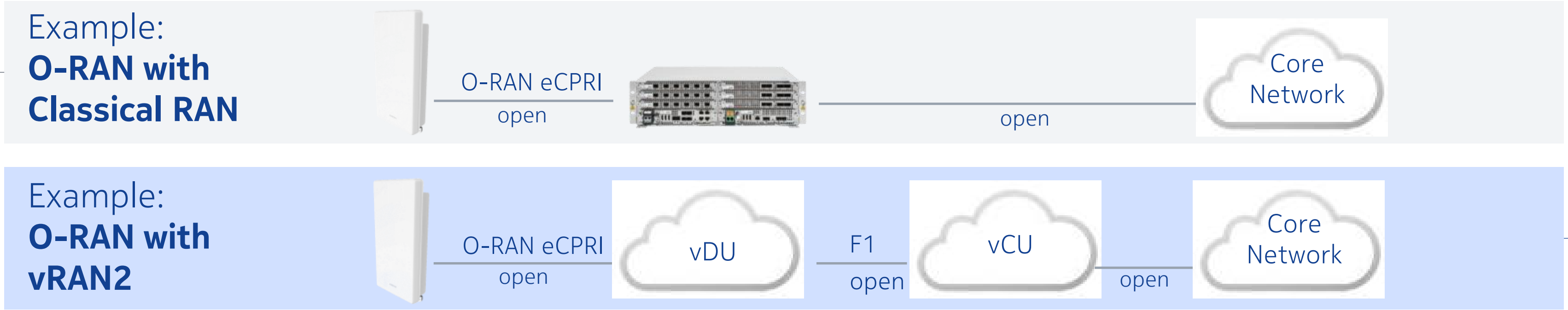
3 What about vRAN? O-RAN and vRAN are inter-related but separable



O-RAN

- “Horizontal openness”
- Open interfaces between network elements allowing for multi-vendor
- can be applied to Classical RAN and vRAN

Front-haul	Mid-haul	MANO / other
eCPRI	F1 (vRAN)	E2, O1, X2

Application
vDU, vCU

Virtualization
OpenStack

Hardware
DataCenter x86

vRAN

- “Vertical openness”
- Targets the separation of baseband hardware and software
- does not require multi-vendor

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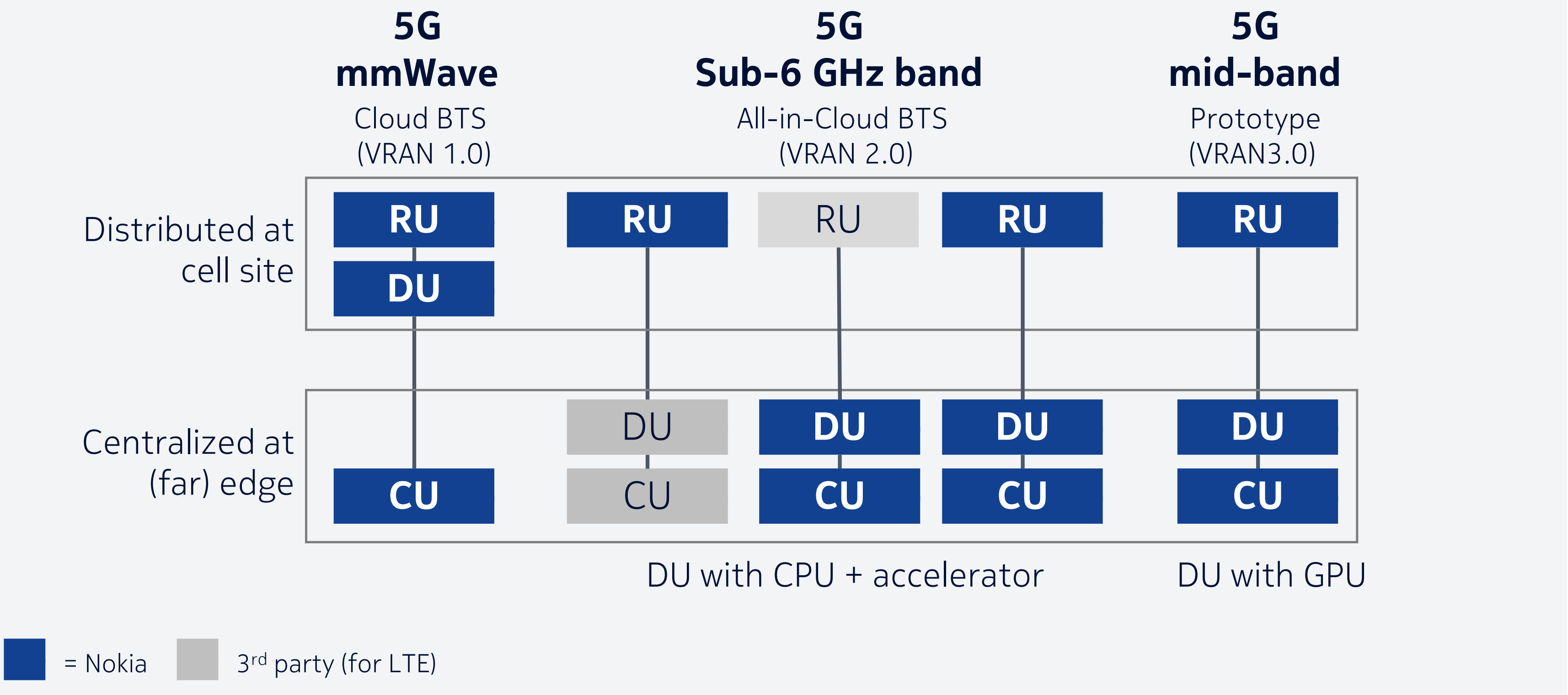
3 Our experience with Open RAN and Virtual RAN architecture



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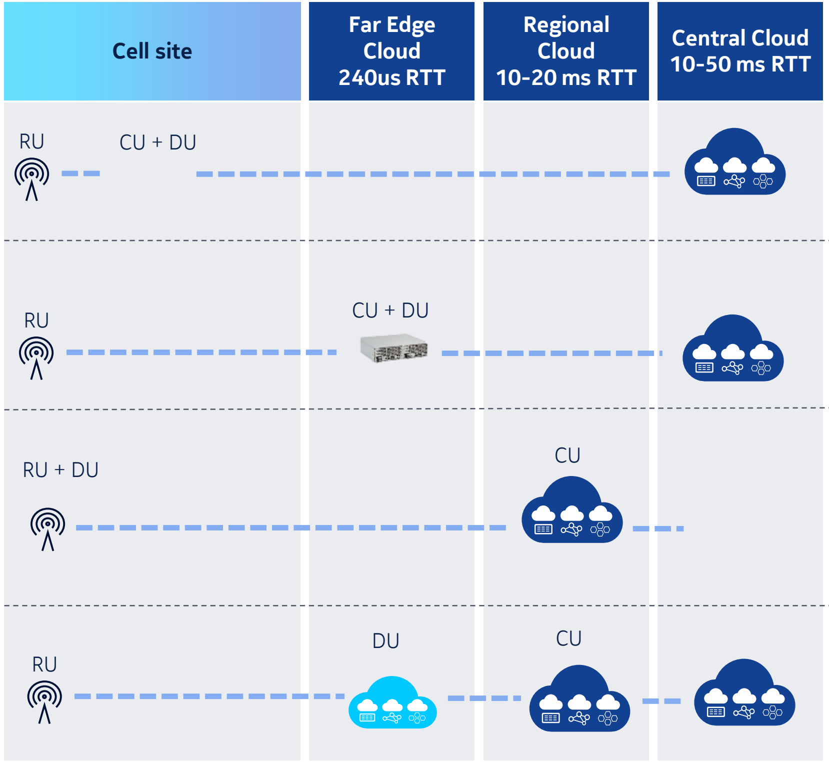
3 vRAN disaggregation: different options with fiber availability & latency and pooling gains



Classic Distributed: RU, DU and CU at cell site
- Typical classical, distributed deployment
- Fiber needed at cell site only

Classic Centralized: CU and DU at far edge site
- Fiber needed from cell site to far edge site
- Classical C-RAN or “baseband hotel” configuration
- Baseband pooling benefits

vRAN 1.0: RU and DU co-located or integrated; vCU
- E.g. mmWave RAP (Radio Access Point) case where DU is integrated with RU
- Flexible Ethernet transport from cell site to regional Cloud site
- Baseband pooling benefits

vRAN 2.0: RU, vDU and vCU disaggregated
- Fiber needed from cell site to far edge site
- Baseband pooling benefits

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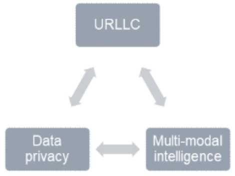
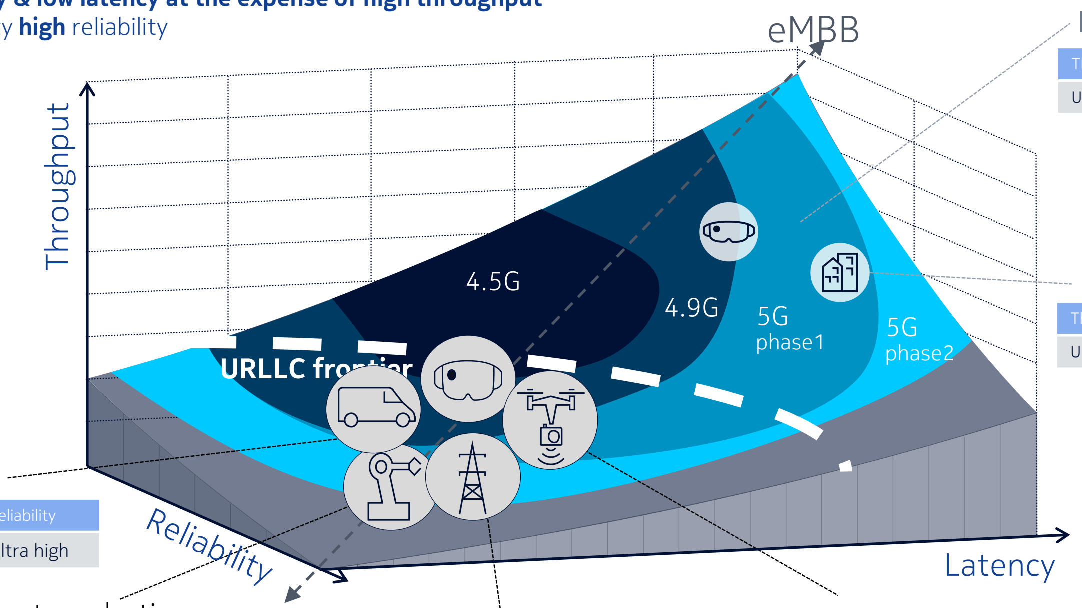
Pushing the network to new frontiers

Evolution of throughput, reliability and latency



Reliability & latency have an inverse relationship with throughput
Can choose high reliability & low latency at the expense of high throughput
e.g. Low bitrate **low** latency **high** reliability



Immersive 360

Throughput	Network Latency	Reliability
UL: U-high/ DL: high	50 – 100 ms	Medium

FWA

Throughput	Network Latency	Reliability
U-high	15 - 200 ms	Low

V2X, intelligent transport [3]

Throughput	Network Latency	Reliability
Low - Medium	3 - 25 ms	Ultra high

Industry robotics and automation [2]

Throughput	Network Latency	Reliability
Low	1 - 50 ms	Ultra high

Electricity distribution [1]

Throughput	Network Latency	Reliability
Low	5 ms	Ultra high

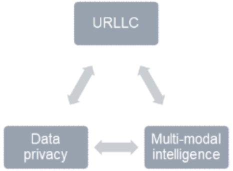
Mobile Tele-Operation
(Vehicle and drone)

Throughput	Network Latency	Reliability
Low-Medium	10 - 100 ms	Ultra high

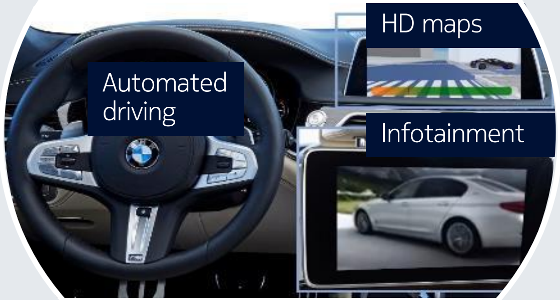
1. TS 22.261 Service requirements for the 5G system
2. TS 22.104 Service requirements for cyber-physical control applications in vertical domains
3 TS 22.186 Enhancement of 3GPP support for V2X scenario

The opportunity is materializing

Nokia is actively piloting 5G far edge use cases



5G V2X connectivity



BMW GROUP

Different automotive and public safety slices running over the same network

5G industrial automation

BOSCH Invented for life

Coupling advanced interactive robots with wireless perimeter intrusion detection

Electricity grid · Harbor automation

ABB · CARGOTEC

Nokia, ABB & Kalmar successfully conducted industry's first trial with URLLC for smart electricity grid & harbor automation in Nov 2018

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Summary O-RAN & vRAN: Opportunities & challenges

Open dimension	Opportunity	Challenge
Front-haul interface	• Low-cost, low complexity radios enabled by diverse eco-system • System integrators can optimize performance management	• Multi-vendor conformance. • Performance management responsibility. • Achieving peak performance
vRAN architecture	• Alignment between webscale providers and operators will drive edge cloud build-out creating significant new innovation • Common accelerator definition leads to diverse ecosystem and uniform architecture for RAN	• Agreement regarding platform management strategy • Alignment on accelerator architecture definition across IT providers, operators, vendors • Portability of SW code cross HW accelerators
RAN Intelligent Controller	• Allows new value creation via RANetwork Platform • Creation of new ecosystem of performance centric partners via open 'xAPP' development	• New platforms could create conflict in parameter and policy choices for common use cases • Additional complexity in the network
Automation and Orchestration	• Alignment on interface definitions allows third parties to enable rapid service launch	• Disaggregated radio access networks can create challenges for centralized orchestration to manage

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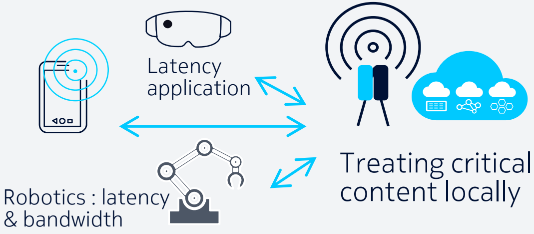
Summary: The potential of O-RAN, vRAN, Edge & E2E

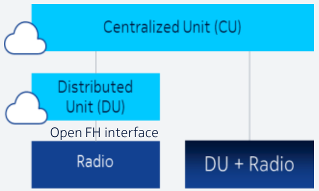
RAN Cloudification

Applications and Services @ Edge



Network Slicing

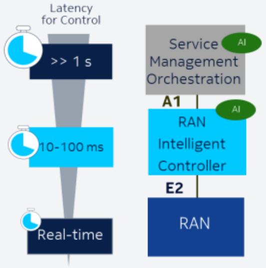
Decomposed RAN Architecture



SW flexibility for fast Innovation leveraging open environment

Open de-composed modular architecture

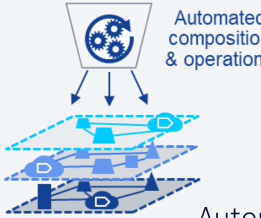
Intelligence with RIC



Open API and AI/ML for RAN programmability at the edge

Intelligent, Flexible Resource optimization

Management & Automation



Zero touch and self-optimizing network through Open API into Analytics

Automated operations and cloud agility

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What's next?

Next big things in wireless

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Next Steps in 3GPP Standards: Release 16 and 17 summary
- Addressing both broadband enhancements and ecosystem expansion

5G
Release 15

Extreme mobile broadband

Broadband enhancement

- Wider market reach with full diversity of user devices
- Natively supporting future manufacturing and industrial control

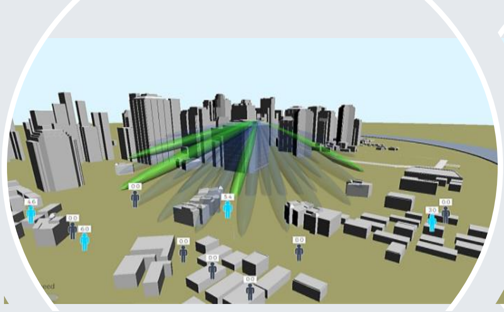
Ecosystem expansion

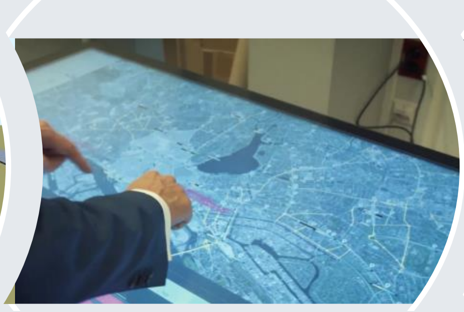
- New deployment capabilities for CSPs and intelligent automation
- Extensions to new verticals

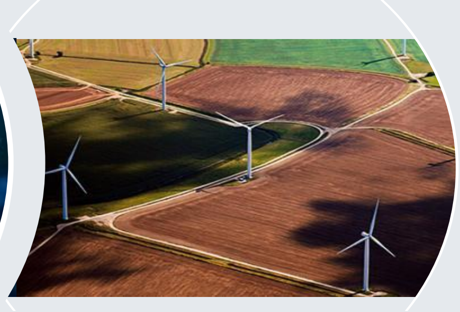
Examples: Ultra reliable communication, Time Sensitive Networks (TSN), private networks, unlicensed band 5G (5 GHz), NR-light, device-to-device, multicast, non-terrestrial networks, railway communication, in-band backhauling, extension to 71 GHz, device power savings, enhanced MIMO, cloud gaming,

Nokia's Next Big Things (NBT) for Radio Network

2020 – 2025







Hyper-efficient radio for extreme spectrum utilization 1

Hyper-flexible network for new business models and architectures 2

Hyper-intelligence with Artificial Intelligence and Machine Learning 3

Hyper-energy efficiency for zero emission by energy efficiency 4

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1. Hyper-efficient radio for extreme spectrum utilization

Extreme massive MIMO

All bands

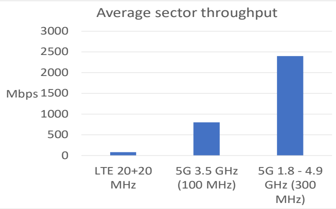
Massive MIMO antenna for all bands 1800 – 4900 MHz

2-10x

Massive MIMO Antenna capabilities will be boosted compare to 1st generation products

Advance Algorithms

- Eigen based beamforming
- Zero forcing
- Distributed MIMO
- Receiver algorithms for 3x uplink efficiency / capacity

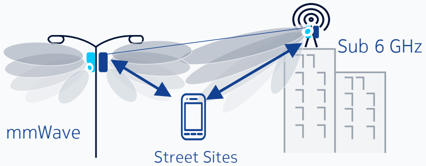


Up-to 30x

capacity with 5G on existing sites (with dual band RRH) compared to LTE

mmWave integration with sub 6 GHz bands

- Carrier aggregation
- Dual connectivity
- Co-sited and new cell sites

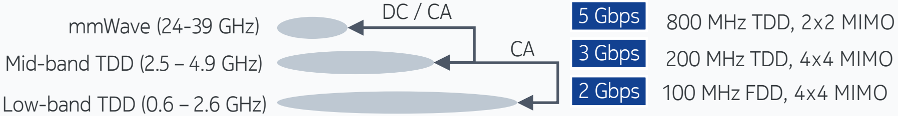


Spectrum aggregation with sub-6 GHz bands

- All bands together
- 5G carrier aggregation
- LTE dual connectivity

Peak rate 5 Gbps

Multiband Integration for Dual Connectivity and Carrier Aggregation

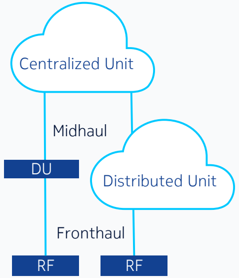


10 Gbps combined data rate

2. Hyper-flexible network for new business models and architectures

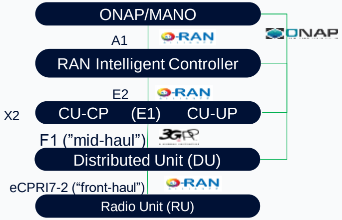
Cloud RAN Architecture

RAN virtualization brings architectural flexible to maximize performance in baseband



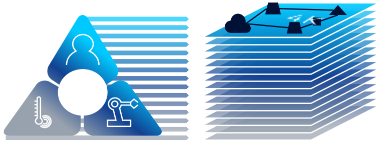
ORAN compliance

Open ecosystem for multivendor support



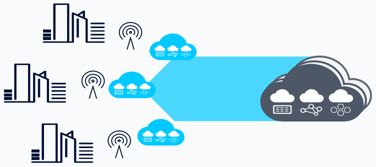
Network Slicing

E2E automated slicing to isolate business services and dynamically evolve as per SLA.



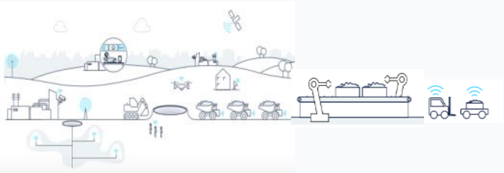
Edge Computing

Edge DC for distributed processing of low latency edge application



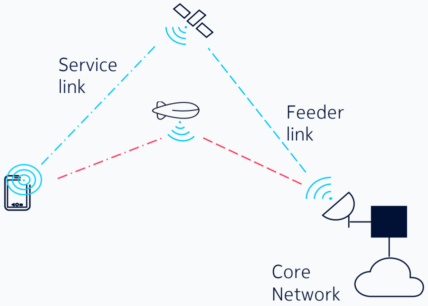
Industry 4.0 and remote control

Critical use cases with 5G supporting ultra reliable, low latency and Time Sensitive Network (TSN) for enterprise verticals



Non-terrestrial networks

To provide global coverage with NR service in area's without terrestrial coverage such as targets service to planes, ships, disaster areas, etc.



3. Hyper-intelligence with Artificial Intelligence and Machine Learning (AI/ML)

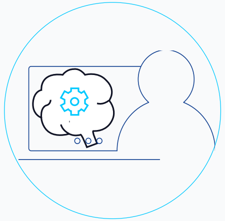
AI/ML solutions required at all levels in the mobile networks to

⇧ Performance, Automation, Customization

⇩ Complexity

Centralized SON
>15min

non-real time predictive optimization



- Remedy modules orchestrator
- Sleeping Cell Prediction
- Cell Outage Prediction
- Cognitive SON Framework
- Predictive Load balancing
- Beamforming Optimization

Edge Computing
>1s

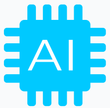
RAN Intelligent Controller based near-real time network optimization

- Advanced Traffic Steering
- Cell Anomaly Detection
- Interference detection
- Beamforming Optimization

Embedded in RAN
>10us

Radio & Cell level radio performance optimization

- DL multi-user pairing mMIMO scheduler
- Power saving
- CA Secondary cell selection

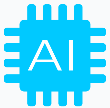


L2 acceleration

Low layer in radio HW
<10 us

for RF and layer-1 optimization

- RF Power Amplifier linearization
- Receiver optimization algorithms



L1/DFE acceleration

   NOKIA

4. Hyper-energy efficiency for zero emission by energy efficiency

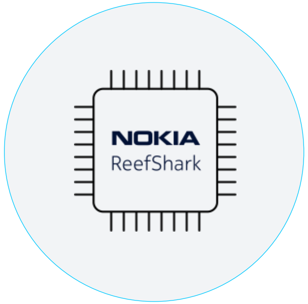
Nokia influencing the 5G standard to enable

5x **Spectral efficiency** with beamforming antennas

5x **Power saving features** to minimize energy usage

5-40x **Bandwidth capacity per cell** using wider bandwidth

Nokia ReefShark SoC technology



40-60%

Power consumption reduction of the digital processing efficiency with **Nokia ReefShark SoC**

Nokia's energy efficiency innovations

Intelligent software for **Zero users – Zero power** consumption

Up-to 70%

Power reduced with **Load Based Massive MIMO Adaptation**

Up-to 66%

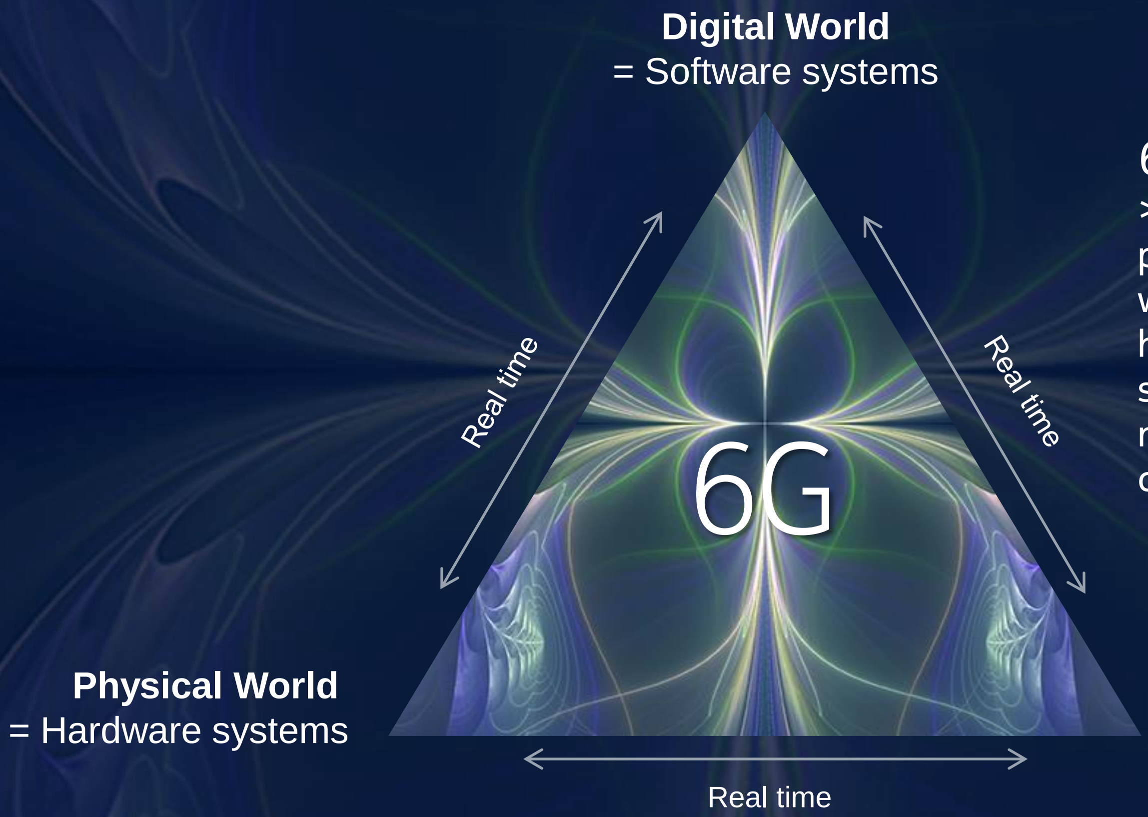
base station energy reduction with **Liquid cooling solution**

NOKIA

And here we are – all things come to an end.

- 5G is here now. It arrived a little early.
- Focus on innovation shifts to creating a more diverse ecosystem of suppliers through O-RAN and with virtualized RAN as an enabling technology.
- Wireless innovation for 5G will focus on enabling automation and intelligent operation with even higher levels of integration.
- 6G is coming?

The enabling foundation for the future … need to unparalled connectivity



6G
>> 5G
physical world and the digital worlds deeply intertwined
human biological systems seamlessly coupled
new human sensory and cognitive dimension

NOKIA

NOKIA

Thank you!

Questions?