Bring 5G into Reality

IEEE ICC 2018

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Huawei Technologies Co. Ltd.

5G Industry Insight

Use Cases

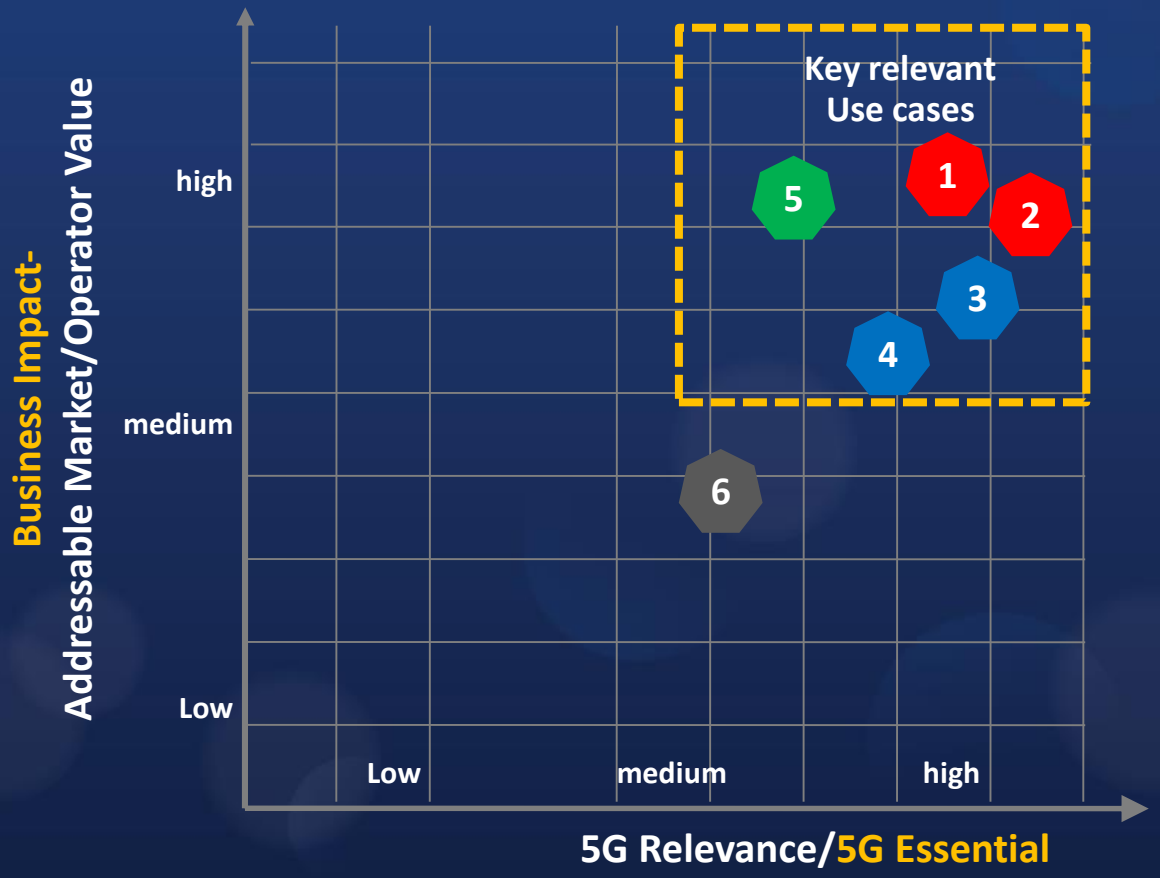
Standard

Spectrum

Huawei 5G Update

5G Use Cases Evaluation & Prioritization

Use Case Evaluation



Use Case Example

1. UHD/3D/Holo… Video
2. AR/VR
3. Connected Vehicle
4. Smart Manufacturing
5. Fixed Wireless Access
6. Delivery Drone

Source: Huawei wireless X Labs

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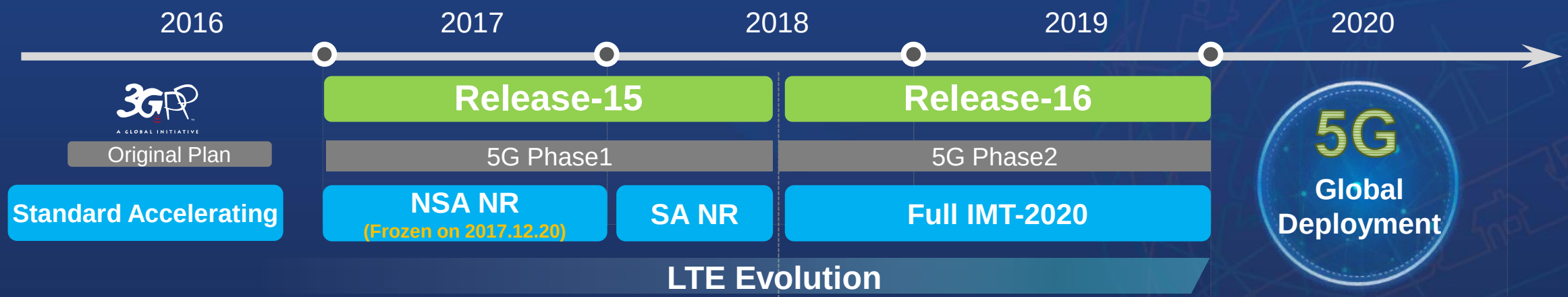
3GPP Accelerating 5G New Radio Standards

---R15 Establishes 5G Foundation, R16 for Full IMT-2020



Satisfy eMBB Universal Demands

NR Framework
- Waveform & Channel Coding
- Frame Structure, Numerology
- Native MIMO
- Flexible Duplex

Architecture
- UL&DL Decoupling
- CU-DU Split
- NSA / SA

Others
- uRLLC

Focus on IoT Diversified Requirements

NR Improvement
- New Multiple Access;
- eMBB Sub6G Enhancement
- Self-Backhaul
- Vertical Digitalization

uRLLC Enhancement
- mMTC
- D2D
- V2X
- Unlicensed

R15 Establishes 5G Foundation, R16 for Full IMT-2020 Scenarios

Experience Enhancement
- Short TTI
- NB-IoT Enhancement
- WTTx Enhancement

Architecture
- LTE/NR DC
- LTE CU/DU Split (SI)
- FeCoMP (Non-Coherent JT)

Experience Enhancement
- MIMO Enhancement
- Mobility Enhancement
- Zero Interruption

Architecture
- NG Core Support
- LTE CU/DU Split(WI)

Vertical Industry
- NB-IoT/eMTC Compatible
- Aerial Vehicles over LTE (WI)

LTE Evolution for All Service Bearer Network

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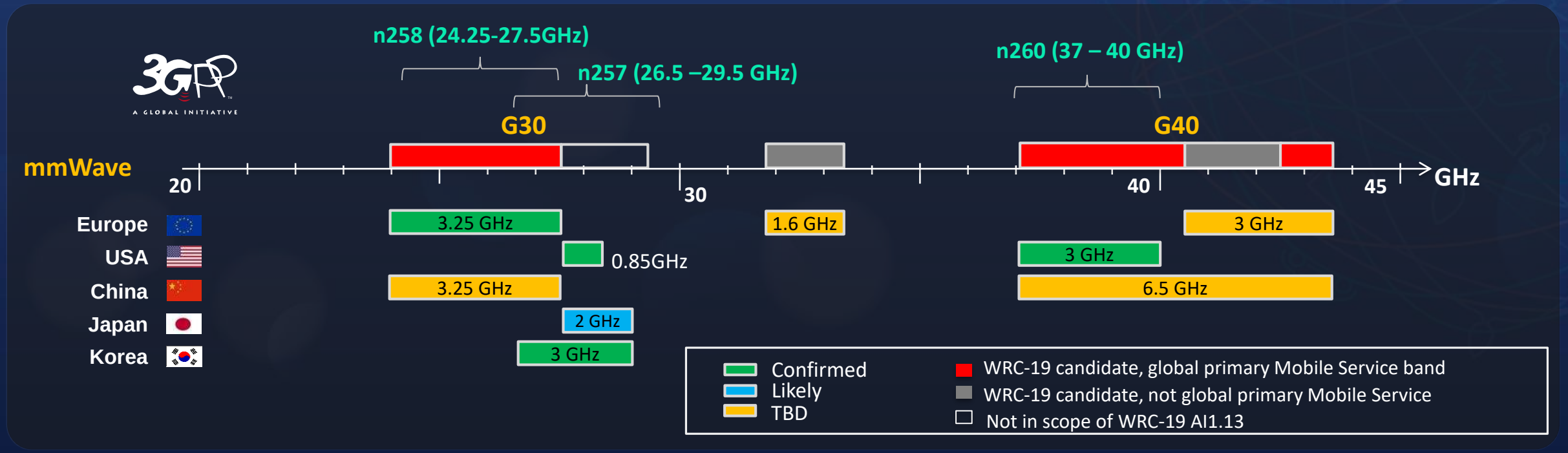
C-band/G30/G40 Potentially Global Harmonized as New Bands



3GPP-Based 5G Pre-Commercial Network in Leading Cities

10+

3GPP-Based
5G Pre-Commercial Network

Toronto, Canada

London, UK

Berlin, Germany

Tokyo, Japan

Dubai, UAE

Seoul, Korea

Milan, Italy

Shanghai, China

Beijing, China

...

30+

Leading Operators

T-Mobile · docomo · TELUS · SoftBank · МегаФон · Singtel · ...

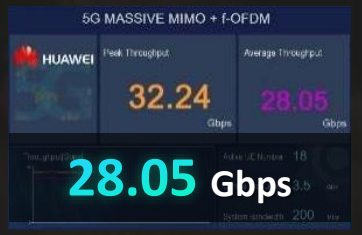
vodafone · 中国移动 China Mobile · LG U+ · BT · TIM · Telefónica · TeliaSonera

Huawei Leads IMT-2020 5G Trial

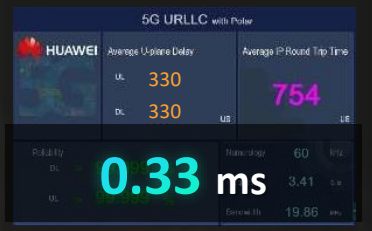
Most Complete
E2E System

Most Comprehensive
Spectrum

Highest
Cell Throughput



Lowest
Latency



Massive
Connections

Most Comprehensive
Interoperability Test

MEDIATEK SPREADTRUM · HUAWEI · ROHDE&SCHWARZ · KEYSIGHT TECHNOLOGIES · 大唐联仪 · StarPoint

Chipset | Instruments

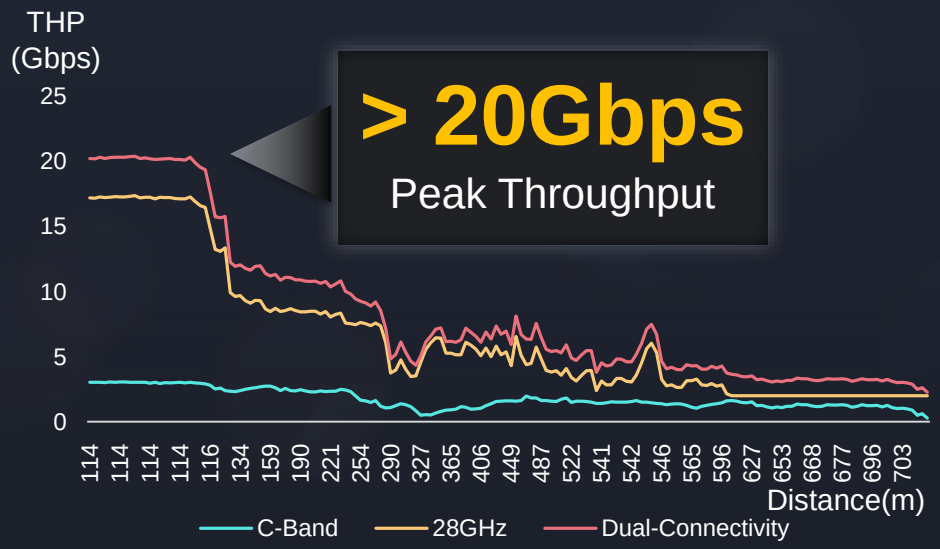
Live Use Cases
to verify NR capability

4k Video

Connected Car

World's 1st mmWave CPE & Dual-Connectivity Field Trial

Sep 2017, 3.5GHz & 28GHz Dual-Connectivity Trial



> 20Gbps
Peak Throughput

Oct 2017, World's First mmWave CPE Trial

5G E2E System | IPTV over 5G

> 2Gbps User Throughput

5G mmWave FWA Service Launched in Vancouver

World's First 5G uRLLC Field Trial

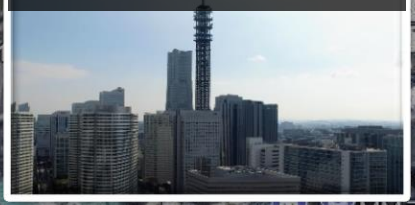
Yokohama, Japan
Nov, 2017

LOS Scenario
Distance >1000m

Mobility Scenario
Distance>600m

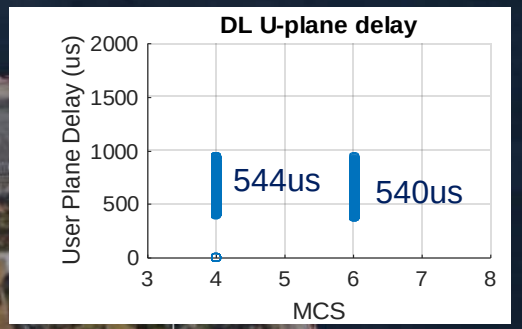
NLOS Scenario
Distance>500m

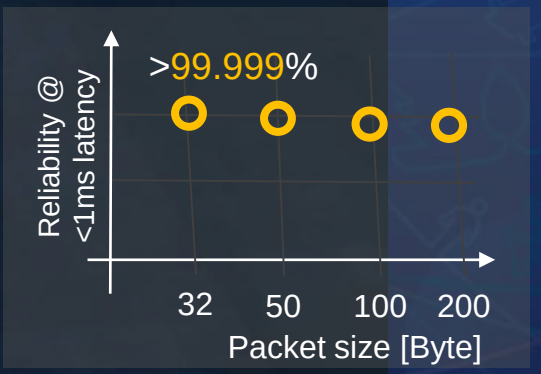
BS



4.5GHz	0.25ms TTI	Grant free
20MHz BW (200MHz total)	Polar code	HARQ

Packet Size: 32/50/100/200 bytes

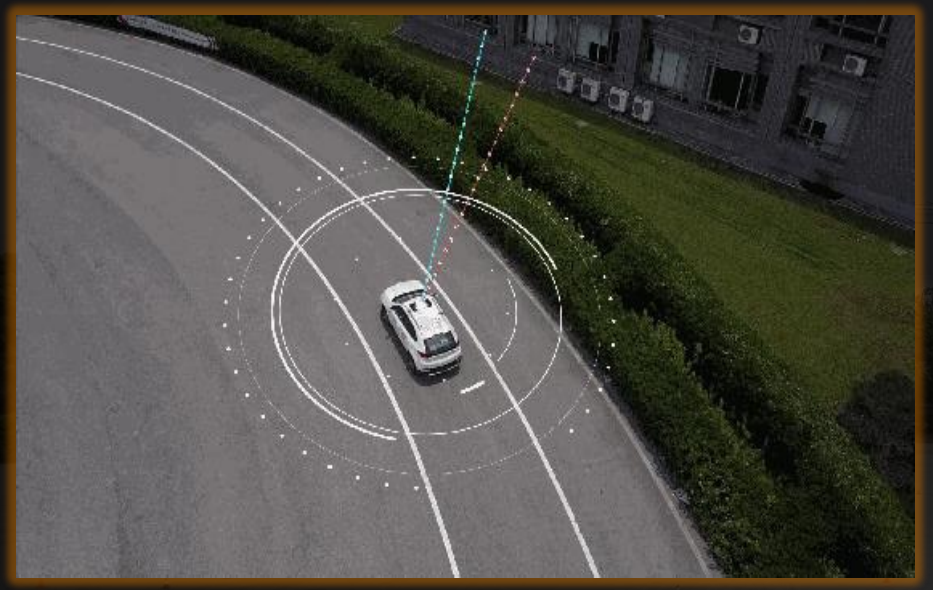




< 1ms
Latency

> 99.999%
Reliability

5G NR Based Tele-operated Driving(ToD) Trial



10ms
E2E Latency
0.12m Break Distance

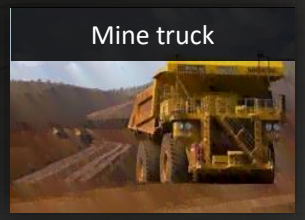
50Mbps
For HD FoV Uploading

UL Live Video

DL Remote Control

Transmission

Application Scenario



Car & Cameras

52.3 km

Remote Control

5G Challenges and Beyond

Architecture

eMBB Capacity

eMBB Coverage

URLLC

mMTC

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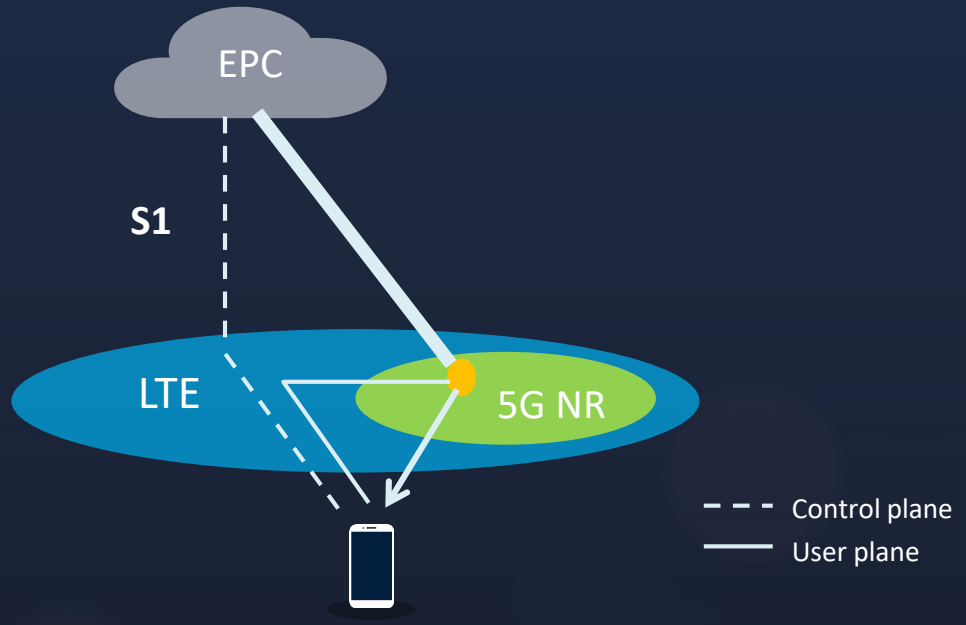
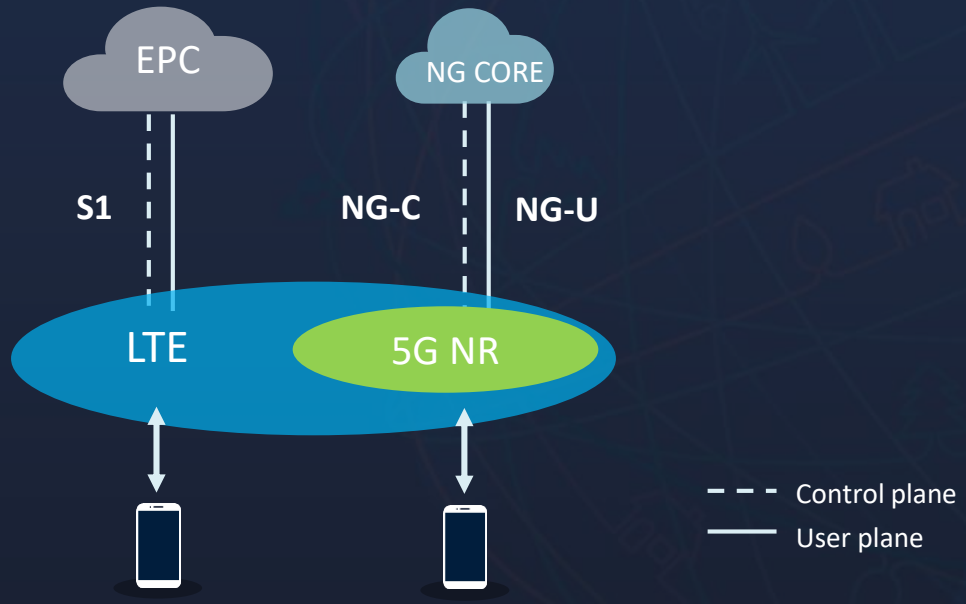
RAN Evolution Path: NSA & SA Both Share the Same Ecosystem

NSA (Non Standalone)



- Focus on eMBB
- LTE as anchor, reuse current EPC, 5G NR quick introduction
- Less requirement for 5G NR coverage

SA (Standalone)

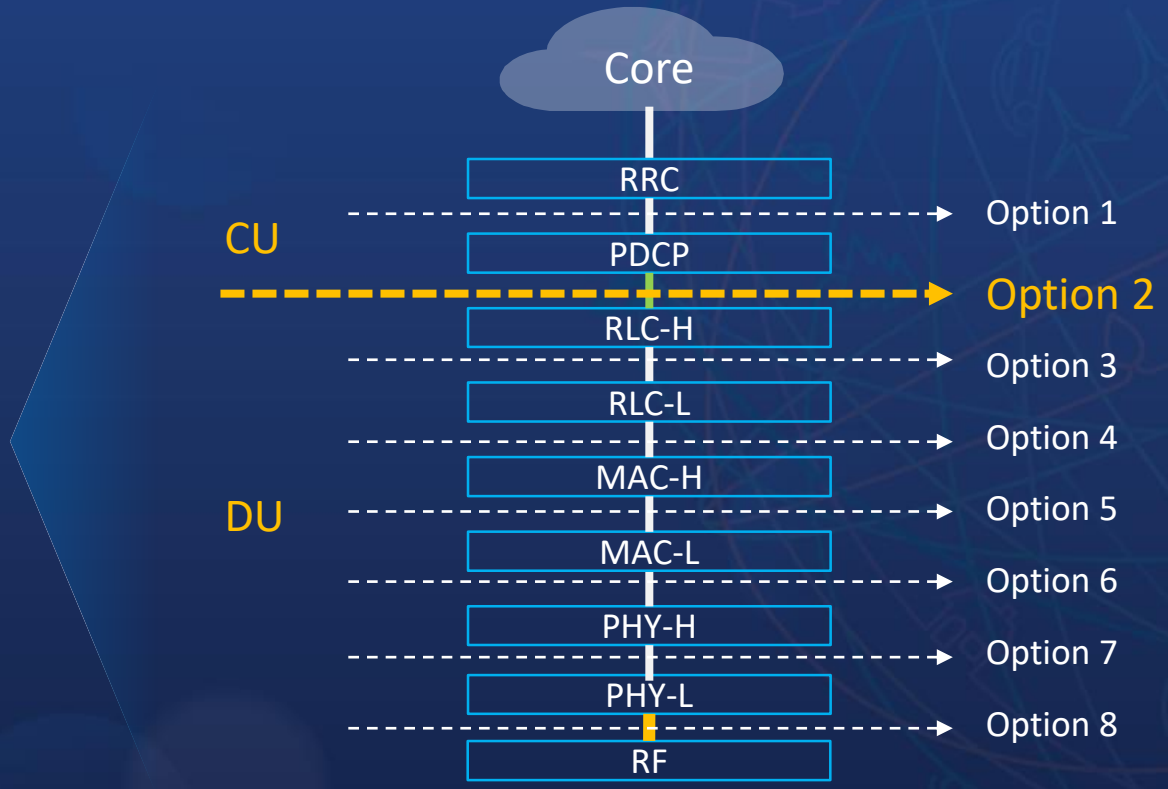


- eMBB/uRLLC/mMTC and network slicing
- New Core **required**
- **High requirement for 5G NR coverage**

CU-DU Split Architecture Defined by 3GPP

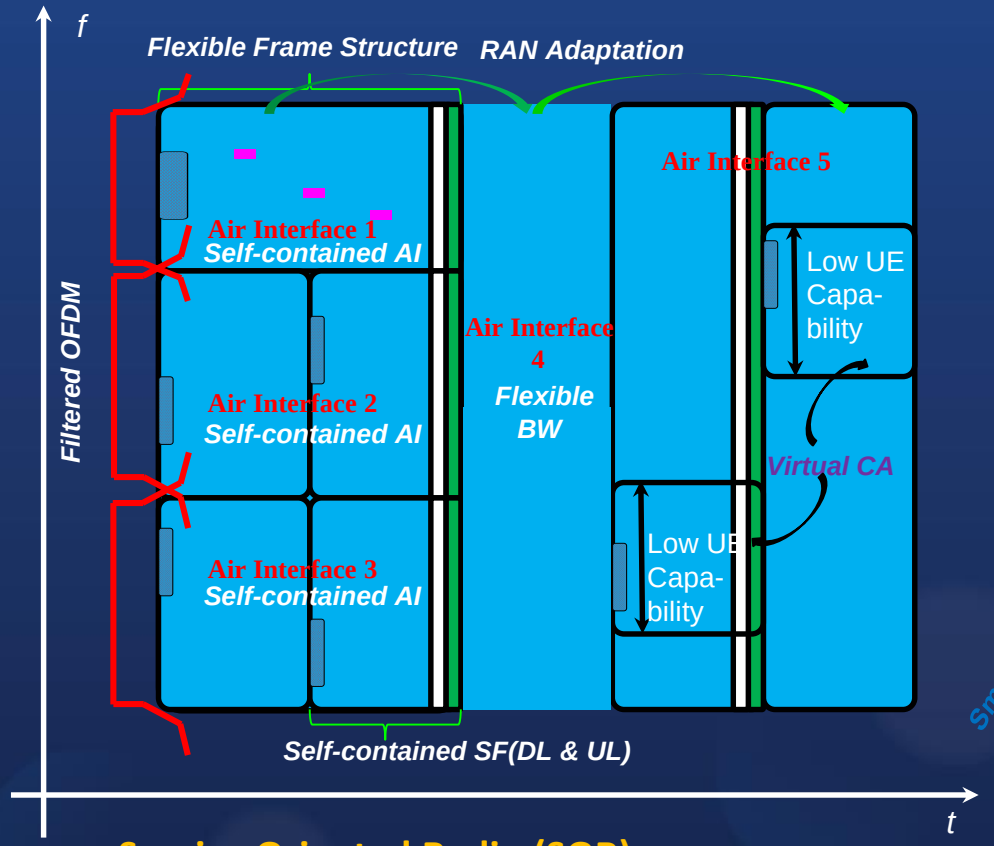
3GPP TSG-WG3 Meeting #95-bis

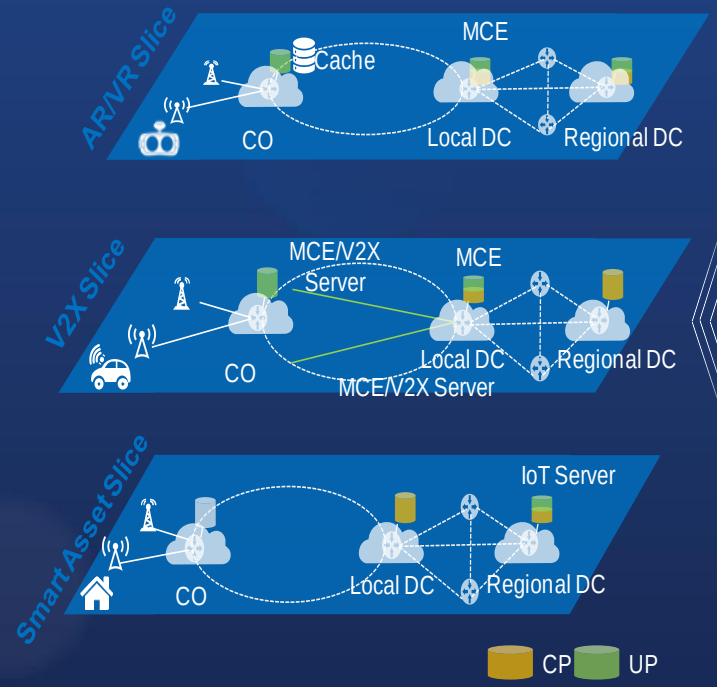
Spokane, USA, 3-7 Apr 2017.

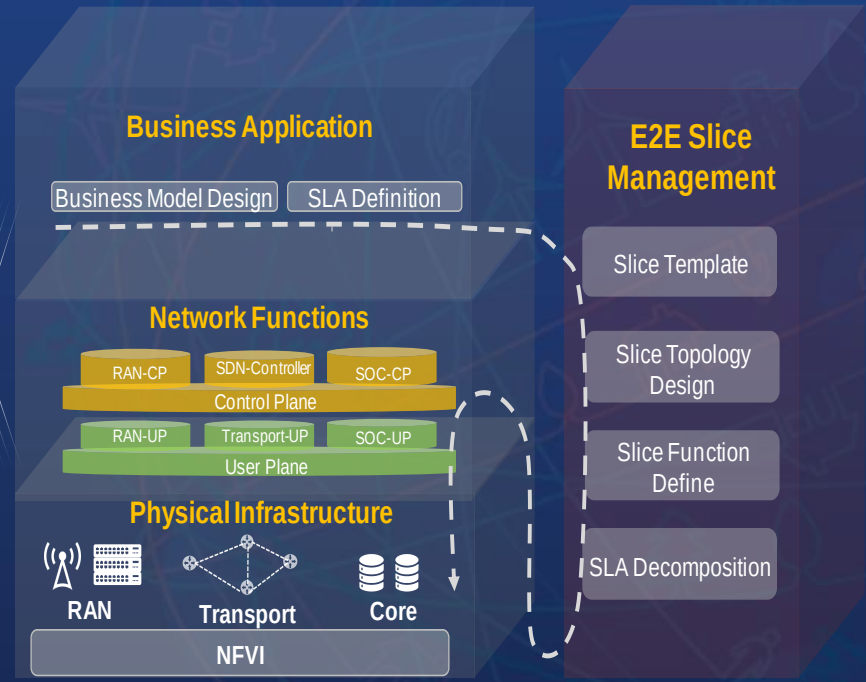


RAN3 has decided to select Option 2 (based on centralised PDCP/RRC and distributed RLC/MAC/PHY) for normative work in Release 15.

Service Oriented Radio and Cloud-Native Architecture

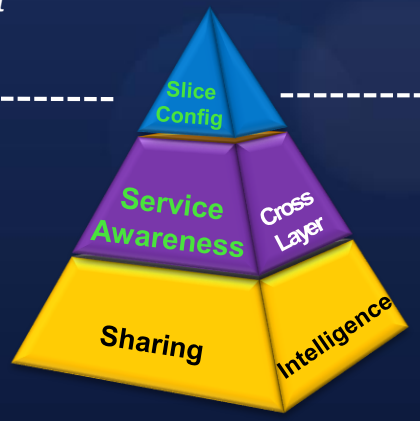






Service Oriented Radio (SOR)

5G Air Interface



Cloud-Native Architecture for E2E slicing

5G Architecture

"5G-Beyond"with service awareness and sharing?

e.g. "Video" RAN Slice w/ cross layer?

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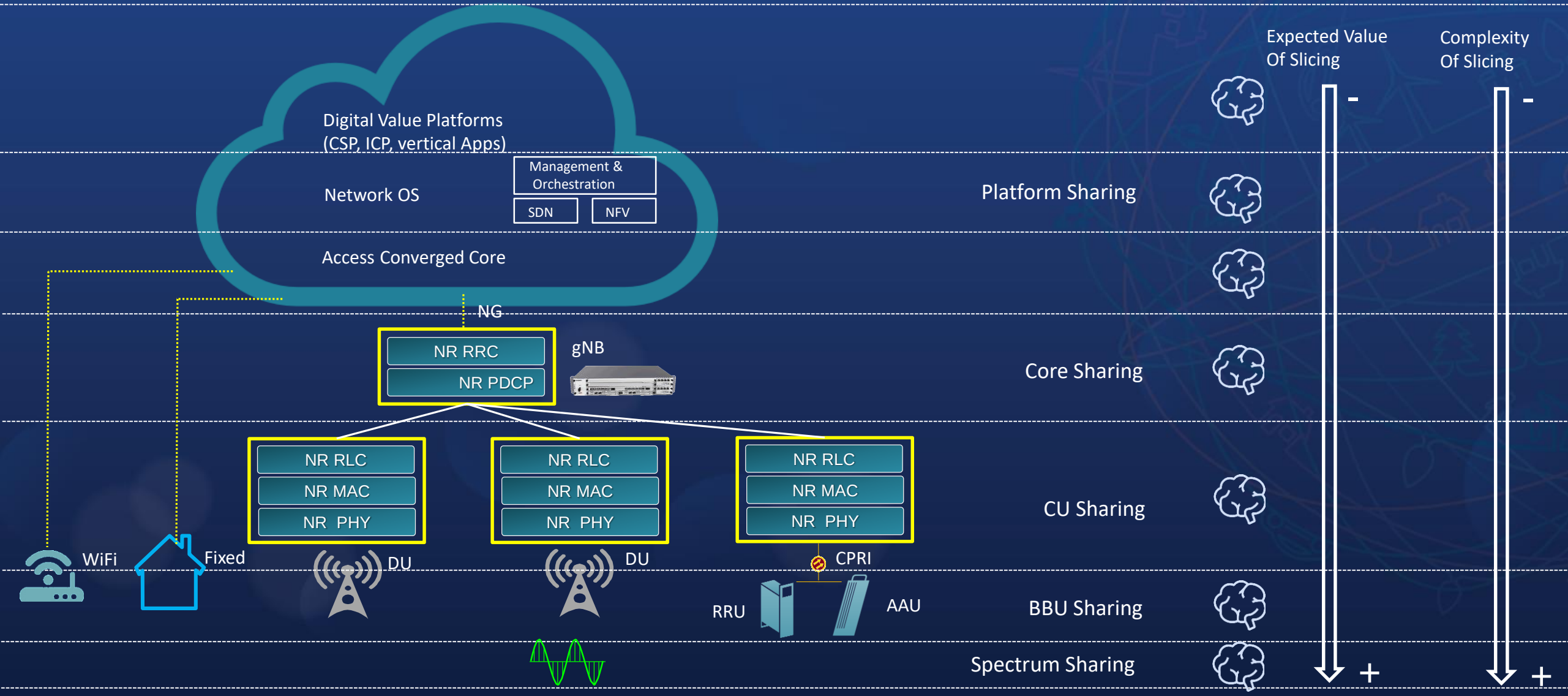
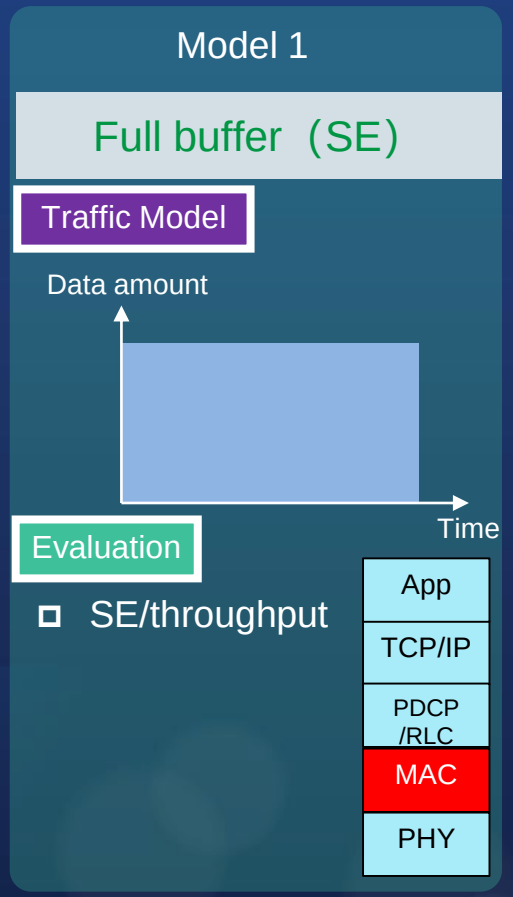
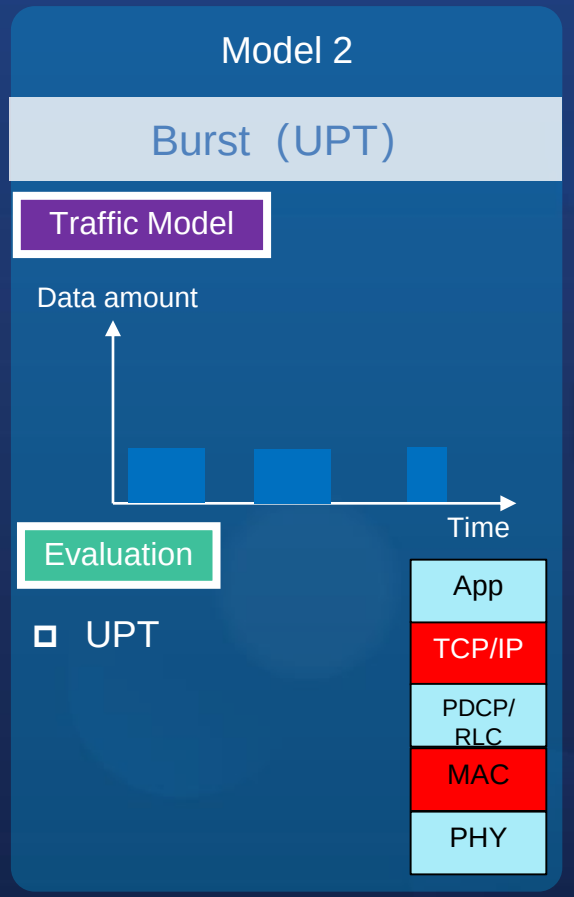
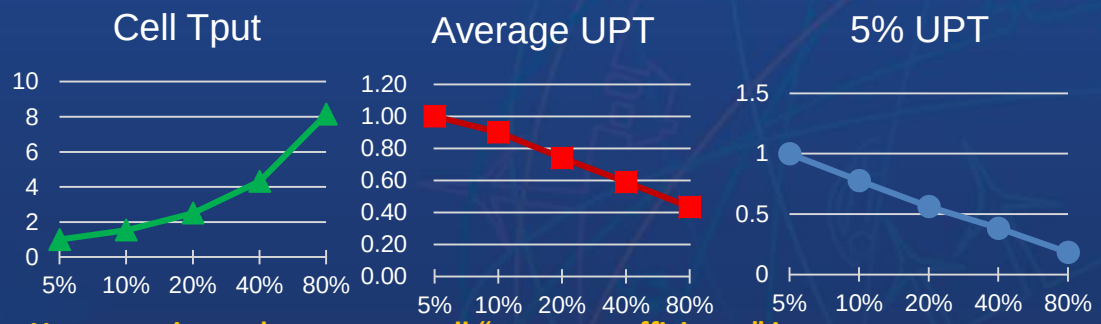
Layered Slicing/Sharing and Layered Intelligence



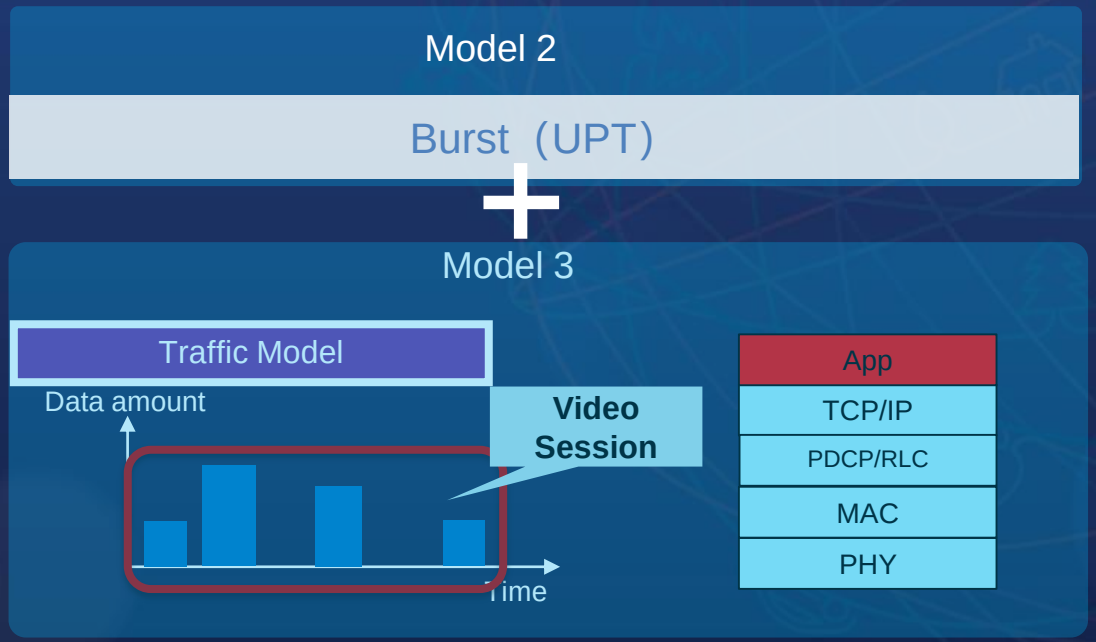
Rethink “Spectrum Efficiency” with QoS constraints







User experience decreases as cell “spectrum efficiency” increases



From “Spectrum Efficiency” to “ User Perceived Throughput”

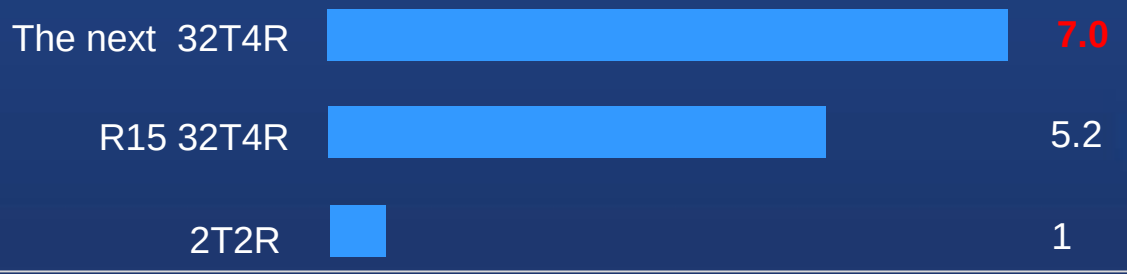
- **User experience need be prioritized**
- **Resource Utilization less than 20% for LTE networks**

From UPT to Service Capacity

- **Service capacity conditioned on user experience is ensured**
  - **UPT of 95% user no less than X**
  - **Reasonable network utilization ratio is hinted**

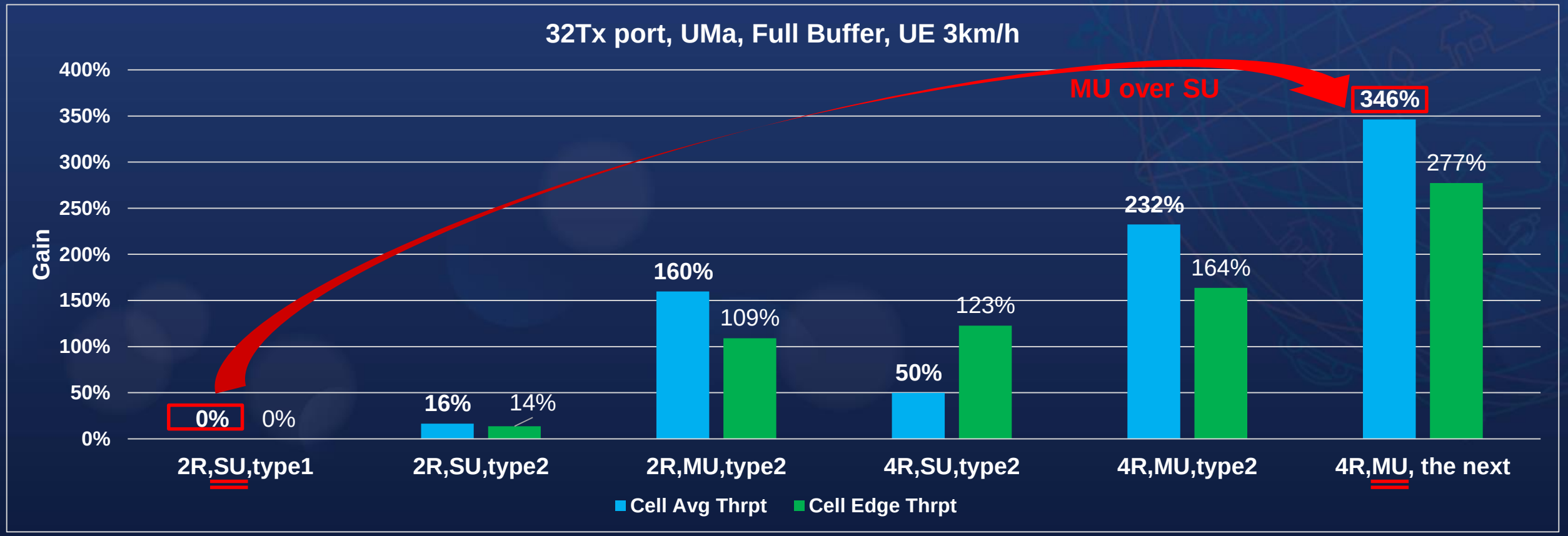
1.8GHz FDD Massive MIMO[1] : Full Buffer

Cell Average SE



Observations

- Most gain from MIMO!
  - 7=1x(1+57%)x(1+346%), hence SU MIMO gain 57%!!!
  - The gain is sensitive to traffic, UE distribution…
- Is it beneficial to afford 1.8GHz M-MIMO with only 20 MHz BW and 57% robust gain?

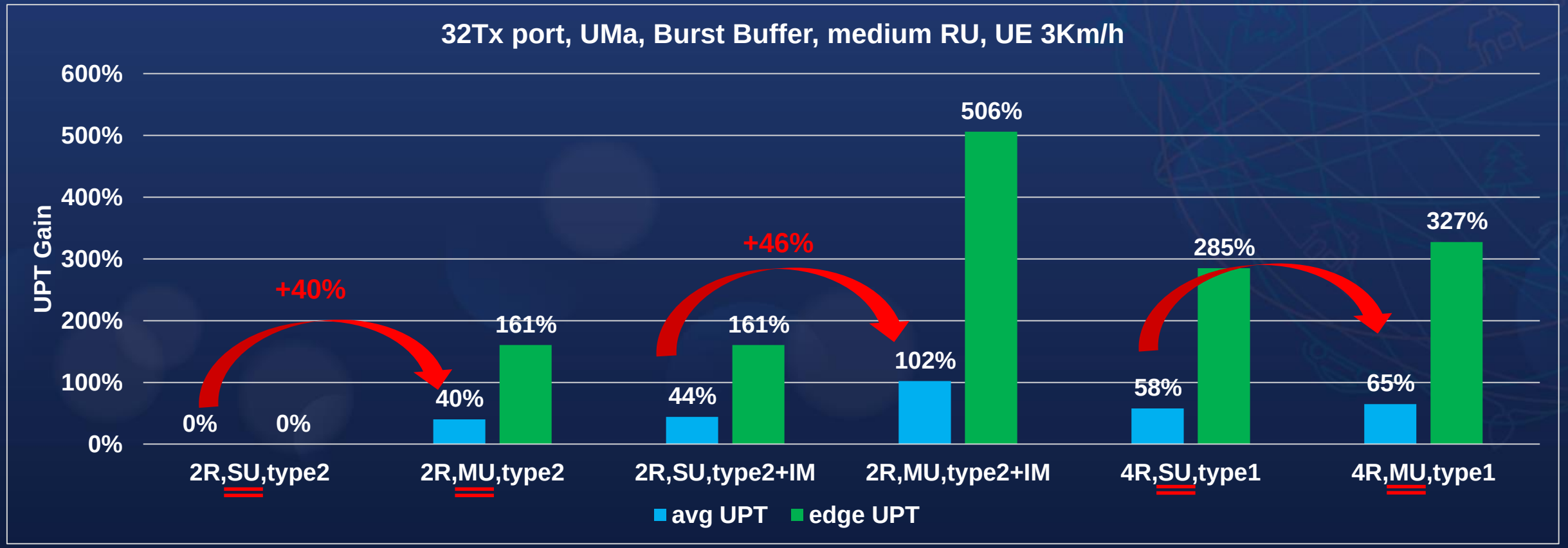


[1]: Simulation conducted with carrier frequency 1800MHz

1.8GHz FDD Massive MIMO[1]: Burst Traffic and New Metric

Observations

- Most Gain is from SU-MIMO! (11.2 out of 20)
  - Better SINR, more layers and more Resource Utilization allowed
  - Robust to user distribution, traffic type…

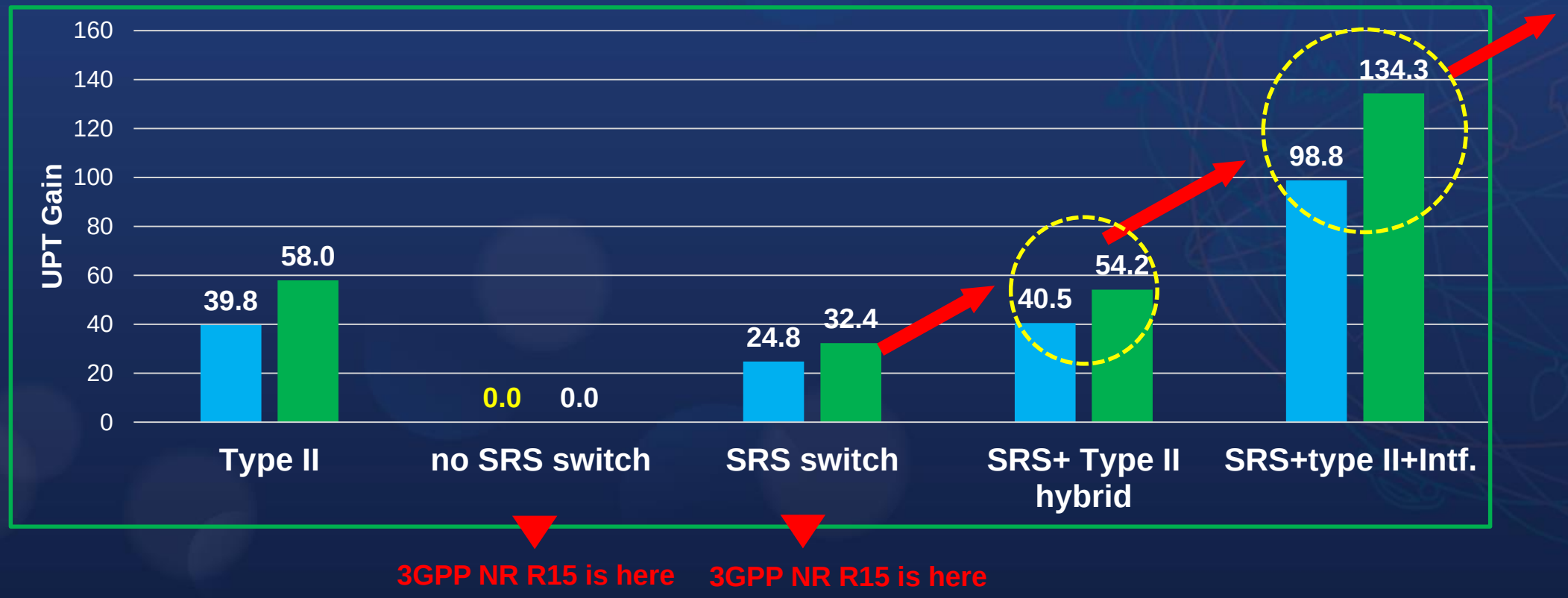


[1]: Simulation conducted with carrier frequency 1800MHz

3.5GHz TDD Massive MIMO[1] : still big room to improve

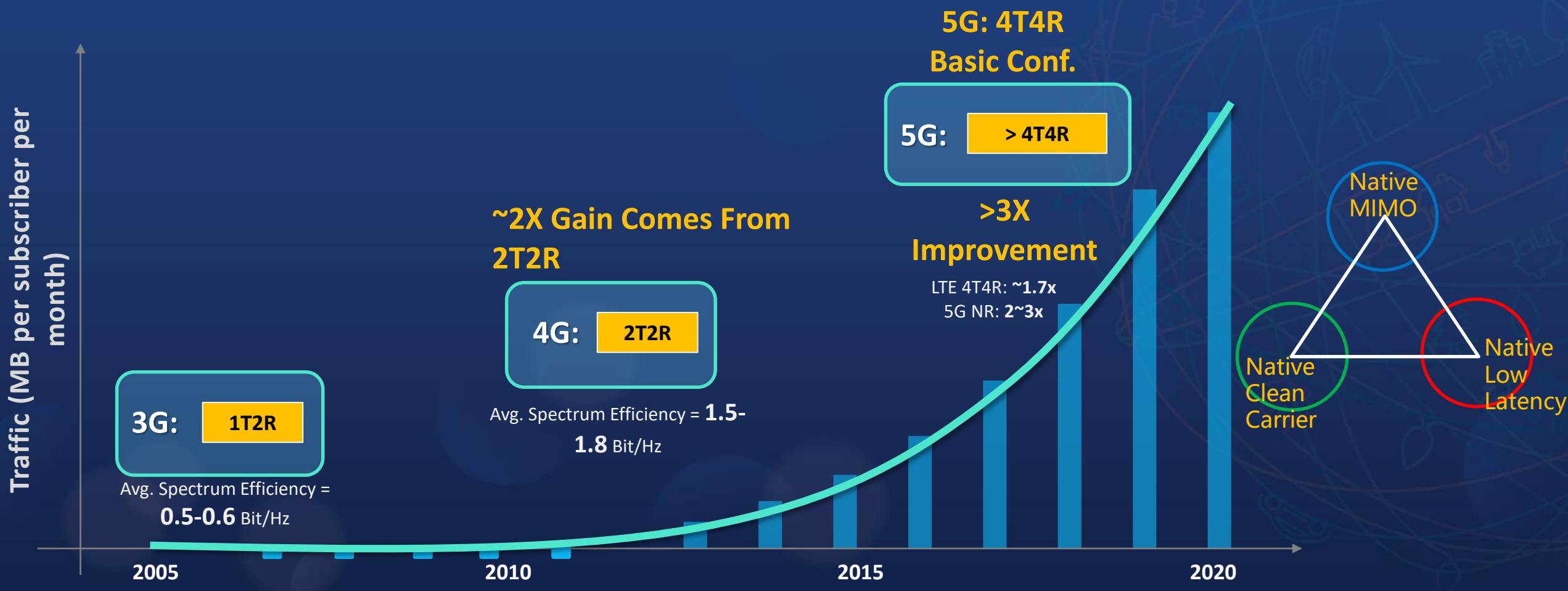
SRS Coverage/SRS Partial Reciprocity/Interference Prediction/…

32Tx, UE 1T2R, UMI, 200m ISD



[1]: Simulation conducted with carrier frequency 3500MHz

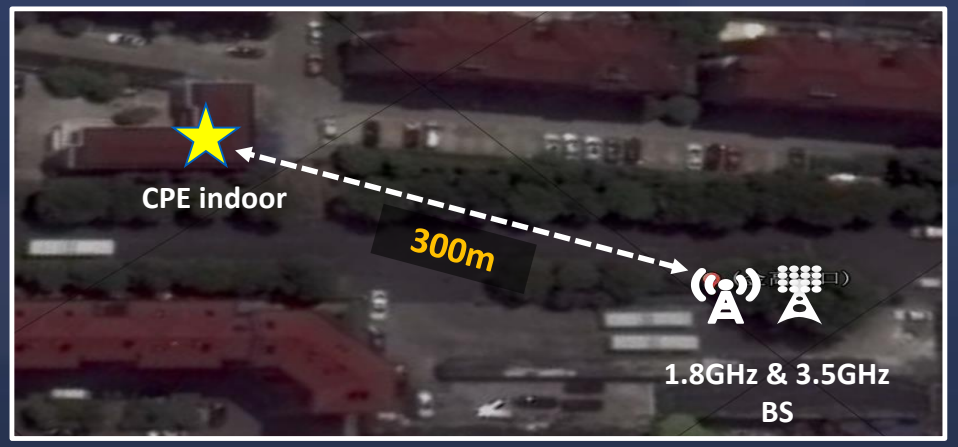
Sub3GHz: 4T4R will be the Basic Configuration



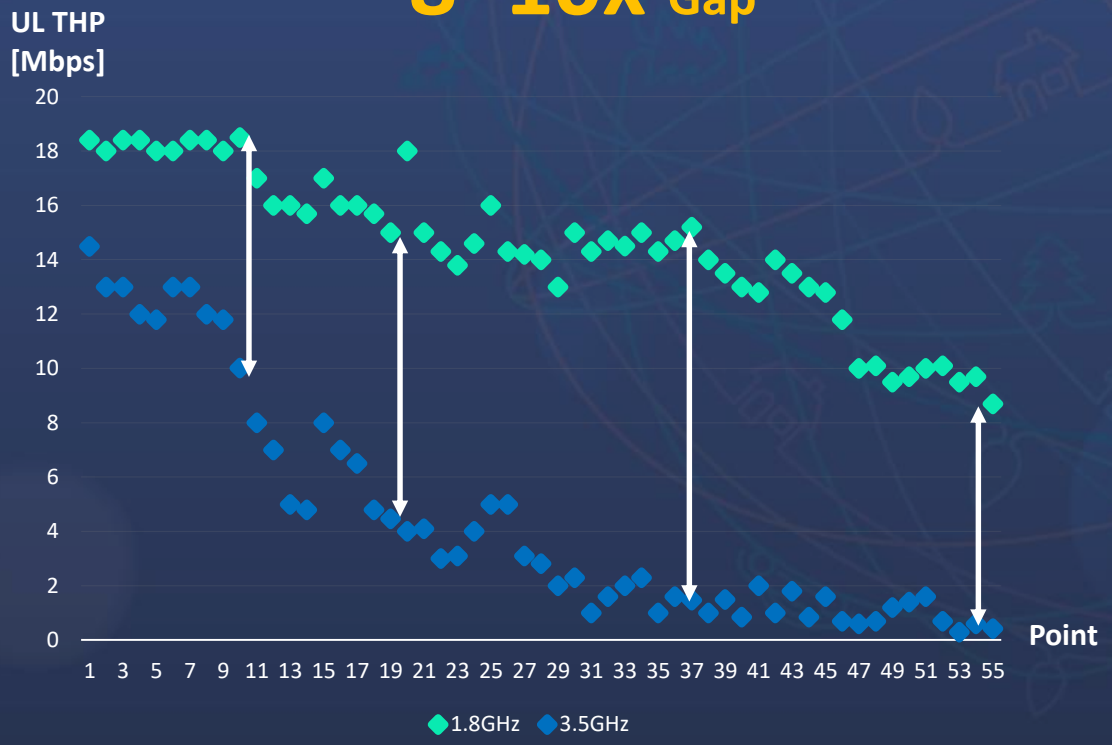
C-band Uplink Coverage Still Needs Improvement

C-band & 1.8GHz Indoor Field Trial

	3.5GHz	1.8GHz
BS Antennas	64T64R	2T4R
TUE Power	23dBm	23dBm
Bandwidth	100MHz	10MHz
DL/UL Conf.	3:1	NA
UE Antennas	2T4R	1T2R



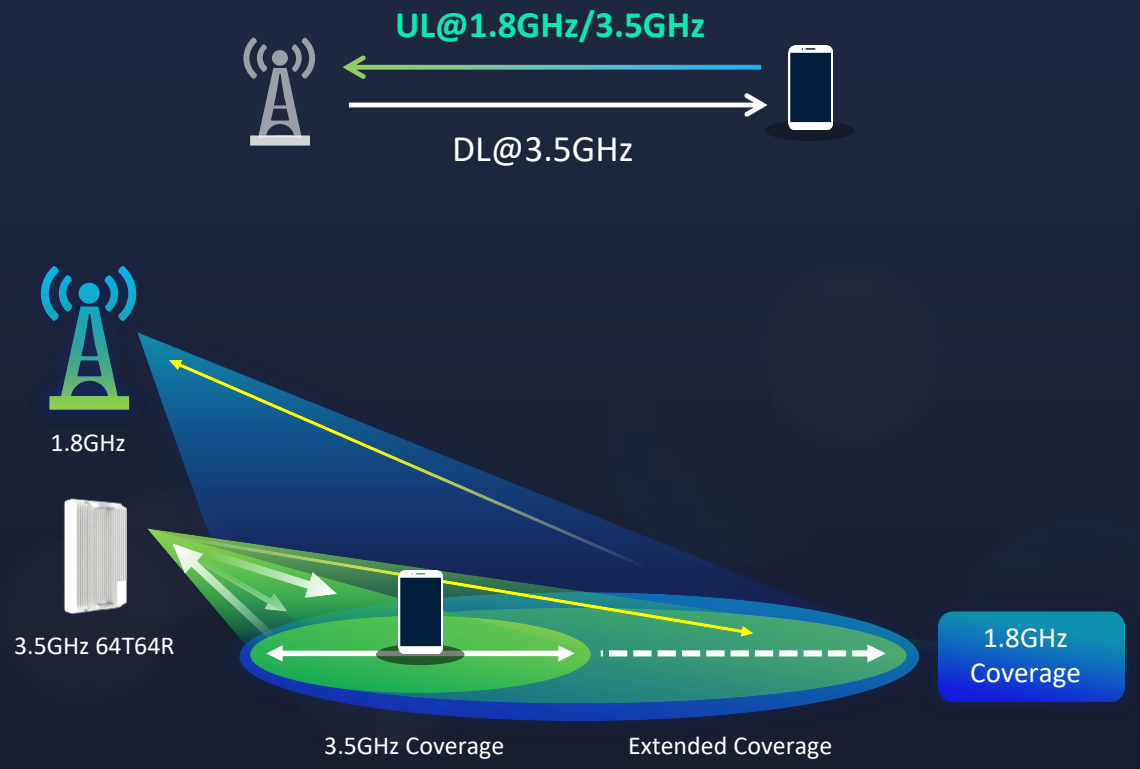
C-band UL Coverage & Experience Limitation



Indoor test from near window to door

UL & DL Decoupling Enables 3.5 & 1.8GHz Co-Site & Co-Coverage

UL&DL Decoupling Extends C-band Coverage



UL&DL Decoupling Adopted by 3GPP R15

*Proposed frequency ranges
1920-1980MHz (UL)/3.3-3.8 GHz (DL&UL)
1710-1785MHz (UL)/3.3-3.8 GHz (DL&UL)
832-862MHz (UL)/3.3-3.8 GHz (DL&UL)
880-915MHz (UL)/3.3-3.8 GHz (DL&UL)
703-748MHz (UL)/3.3-3.8 GHz (DL&UL)
880-915MHz (UL)/4.4-5.0 GHz (DL&UL)
1710-1785MHz (UL)/4.4-5.0 GHz (DL&UL)

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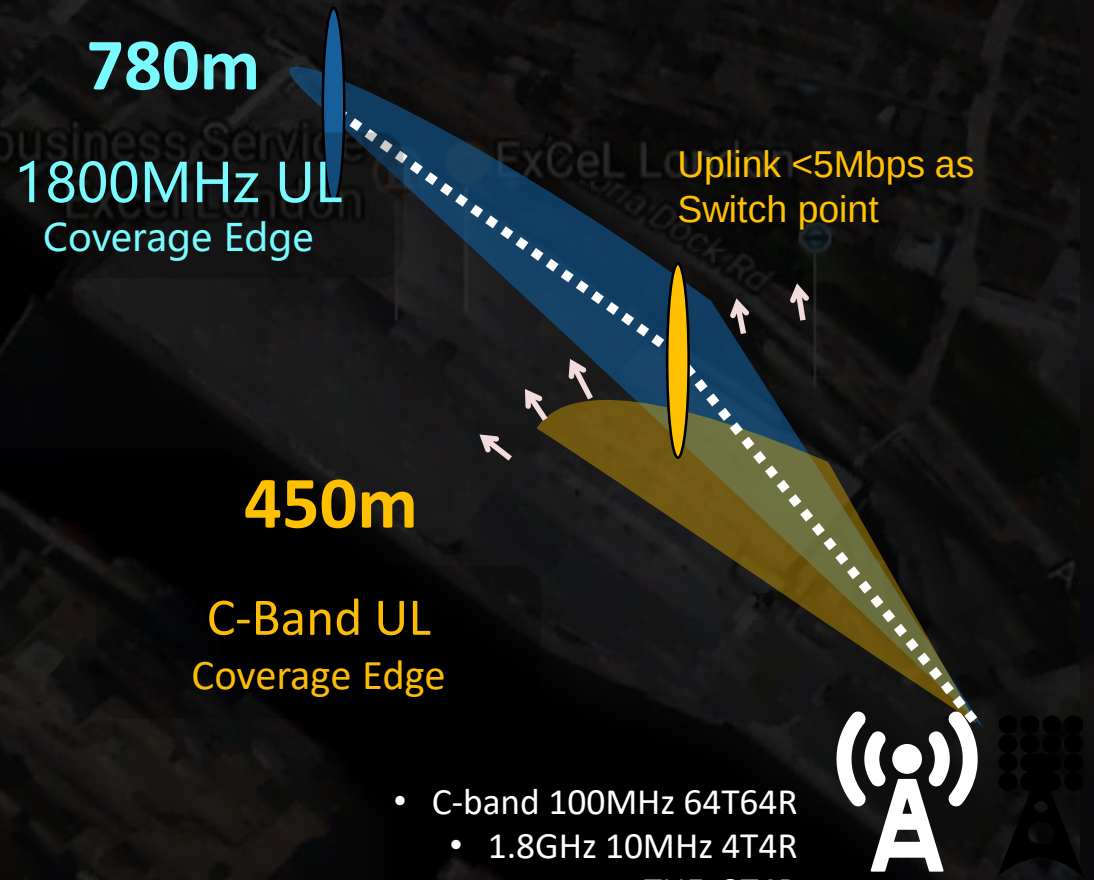
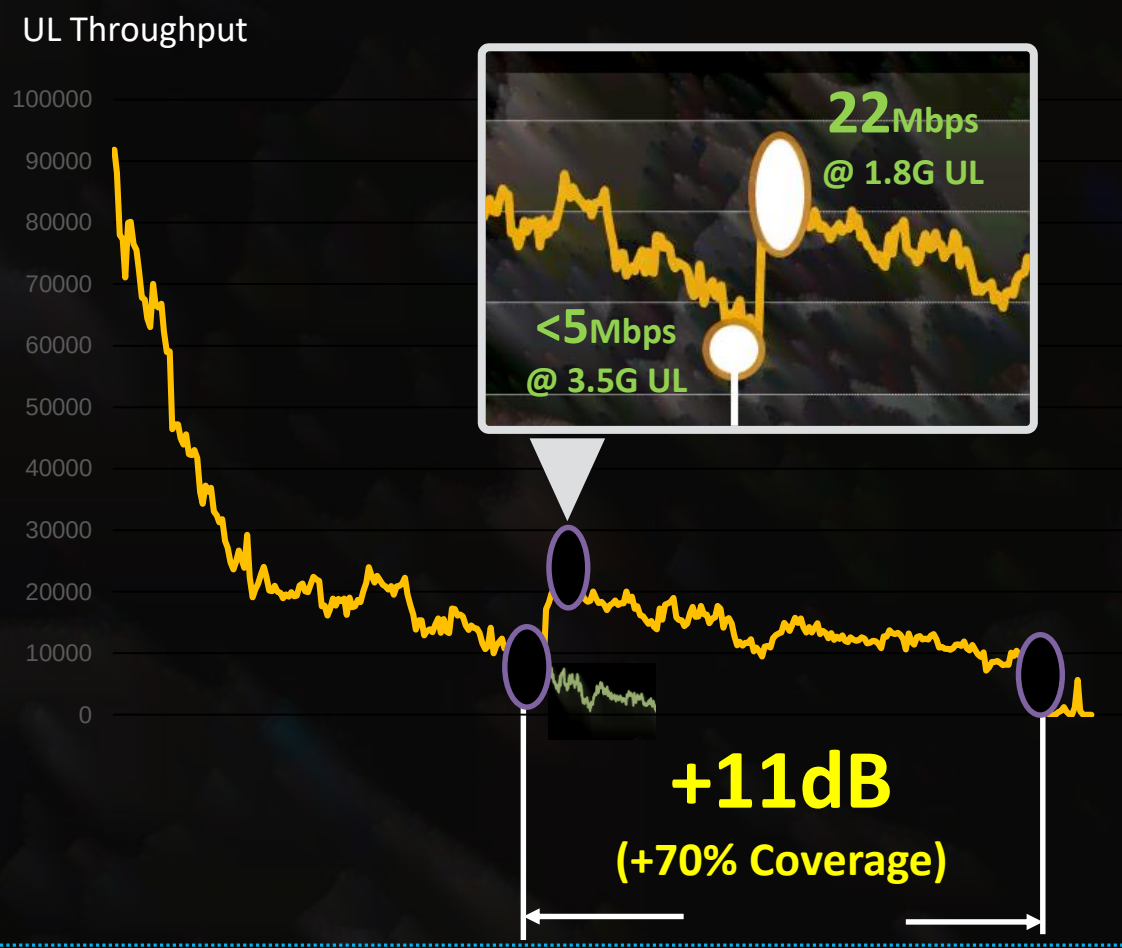
Live Demo of UL & DL Decoupling in London
70%+ C-band Coverage Extended



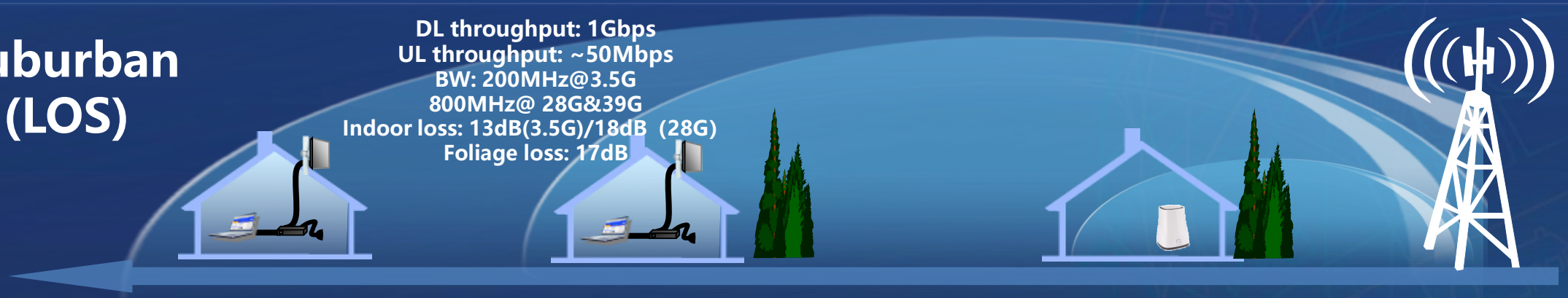


How to deal with C-band only case?

5G WTTx Coverage Capability Evaluation

Suburban (LOS)

DL throughput: 1Gbps
UL throughput: ~50Mbps
BW: 200MHz@3.5G
800MHz@ 28G&39G
Indoor loss: 13dB(3.5G)/18dB (28G)
Foliage loss: 17dB



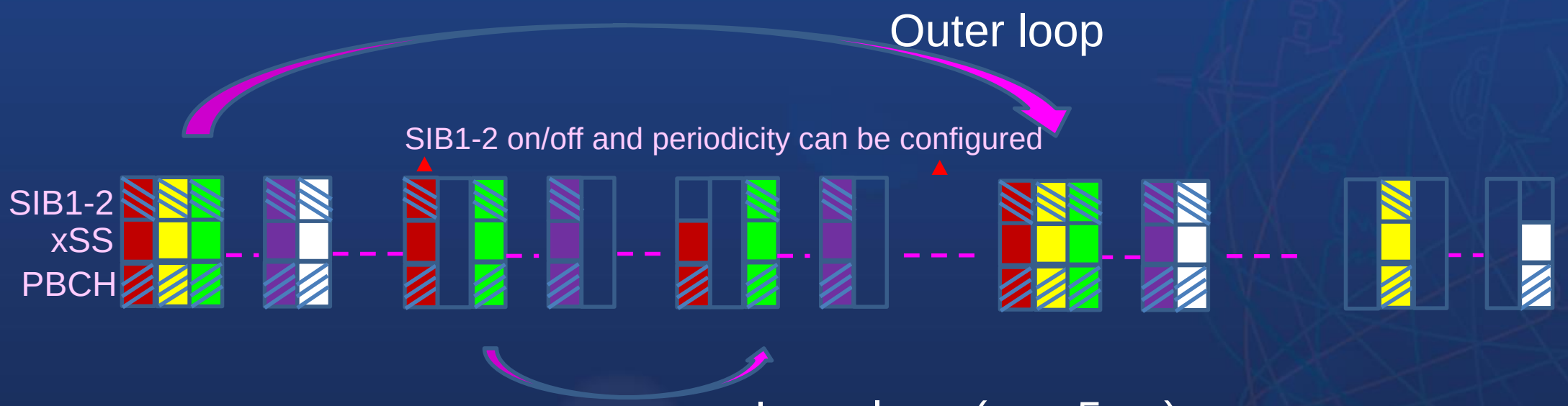
	Outdoor CPE	Outdoor CPE With Foliage	Indoor CPE With Foliage	gNB
(*3.5GHz/28HGz)	6867m/4279m	1429m/604m	366m/73m	

Urban (NLOS)

DL throughput: 1Gbps
UL throughput: ~50Mbps
BW: 200MHz@3.5G
800MHz@ 28G&39G
Indoor loss: 13dB(3.5G)/18dB (28G)
Foliage loss: 17dB

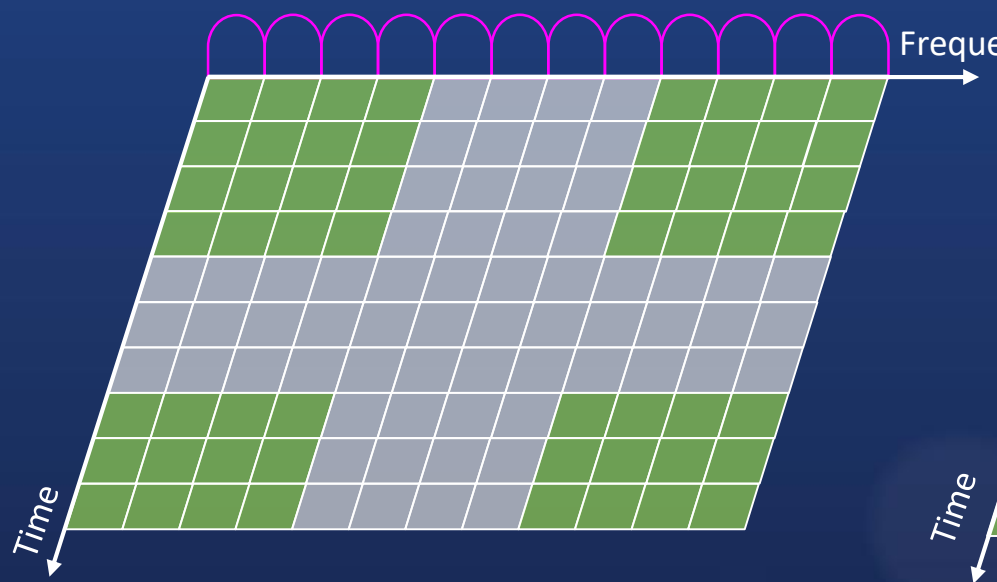
	Outdoor CPE	Indoor CPE	gNB
(*3.5GGz/28HGz)	299m/220m	133m/74m	

Beam Based Access

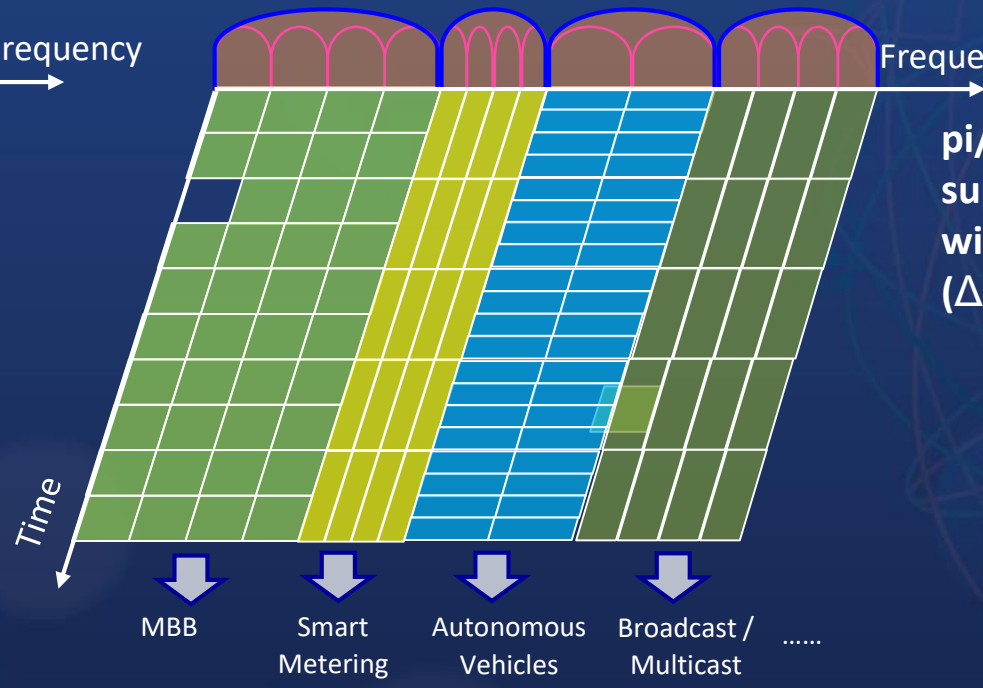


Low PAPR 5G Waveform

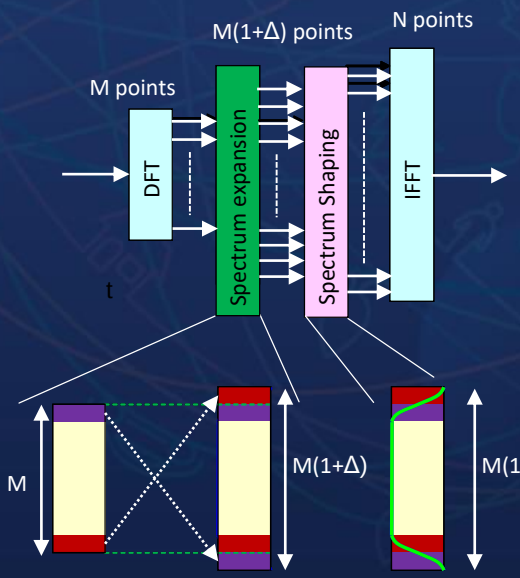
DL waveform is OFDM
QPSK/16QAM/64QAM/256QAM



Filtered-OFDM with better spectrum utilization efficiency



pi/2 BPSK DFT-s-OFDM supports spectrum shaping without spectrum expansion (Δ=0), standard transparent



(for further lower PAPR)

UL waveform is OFDM or DFT-S-OFDM
QPSK/16QAM/64QAM/256QAM
Pi/2 BPSK is also supported for DFT-S-OFDM

(for lower PAPR)

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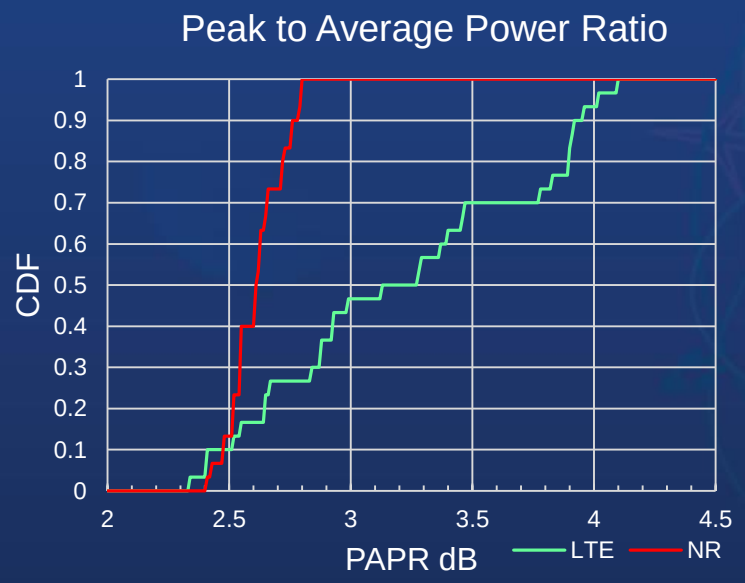
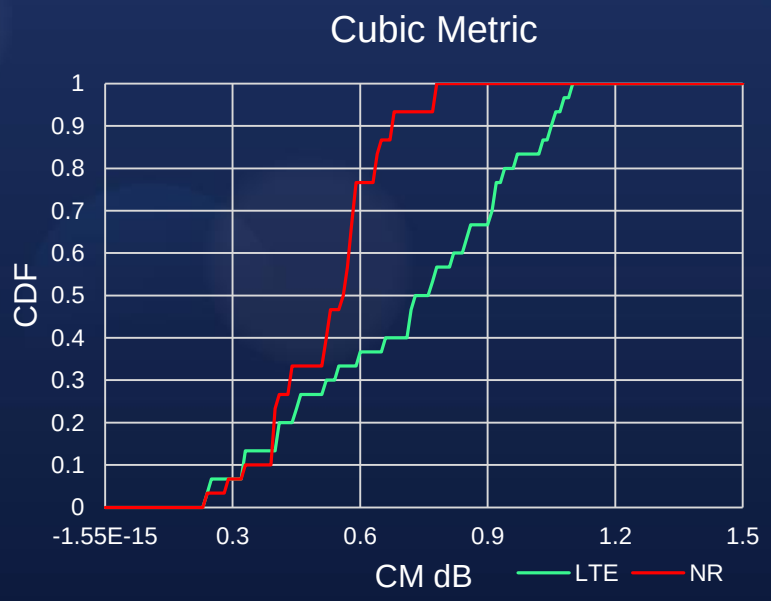
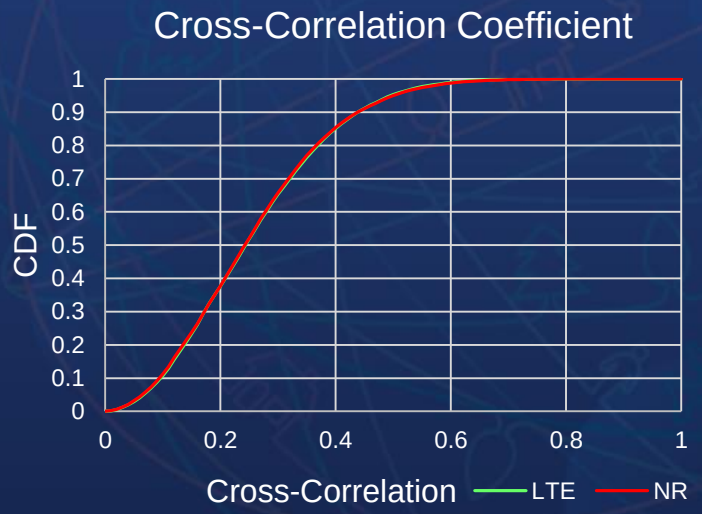
Low PAPR 5G UL Pilot: new Computer Generated Sequences

$$r_k(n) = \exp(j\pi\varphi_k(n)/4)$$

Seq. Index	φ											
0	1	-1	3	1	1	-1	-1	-1	1	3	-3	1
1	-1	-1	-1	-1	1	-3	-1	3	3	-1	-3	1
2	-3	1	-3	-3	-3	3	-3	-1	1	1	1	-3
3	-3	3	1	3	-3	1	1	1	1	3	-3	3
4	-3	1	3	-1	-1	-3	-3	-1	-1	3	1	-3
5	-1	1	1	-1	1	3	3	-1	-1	-3	1	-3
6	-3	-3	-1	3	3	3	-3	3	-3	1	-1	-3
7	-3	3	-3	3	3	-3	-1	-1	3	3	1	-3
8	-3	-1	-3	-1	-1	-3	3	3	-1	-1	1	-3
9	-3	3	3	3	-1	-3	-3	-1	-3	1	3	-3
10	1	3	-3	1	3	3	3	1	-1	1	-1	3
11	-1	-3	3	-1	-3	-3	-3	-1	1	-1	1	-3
12	3	1	3	1	3	-3	-1	1	3	1	-1	-3
13	-3	-3	3	3	3	-3	-1	1	-3	3	1	-3
14	-3	-1	1	-3	1	3	3	3	-1	-3	3	3
15	-3	-3	3	1	-3	-3	-3	-1	3	-1	1	3
16	-1	1	3	-3	1	-1	1	-1	-1	-3	1	-1
17	-3	-1	-1	1	3	1	1	-1	1	-1	-3	1
18	-3	-1	3	-3	-3	-1	-3	1	-1	-3	3	3
19	-3	-3	3	-3	-1	3	3	3	-1	-3	1	-3
20	-3	1	-1	-1	3	3	-3	-1	-1	-3	-1	-3
21	-3	1	3	3	-1	-1	-3	3	3	-3	3	-3
22	-3	-1	-1	-3	-3	-1	-3	3	1	3	-1	-3
23	-3	-1	3	1	-3	-1	-3	3	1	3	3	1
24	-3	3	3	1	-3	3	-1	1	3	-3	3	-3
25	3	-1	-3	3	-3	-1	3	3	3	-3	-1	-3
26	1	-1	3	-1	-1	-1	-3	-1	1	1	1	-3
27	-3	3	1	-3	1	3	-1	-1	1	3	3	3
28	-3	3	-3	3	-3	-3	3	-1	-1	1	3	-3
29	-3	3	1	-1	3	3	-3	1	-1	1	-1	1







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5G Beyond: from eMBB to Full Digital Society

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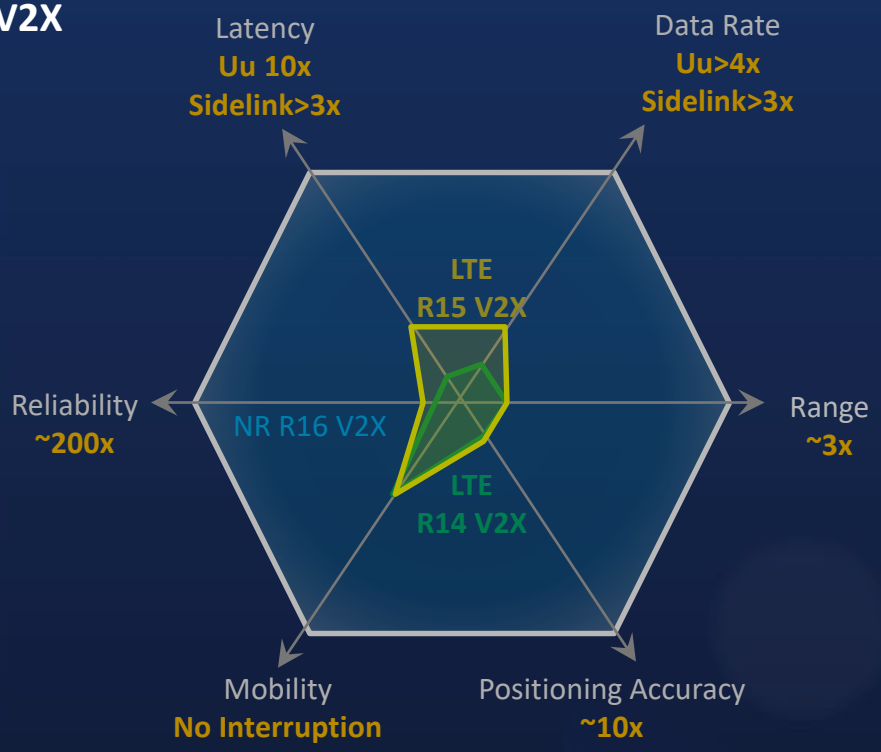
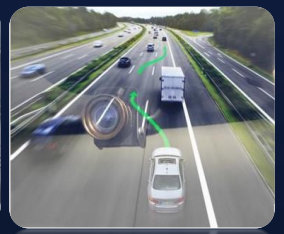
Status of URLLC/Industrial IoT/C-V2X and Evolution

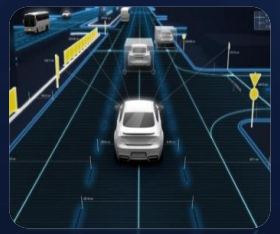
C-V2X



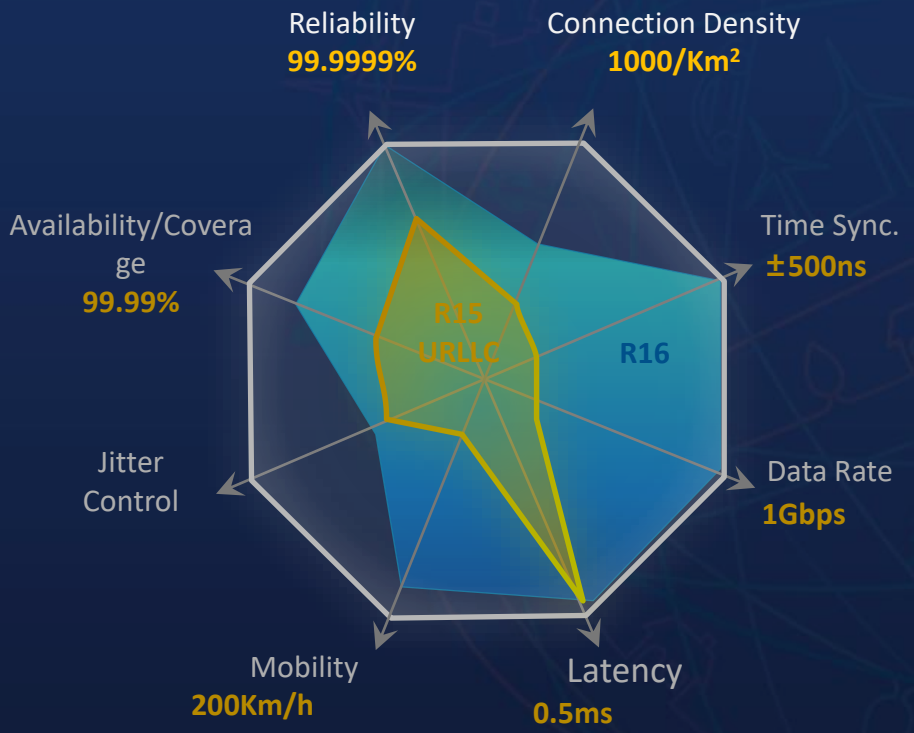

Vehicle Platooning


Sensor Sharing


Remote Driving


Advanced Driving

URLLC/Industrial IoT

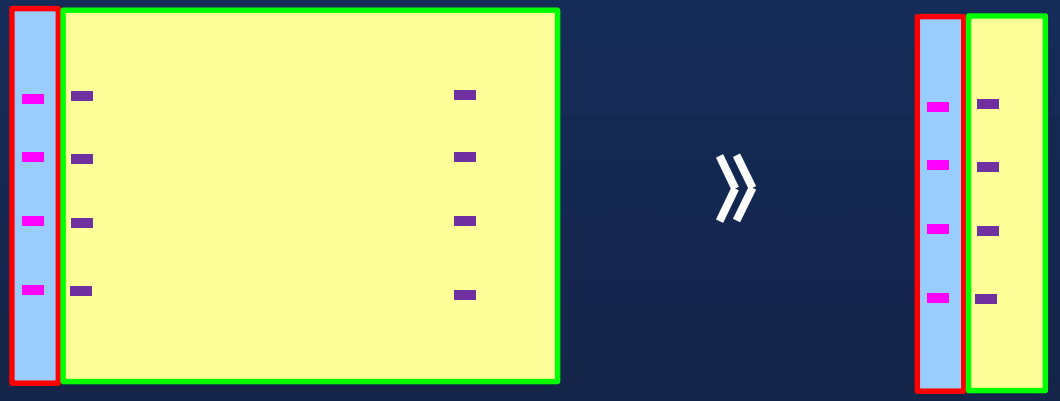


R15 URLLC: Basic Functionality, e.g. non-slot based Tx.
R16 URLLC: NR-NR DC/Enhanced UL Scheduling/RRC duplication/R15 leftovers…
R16 Industrial IoT:
- Integrate 5G connectivity with (Industrial) Ethernet
- Accurate time reference for (robotical) applications/wireless TSN
- Maybe merged with R16 URLLC

More and more services/use cases/ beautiful KPIs to be supported,.

Behind the beautiful KPIs…

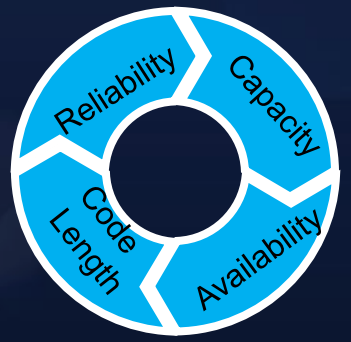
Overhead (RS and control) is now getting bigger



Frame structure

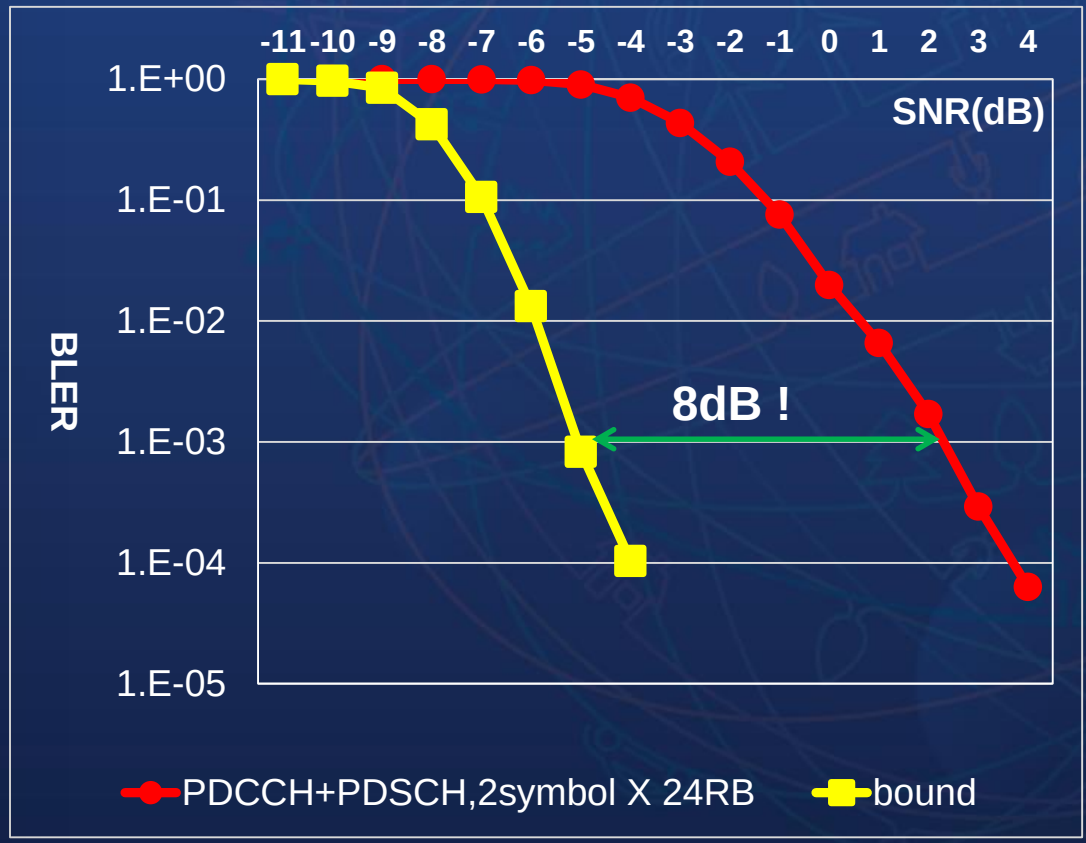
Very low efficiency when this scales to short duration transmission

Information Theory tells us KPIs are related and best tradeoff exists



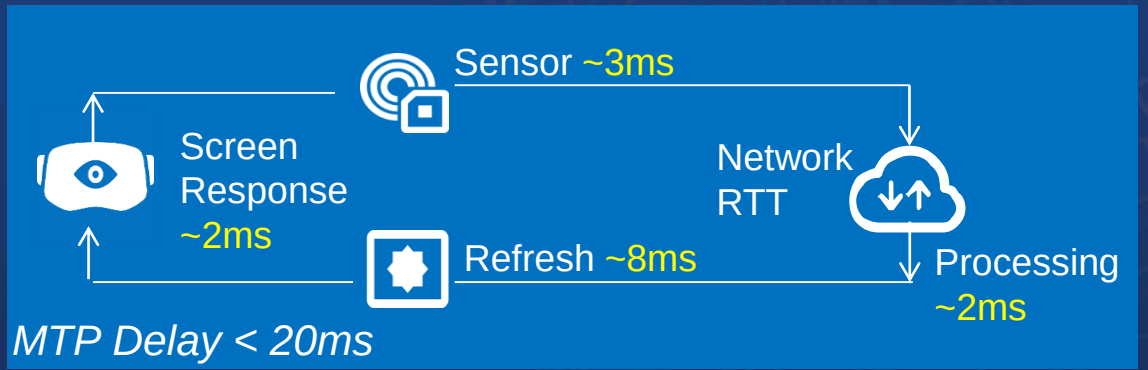
Example

- **10 bytes control information**
- **10 bytes data**



The beautiful KPIs are supported very inefficiently.

Cloud Based AR/VR with High Requirements on the Network



Acceptable Experience	**125Mbps**	RTT Latency
Ultra Retina Experience	**3.2Gbps**	**< 5ms**

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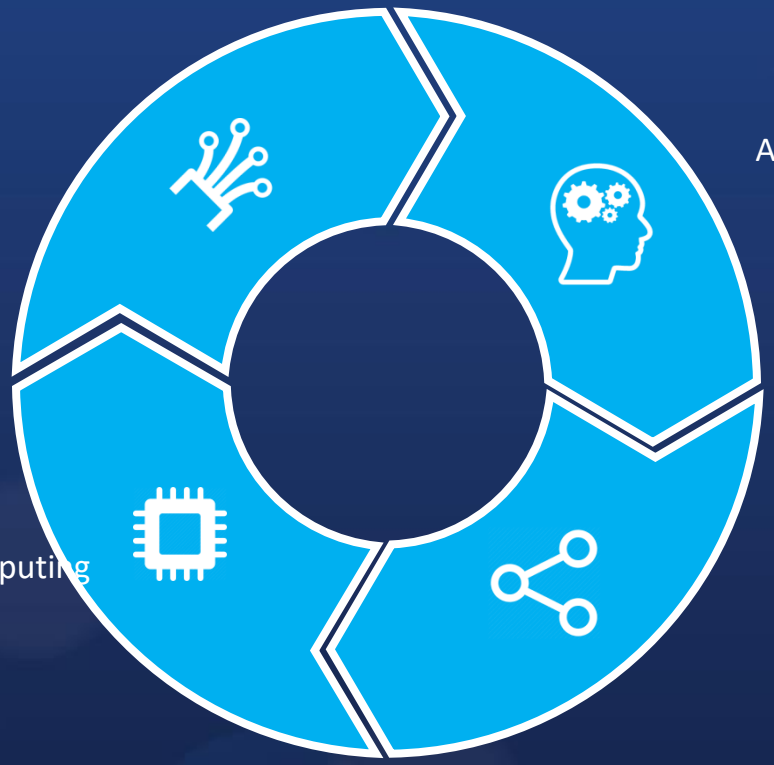
Key technologies to shape the VR/AR/MR landscape

New Display

From conventional optics to Optoelectronics /Photonics, (nano fabbed light sources and ultra fast MEMs)



AI

ASR, Conversational NLU, Visual Story Telling,

Evolution of Processing

Vision chips, Deep Neural Networks, neuromorphic computing

Ultrafast Networking

Wireless at FiberOptic Speeds

Deep Perception

Sensing, large scale learning and tracking, 3D real time reconstruction, Holographics

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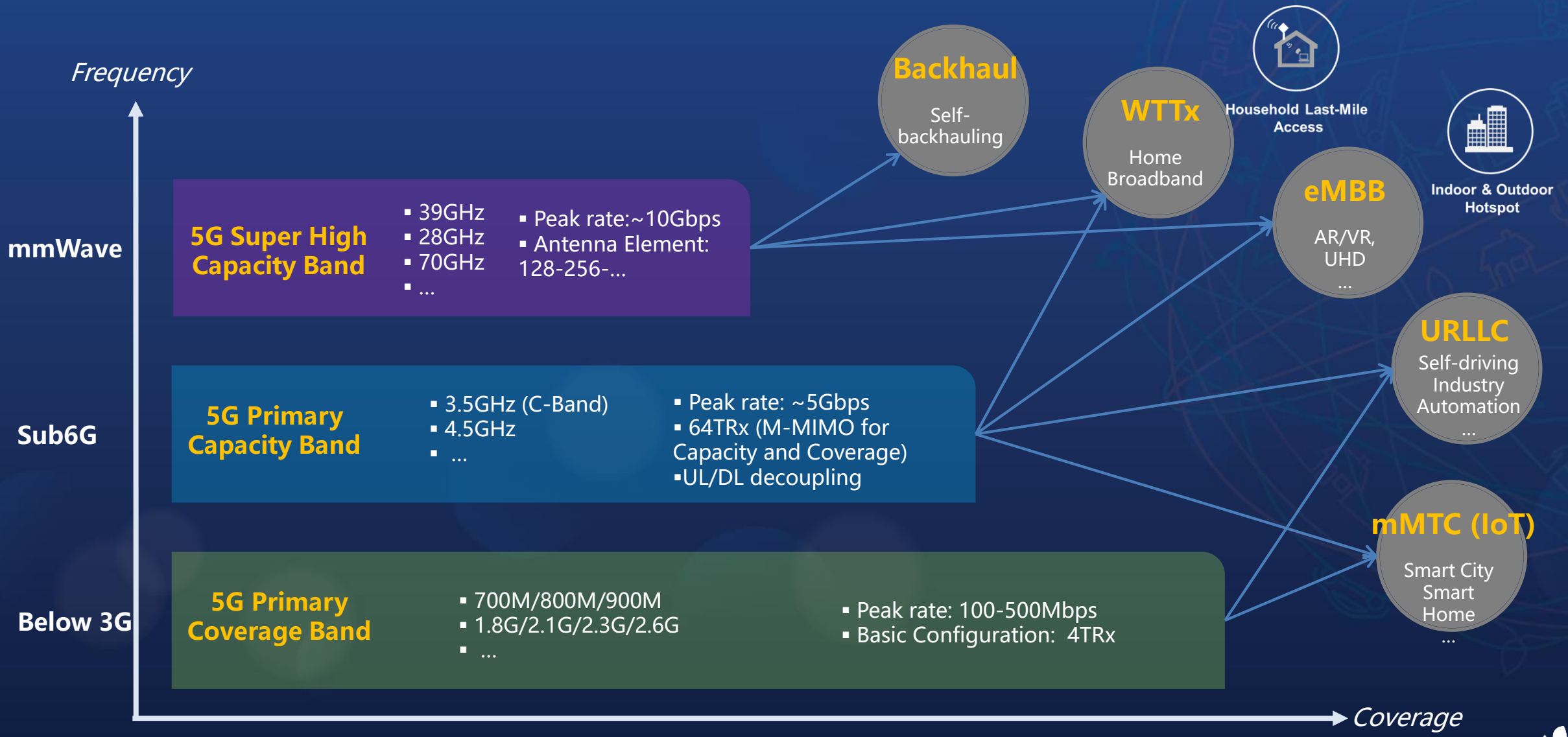
LPWA to Represent 70% of Cellular IoT Connections

Market Segment	Connections in 2020 (Billion)	Requirements	Technology
• CCTV(Camera) • In-vehicle Entertainment…	0.2B	l >10Mbps	3G/4G
• IoT Gateway Backhaul • Wearable • …	0.8B	l ~1Mbps l Low power consumption	2G/3G/Cat-1 Cat-M1
• Sensors, Meters • Asset Tracking • Smart Parking • Smart agriculture …	2B	l Low Throughput (<100kbps) l Deep Coverage (20dB) l Low power (10 Years) l Low cost (<$5)	Short Range Tech. Sigfox, LoRa NB-IoT
• Smart Retailing • Logistics • …	xB	l Wide Coverage (~100m) l Lower power (infinity years) l Low cost (<$1)	Backscatter Energy Harvesting

LPWA: Low Power Wide Area

To Map Spectrum with Diversified Services



Many Challenges Remain …

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What type of research is needed? Up to your imagination…

Spectrum Ready

- New spectrum:700MHz/ 3.5GHz/ 26/28GHz
- Antenna Technology (metamaterials)
- Filter technology (materials)
- …

Sites Ready

- Space ready(site/DC)
- Alternative deployments
- Energy
- nTnR, Massive MIMO…
- …

Architecture

- Cloud RAN/Cloud Native
- NFV/SDN
- Backhaul
- …

Adjacent Domains

- Electro/Optical/Fotonics
- Devices/Chipsets
- Materials
- AI/DL
- Software/Cloud/IT Technologies
- Computing

Challenges: To ensure that the potential of 5G does not go unfulfilled a full collaborative ecosystem is needed.

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Thank You

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