

Prospect of 5G: Opportunities and Challenges

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The 3rd Paradigm Shift of the Mobile Industry is Happening

198x



Voice Era (1G)



Connectivity as a Service

2000

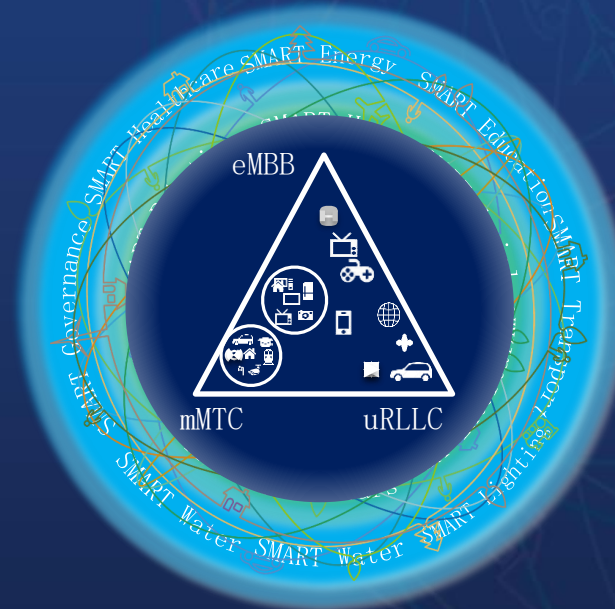


MBB Era (3G)



Connectivity as a Service

2020 and Beyond



Super Connected World (5G)

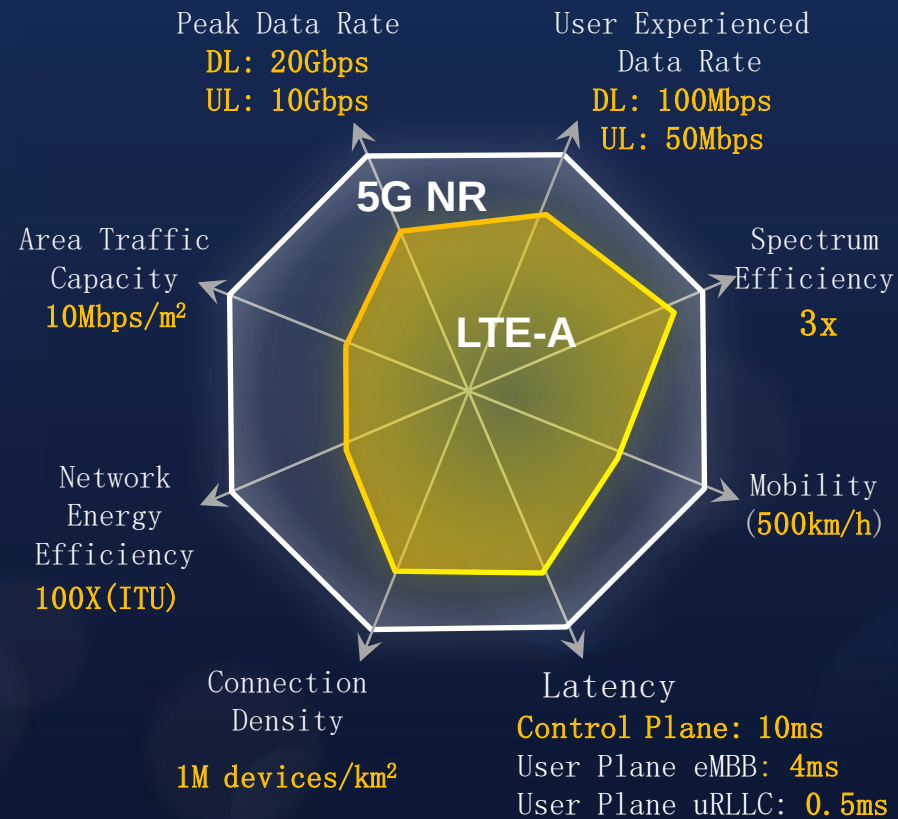
eMBB + uRLLC + mMTC

Network Slice as a Service

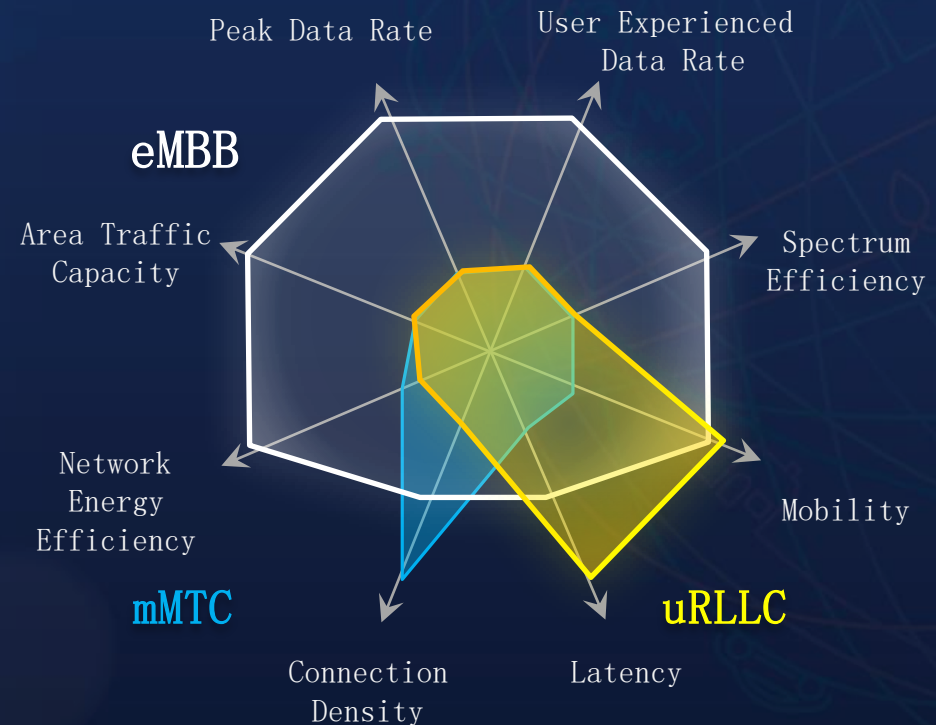
Cloudification

5G Capability Requirements Defined by 3GPP

3GPP Standardization Targets for 5G NR

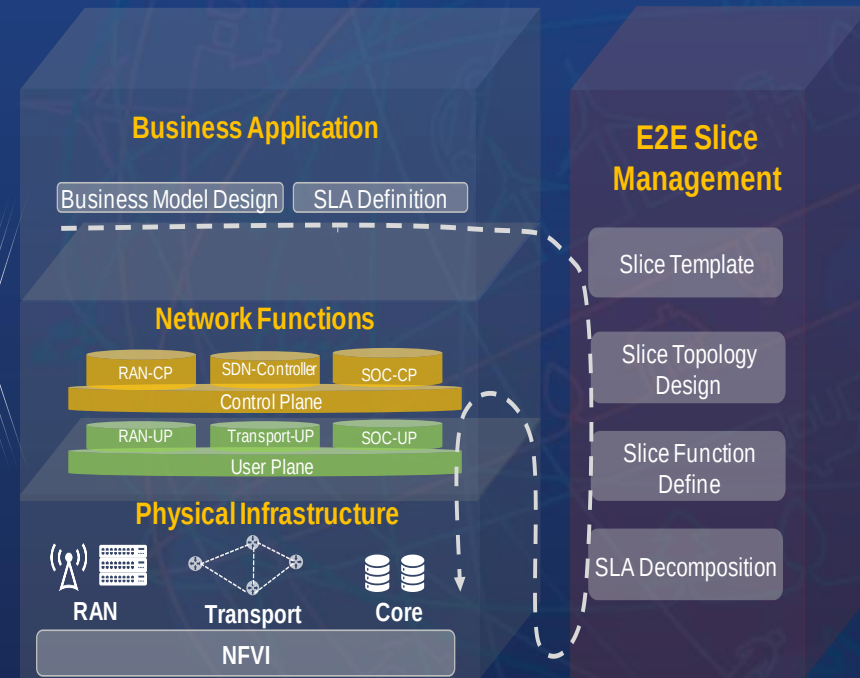
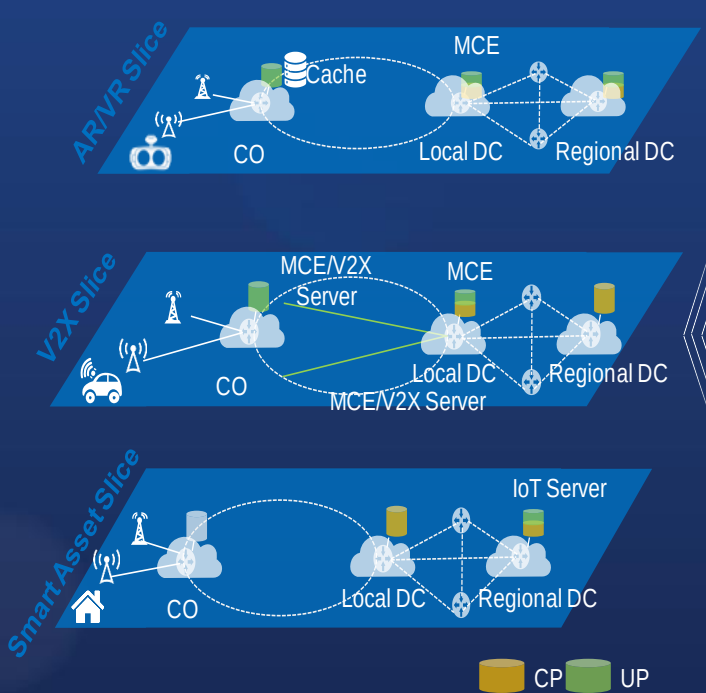
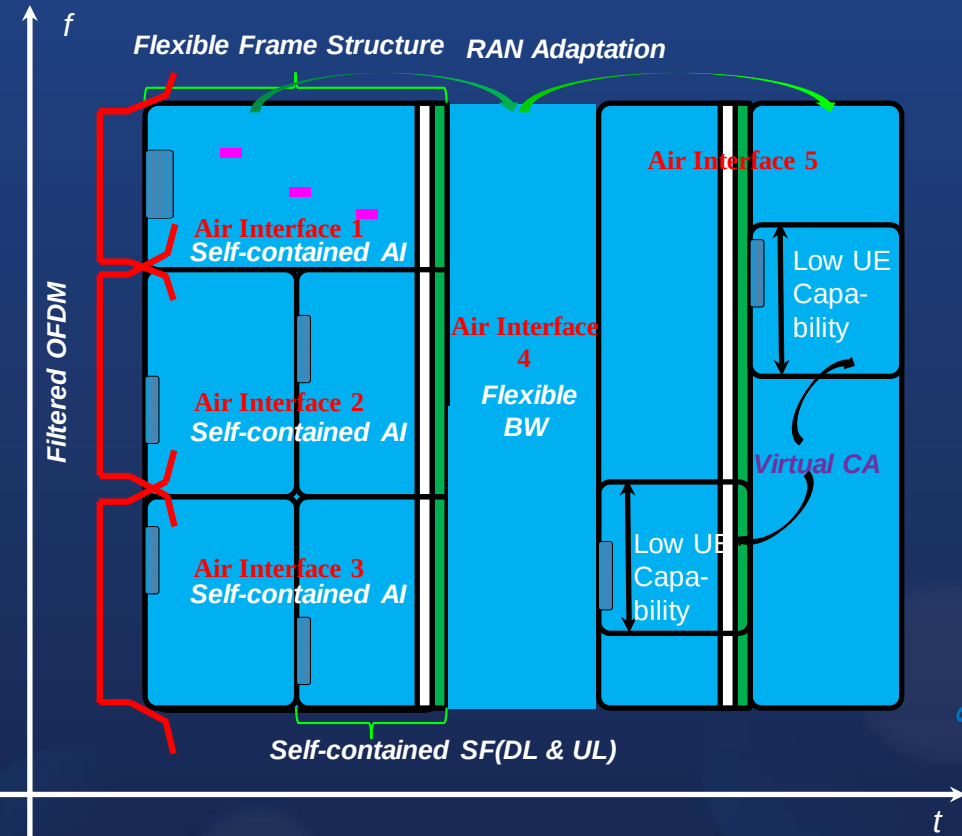


Requirements of Different Services



Source: 3GPP TR 38.913

Service Oriented Radio and Cloud-Native Architecture

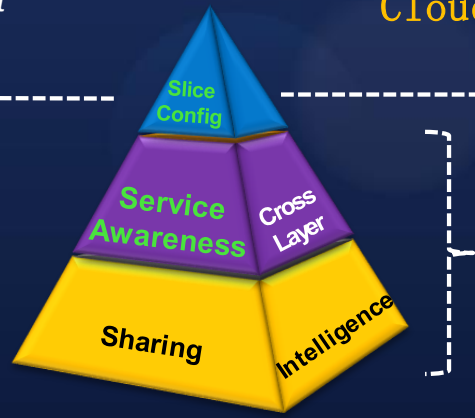


Service Oriented Radio (SOR)

5G Air Interface

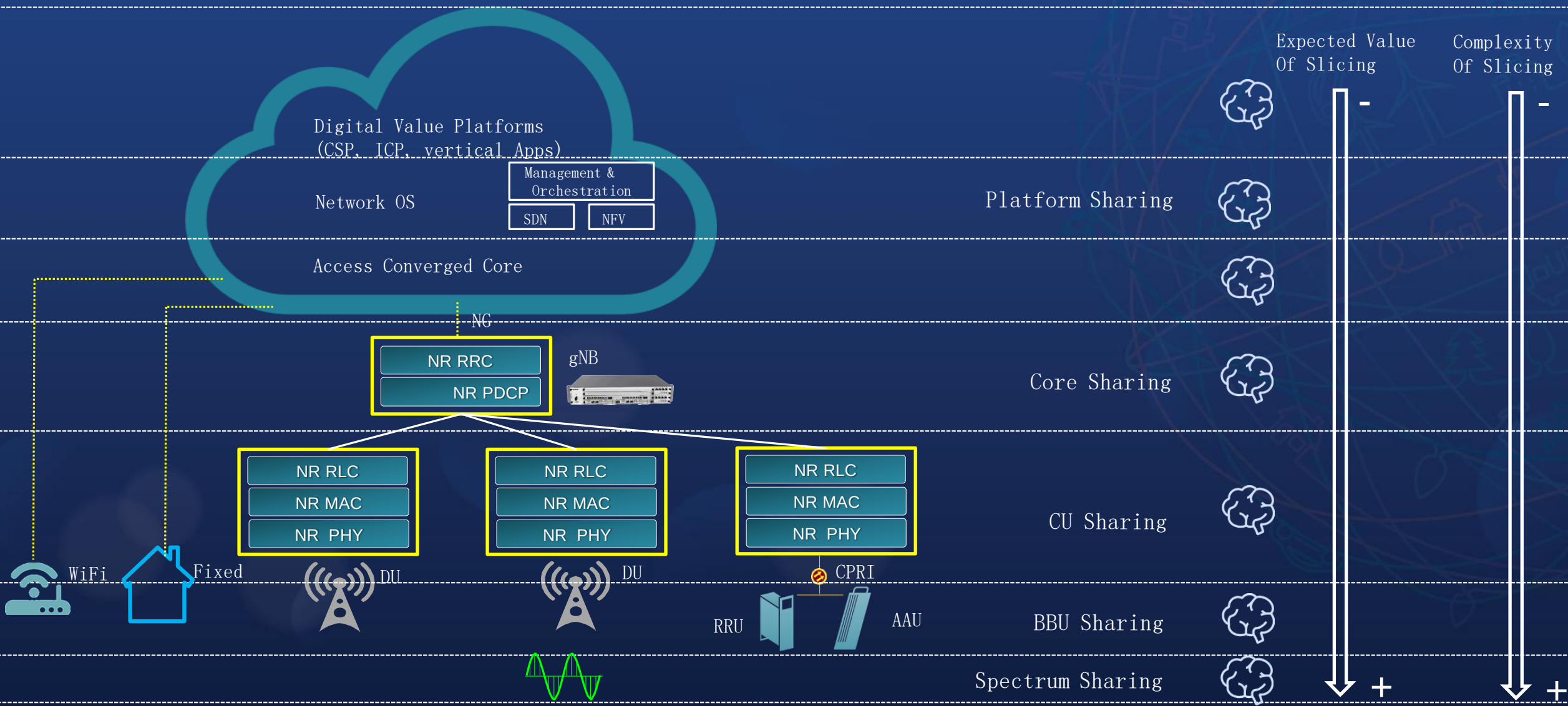
Cloud-Native Architecture for E2E slicing

5G Architecture



"5G-Beyond" with service awareness and sharing?
e.g. "Video" RAN Slice w/ cross layer?
e.g. Network/Spectrum Sharing?

Layered Slicing/Sharing and Layered Intelligence



Outline



Use Cases



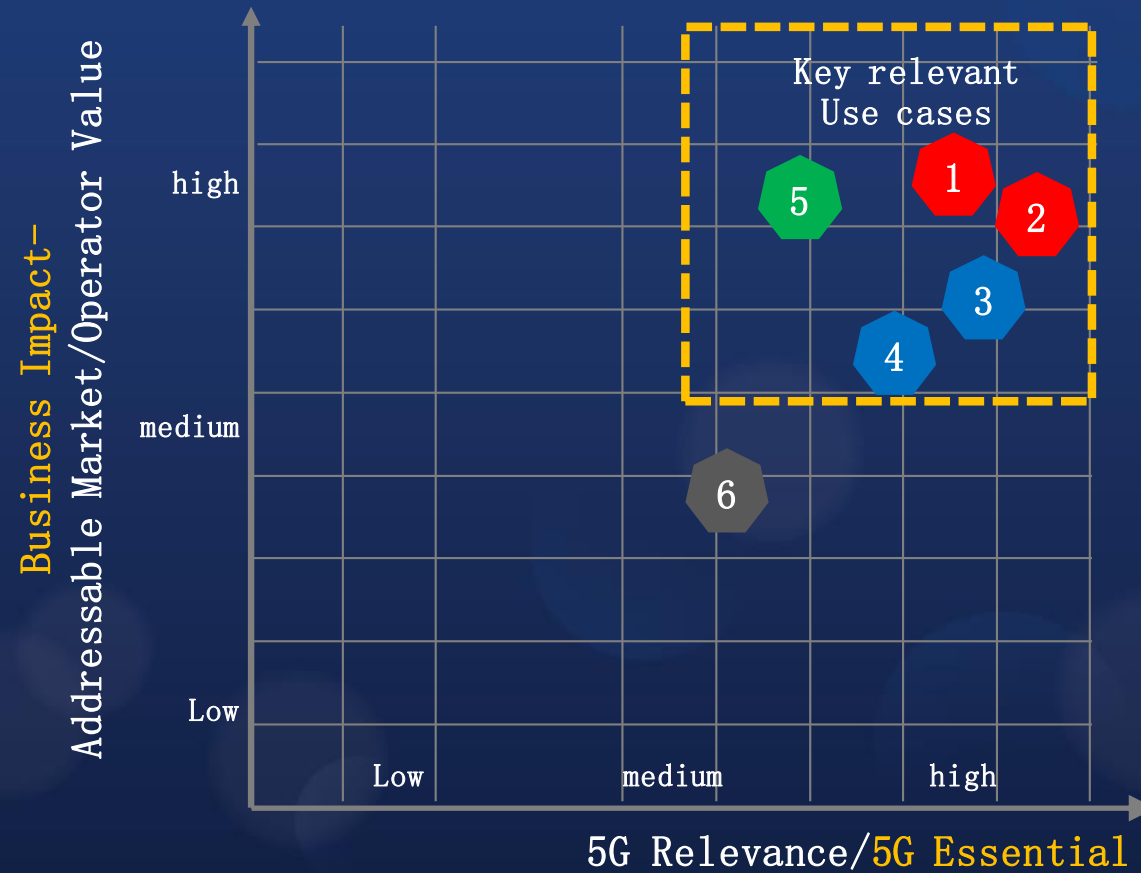
Spectrum



Challenges and Solutions

5G Use Cases Evaluation & Prioritization

Use Case Evaluation



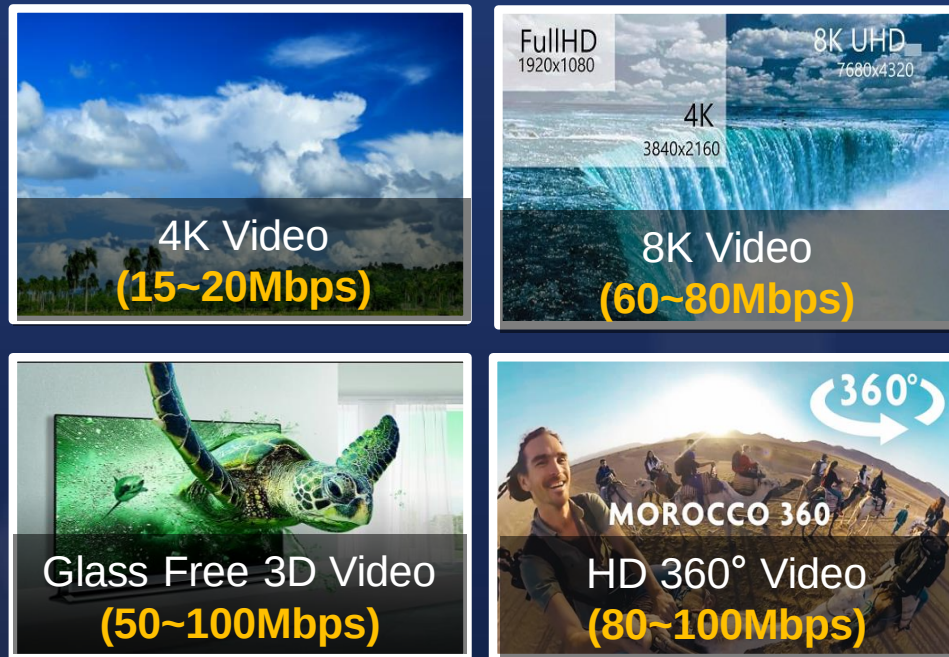
Use Case Example

- 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

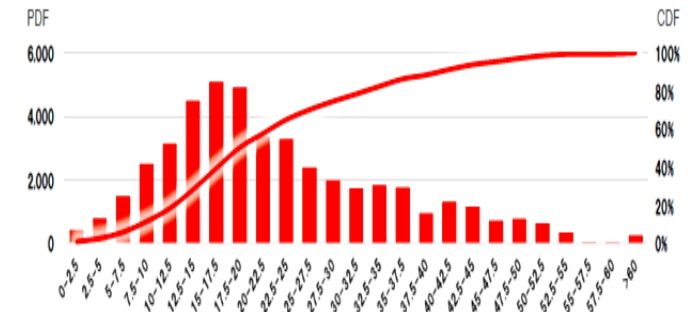
Use Case #1: 100Mbps Everywhere is the Benchmark to Deliver Better MBB Experience

100Mbps Satisfy Most Applications

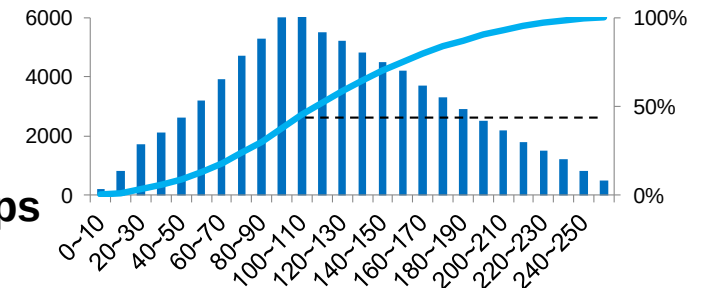


5G Target: Ave. Speed 100Mbps

**Current
LTE**
Ave. **22.9Mbps**

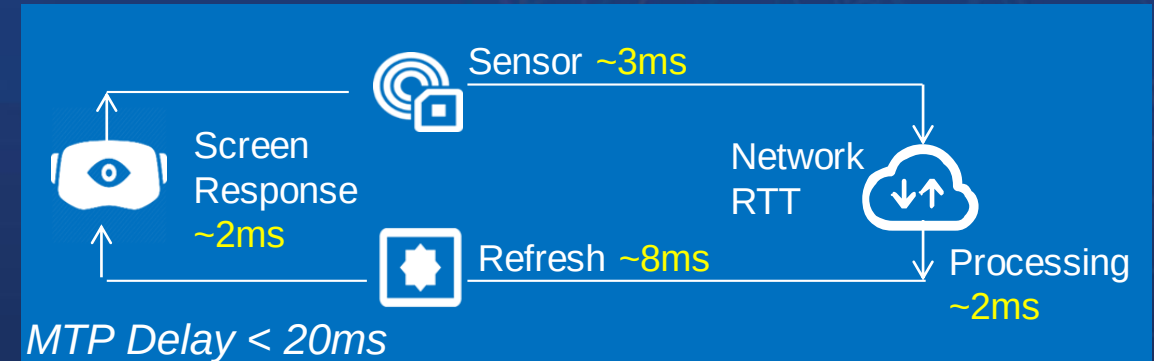


5G
eMBB Target
Ave. **100Mbps**



Source: Huawei Wireless X Labs

Use Case #2: Cloud Based AR/VR with High Requirements on the Network



Acceptable
Experience

125Mbps

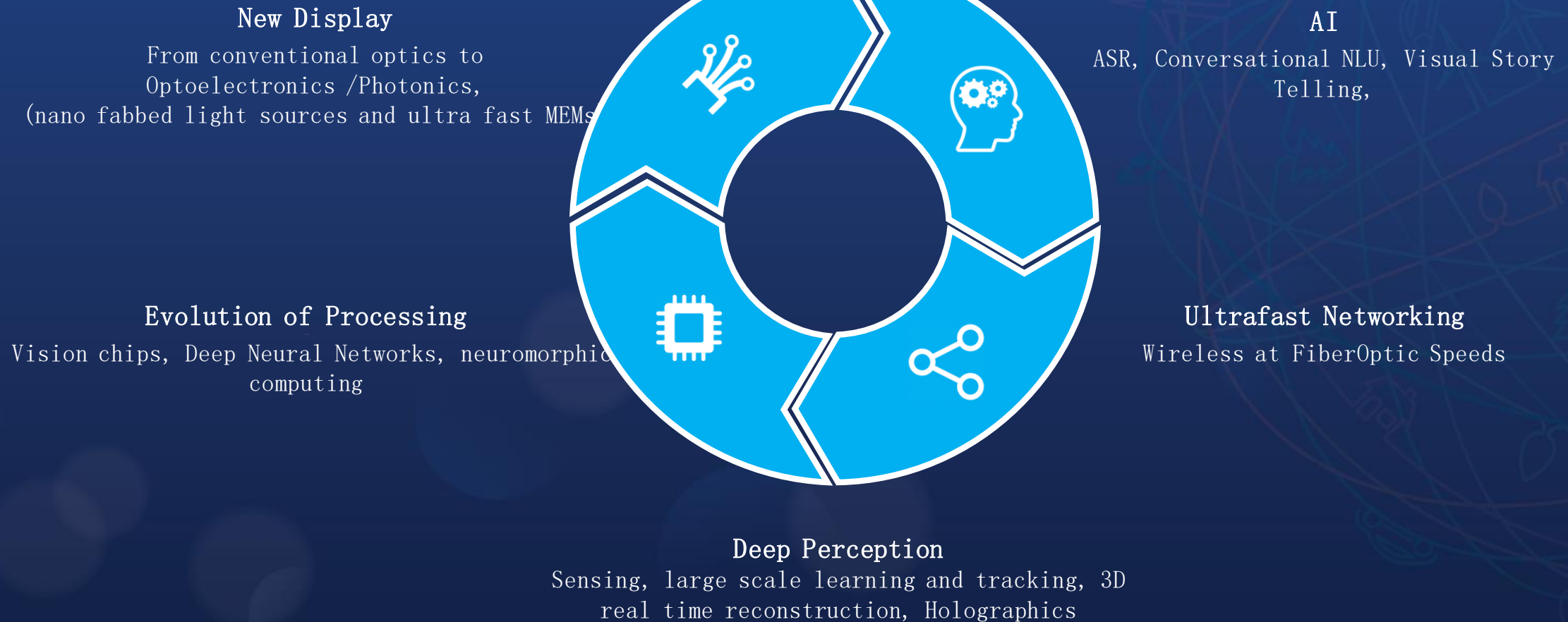
RTT Latency

Ultra Retina
Experience

3.2Gbps

< 5ms

Some Key technologies shape the VR/AR/MR landscape



Use Case#3: Autonomous Driving Will Commercialize in 5G Era

Stage 4 Full Automation 2020~



Tele-Operated Driving



Automated Platooning



Cooperative Autonomous Driving

...

5G

Stage 3 Partial Automation 2015~



Road Assistance



Smart Warning

LTE-V

Stage 2 Telematics 2000~

infotainment, on-line navigation,
remote diagnostics, e-call
communications...

2G/3G/4G

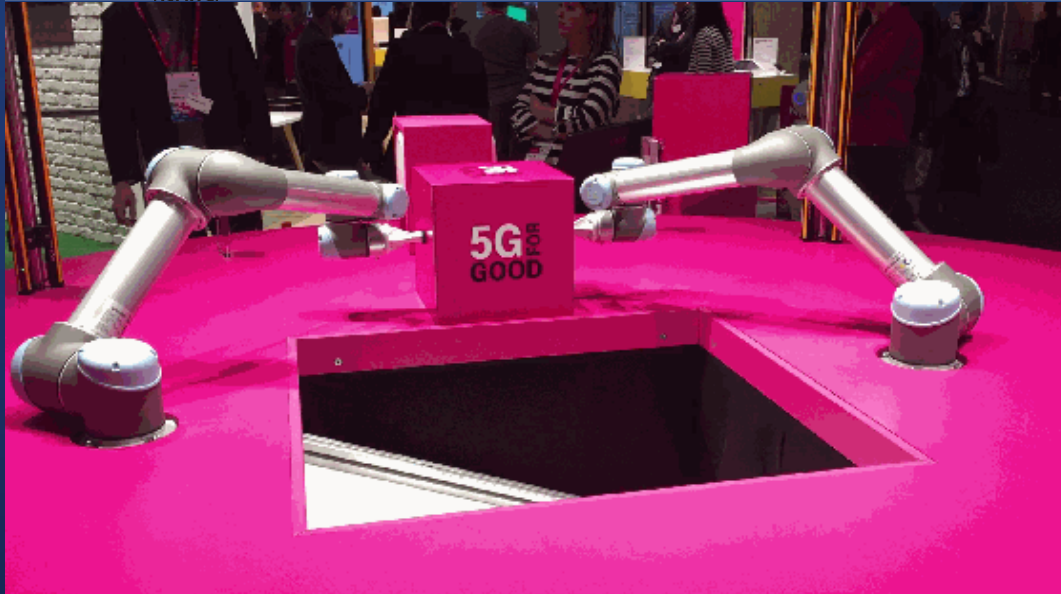
Stage 1 Roadside Communication 1990~

Wired / Wireless for RSU

Use Case #4: 5G Helps Make Factories Smarter and More Efficient



Wireless coordinated robots via 5G



Loading work at port



Plant manufacturing



E2E Network
Latency

5~100ms

5G/5G+ Enabled Output in Manufacturing by 2035: **\$3.4 Trillion**

Source: IHS The 5G Economy Report, 2017

Connectivity, sensors, analytics/AI, cloud, ...

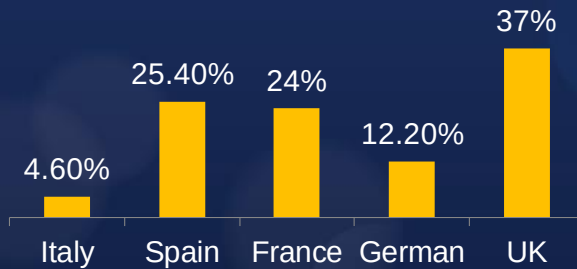
Use Case #5: Fixed Wireless Access for Home Broadband

Target & Existing Gap



Target: By 2020 **50%**
Households > **100Mbps**

Households > 30Mbps(%)



Target: By 2020 **100M**
Households > **100Mbps**

Households > 100Mbps(million)



Source: Broadband Europe Strategy 2015/ FCC 2016

5G Home Access

X Gbps Throughput

Fast TTM & ROI

Major use case for 5G
early deployment

US operators have taken a leadership position on this Use Case

5G WTTx Typical Scenarios and Use Cases

Urban Single house



- Typical user density: 500 – 1000 HH / km²
- Huge potential for business

Urban Multi Dwelling Unit



- Limited business feasibility for indoor deployment
- This Scenario is suitable for Fiber

Rural/Suburban



- Density: <300 HH/km²
- WTTX can be the only good choice for data access, but less business potential

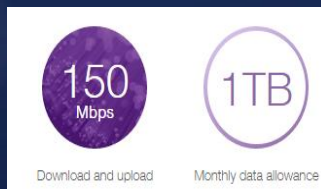
Internet 150

OTT Video

IPTV

VR(Game, Movie, Tourism), Monitoring

Existing Service



1Gbps



4K (25Mbps)/8K(100Mbps)



New Service

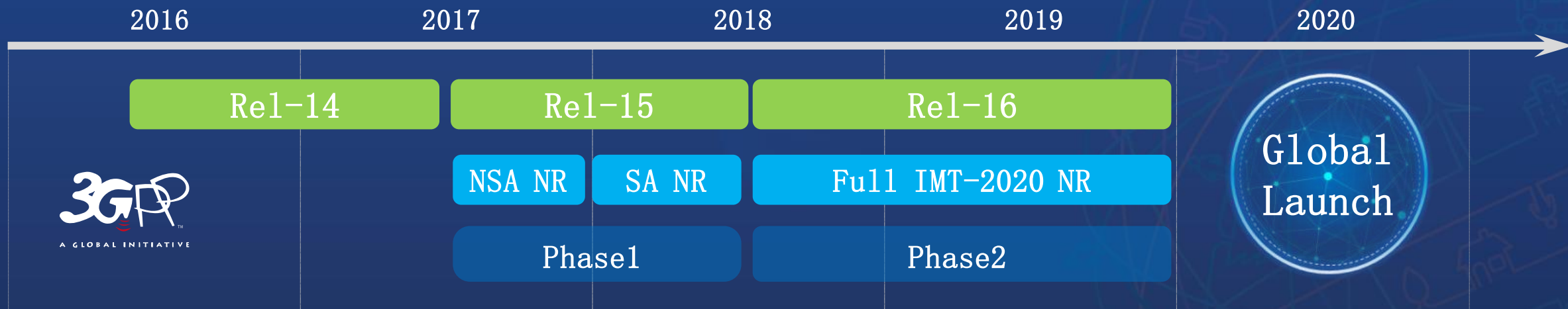


50Mbps-4Gbps

5G First Use case:
Wireless Fiber to Home



5G Standard Progress Update



Phase 1

NR Framework

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

Others: uRLLC

Architecture

- NR/LTE Co-existing
- UL&DL Decoupling
- CU-DU Split
- NSA / SA

Phase 2

NR Improvement

- New Multiple Access
- eMBB Sub6G Enhancement
- Self-Backhaul

Vertical Digitalization

- uRLLC Enhancement
- mMTC
- D2D
- V2X
- Unlicensed

3GPP is key standards body for 5G but there are other industry groups addressing many aspects of the network and business transformation

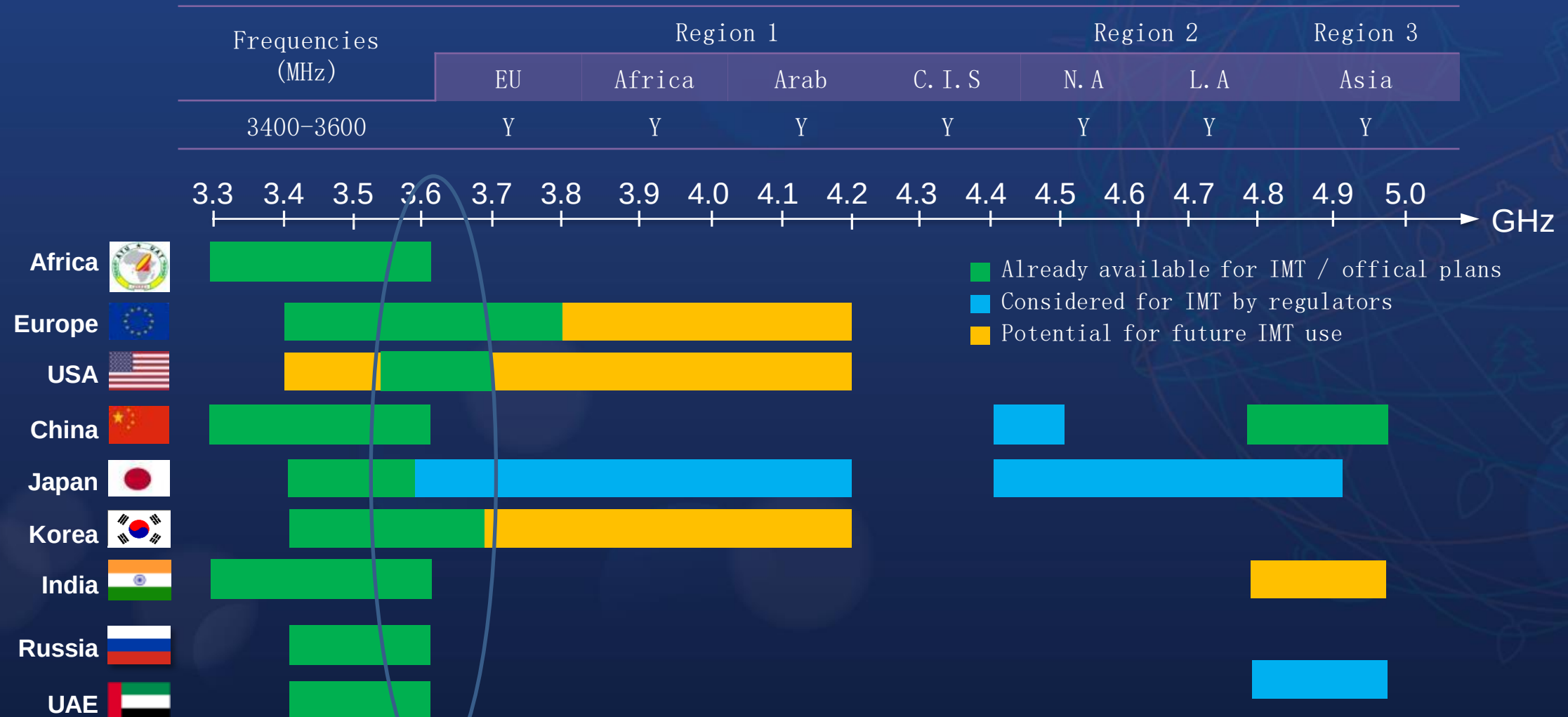
5G Supports Full Spectrum Access



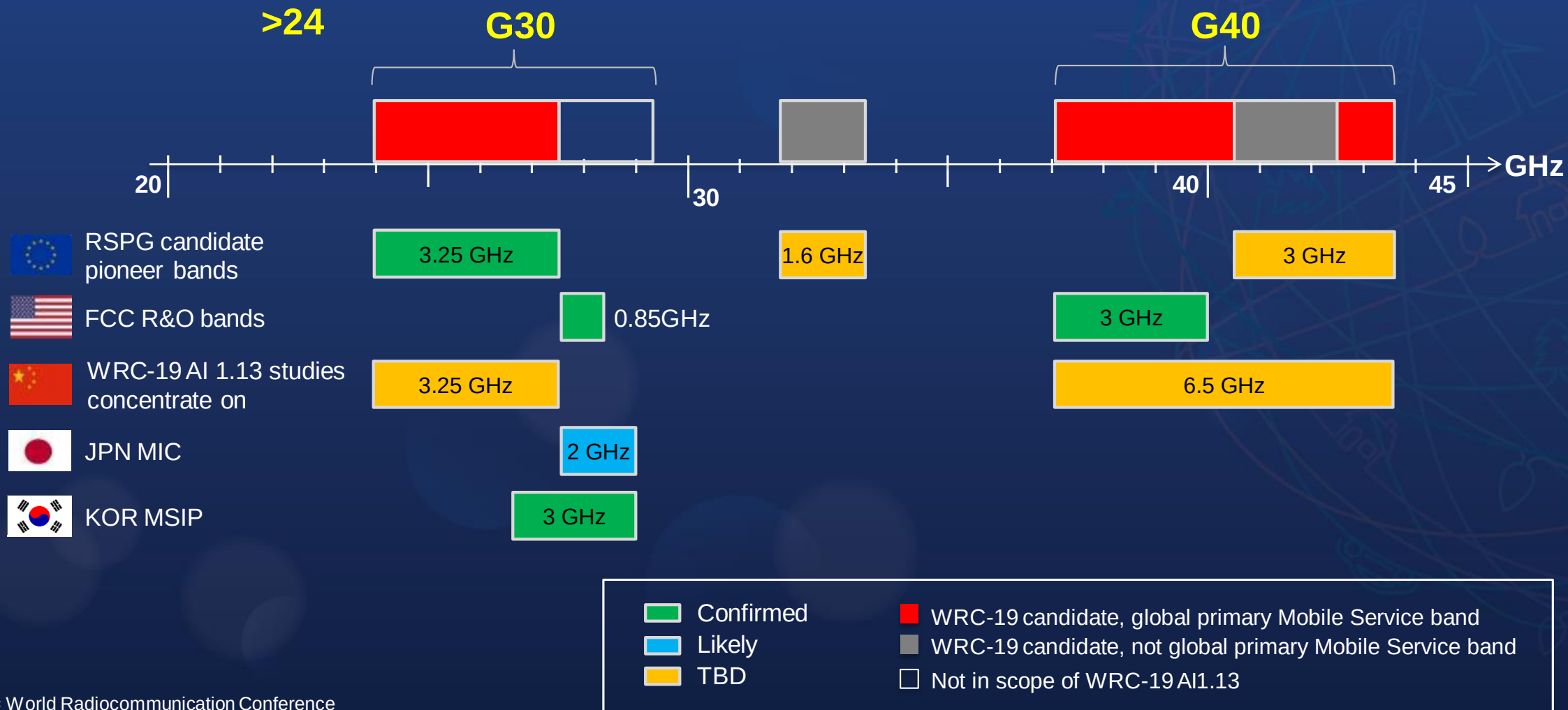
- All Spectrum available
- C-band Suitable for 5G as global harmonized spectrum.
- mmWave: Seeking for global harmonized spectrum on Group 30 & 40.

Challenges: Band mix, antenna densification, filters, optimal spectrum usage, ...

C-Band is Potentially Global Harmonized Band for 5G



30/40G will be Global Harmonized Band for 5G



WRC = World Radiocommunication Conference

WRC-19 will be vital to realize the ultra-high-speed vision for 5G

Challenges and Solutions



**Capacity and
Spectrum Efficiency**



Coverage

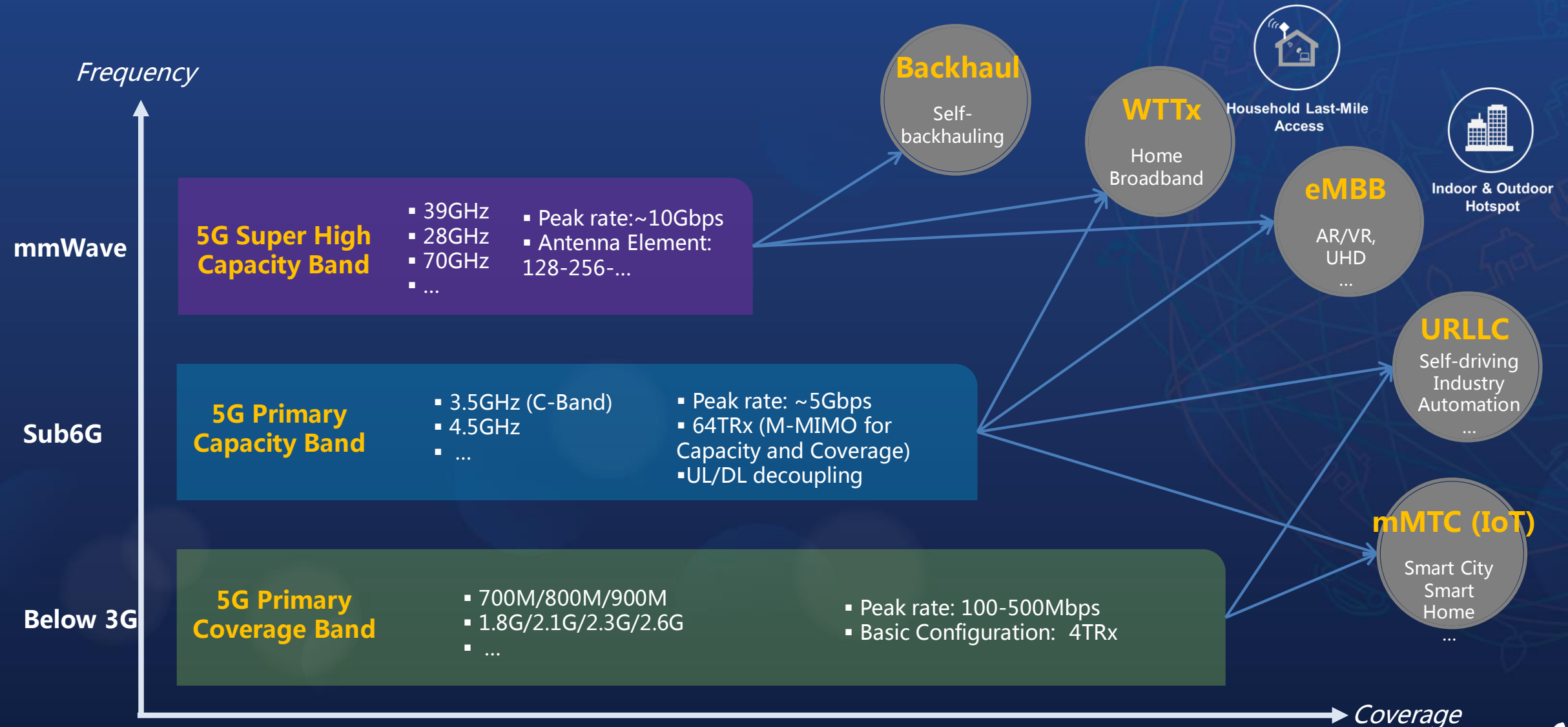


Cost



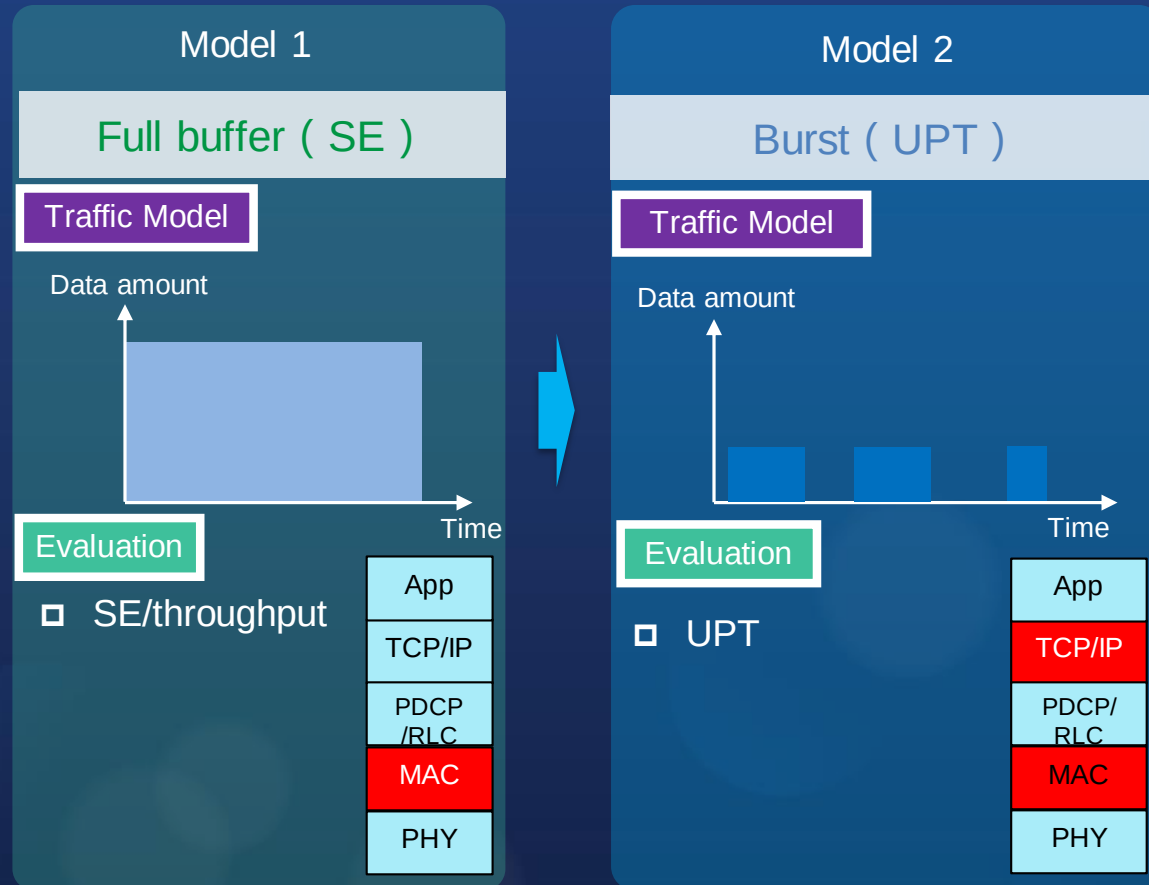
Network Architecture

Three Layers to Satisfy Demand of Diversified Services



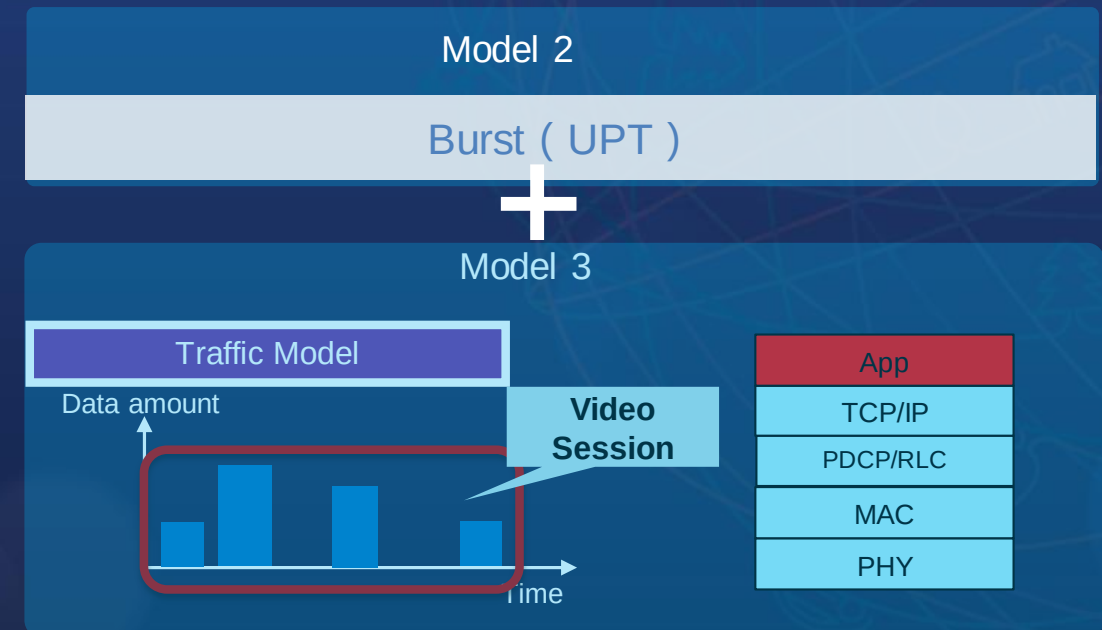
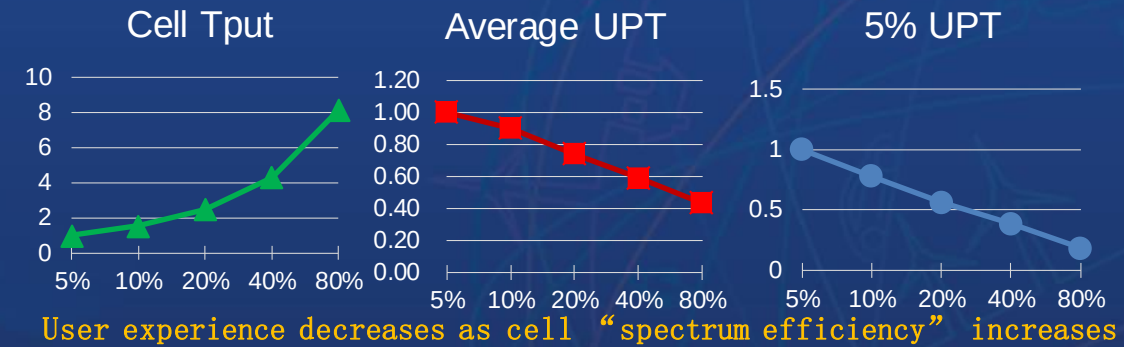
Many Challenges Remain ...

Rethink “Spectrum Efficiency” with QoS constraints



From “Spectrum Efficiency” to “ User Perceived Throughput”

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

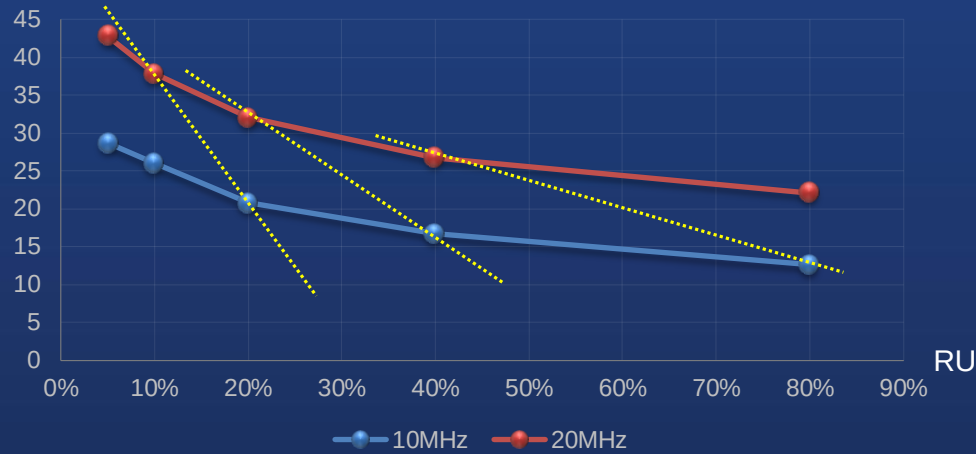


From UPT to Service Capacity

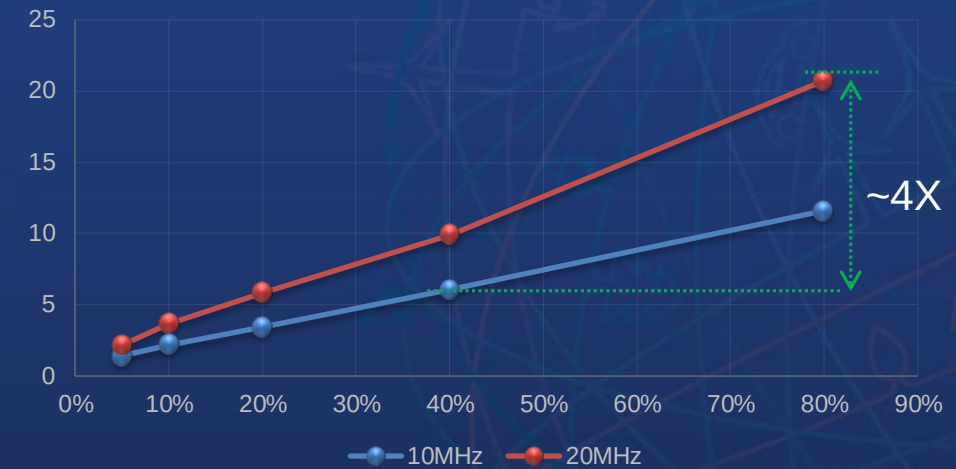
- Service capacity conditioned on user experience is ensured
 - UPT of 95% user no less than X
 - Reasonable network utilization ratio is hinted

“Spectrum Efficiency” Changes with Bandwidth

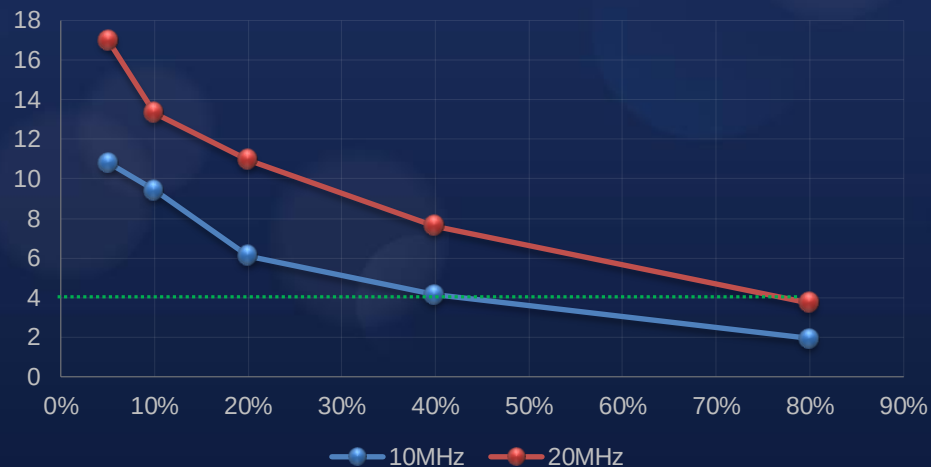
Average UPT(Mbps)



Cell throughput(Mbps)



5%UPT(Mbps)



“Spectrum Efficiency” Changes with Bandwidth

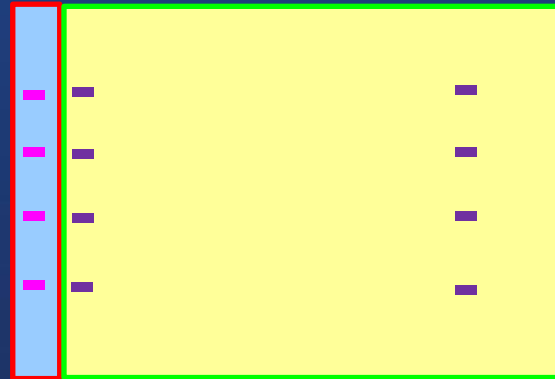
– e.g. if 4Mbps 5% UPT required, 20MHz cell throughput is 4 times of 10MHz (i.e. SE is 2 times)

User Perceived Throughput normalized with used resource Changes with Bandwidth

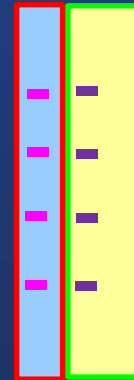
–20MHz UPT/Hz is approximately 2 times of 10MHz (a.k.a Trunking gain)

Observations: “SE” gain $\approx$ UPT gain?

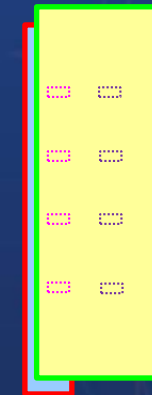
Rethink "Spectrum Efficiency" with Joint Pilot and Data



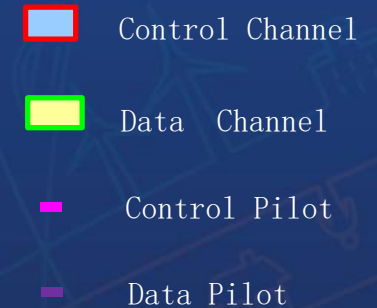
Control /Pilot/Data separately optimized



Self-contained transmission (short duration)
for analog switching (mmWave)
/Interference agility (unlicensed spectrum)
/URLLC



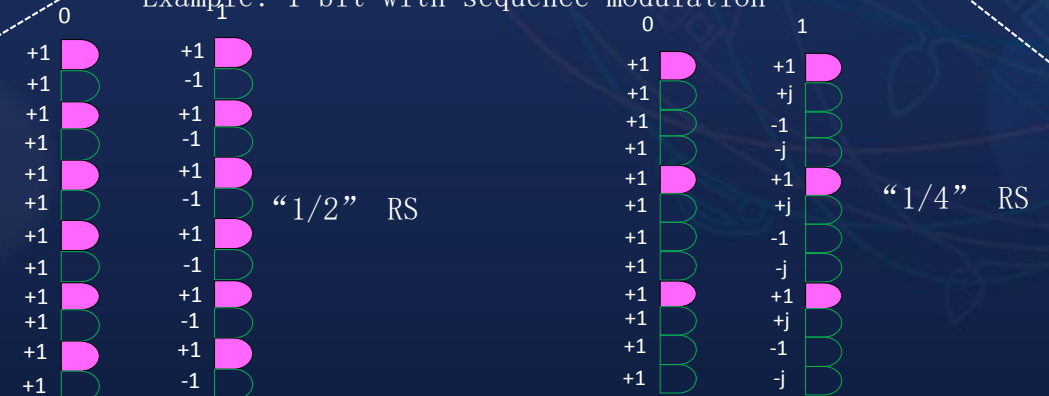
Self-contained transmission with
overlaid data/pilot/control
(Joint Optimization of
data/pilot)



Experiments show better performance of "1/2" RS against "1/4 RS" for 1 bit data; but "1/4" RS is better than "1/2" RS for 2 bit data

How to achieve the best "Spectrum Efficiency" with joint Pilot and Data?

Example: 1 bit with sequence modulation

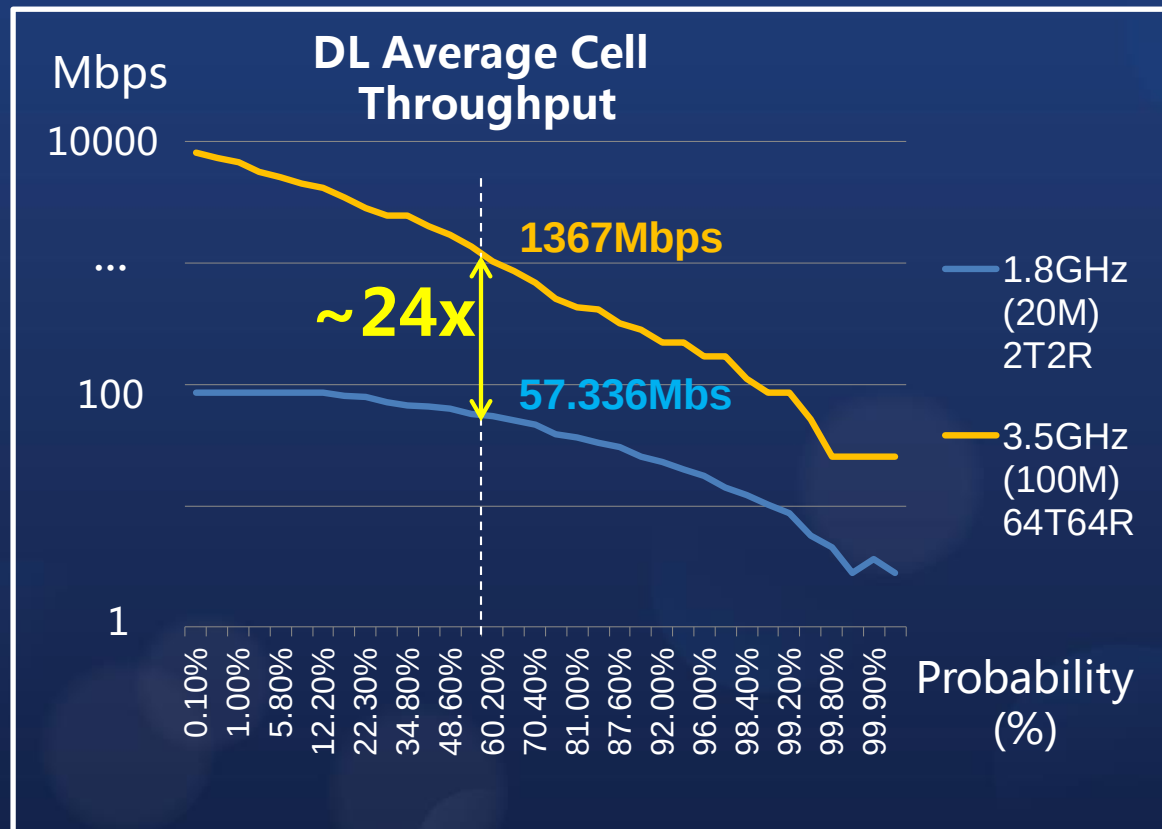


Sub3GHz: 4T4R will be the Basic Configuration

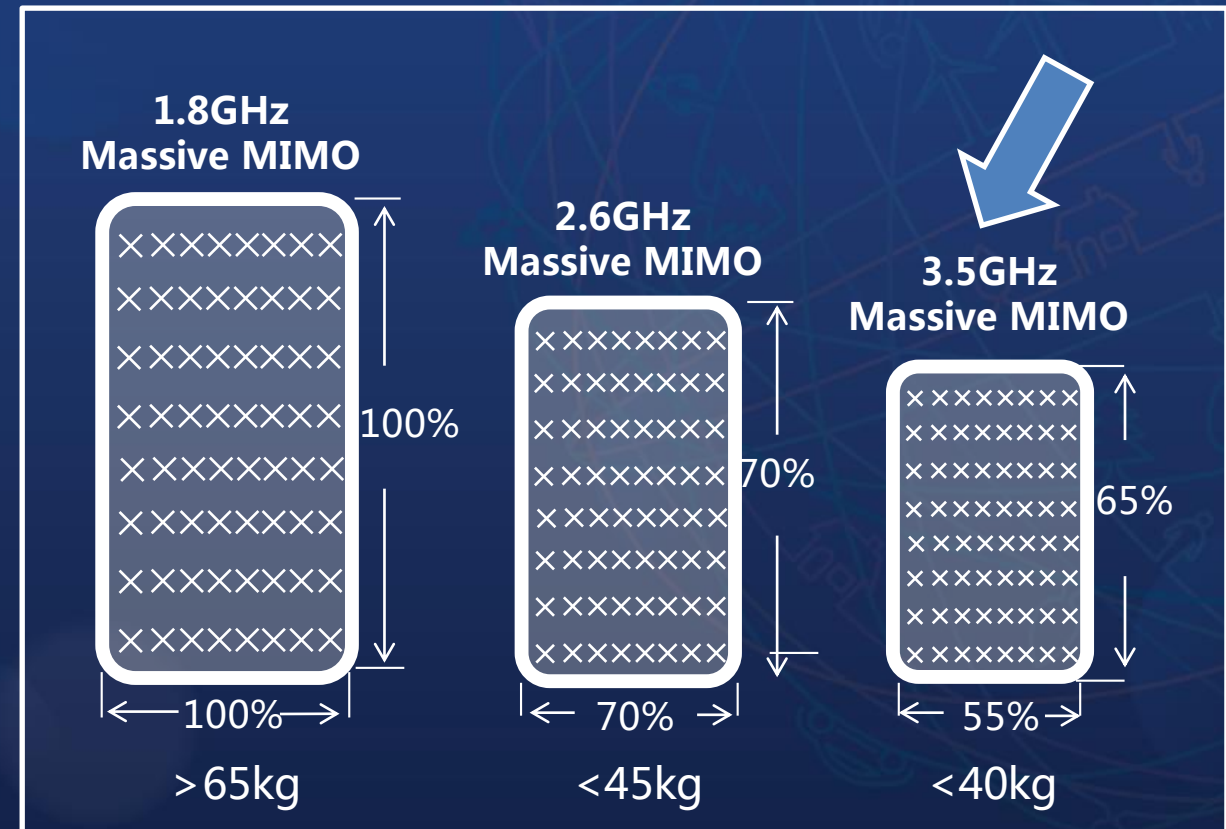


Sub6G with M-MIMO Boosts System Capacity

Sub6G + M-MIMO Boosts DL Capacity

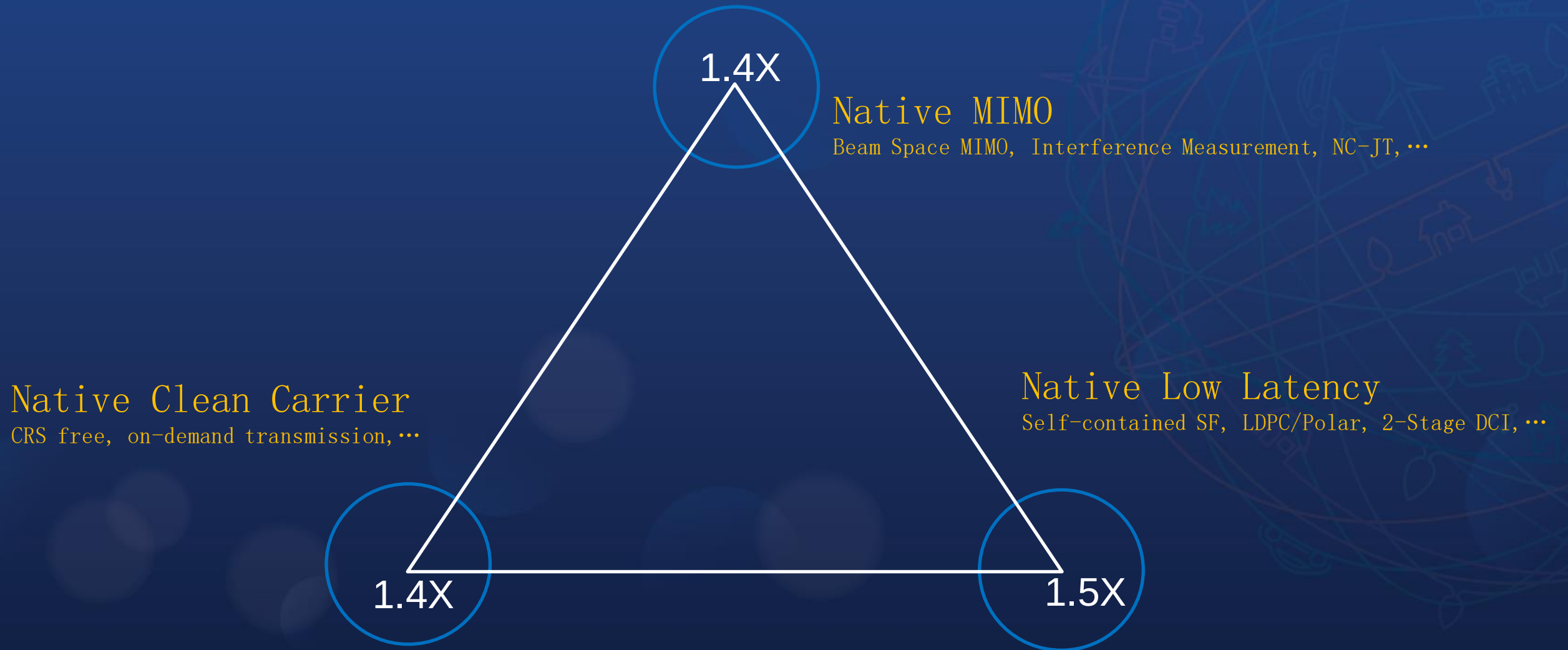


Support M-MIMO with Affordable Complexity



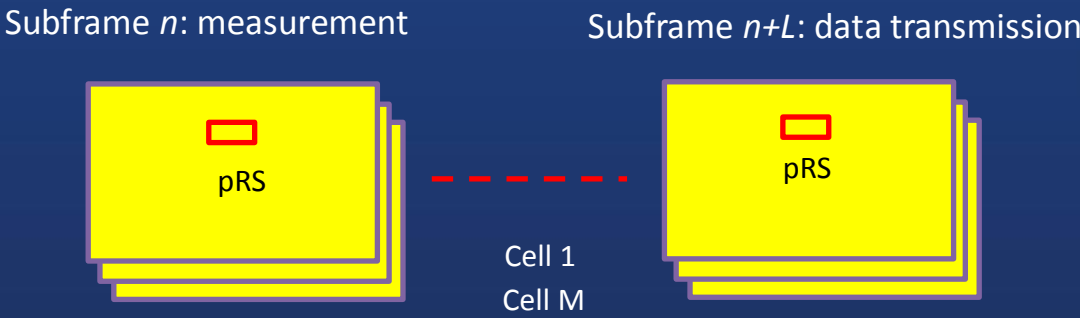
Challenges: Size, Weight, Performance Improvements...

eMBB for 5G : 3X UPT with same Tx/Rx antennas

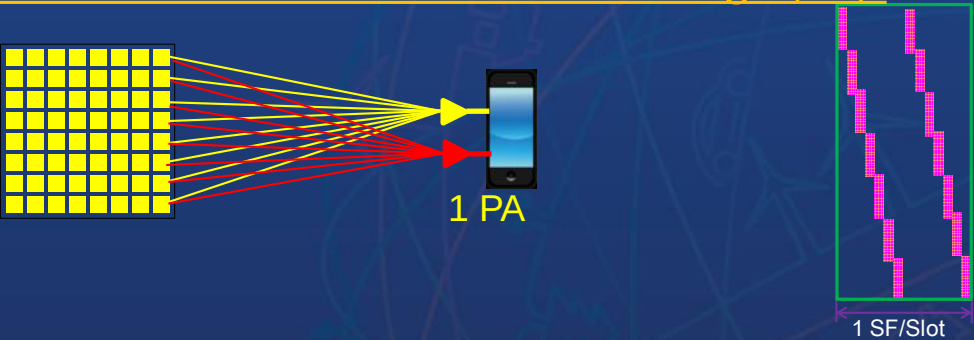


Native MIMO

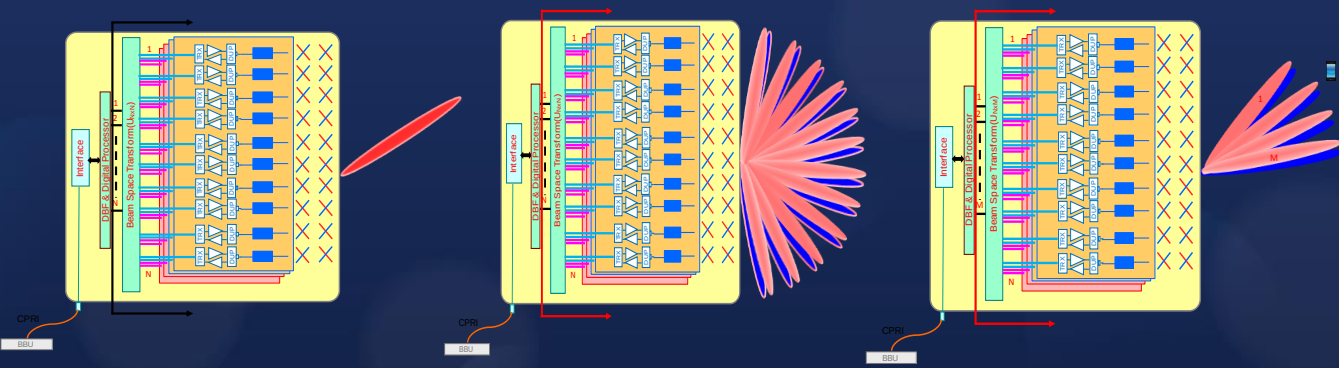
Interference Measurement (HL, LL)



Partial CSI and Condensed Sounding (HL)

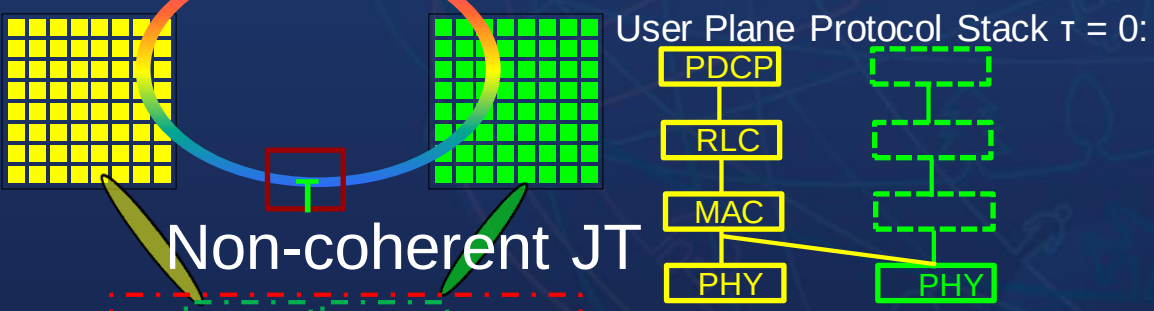


Beam Space MIMO (HL)

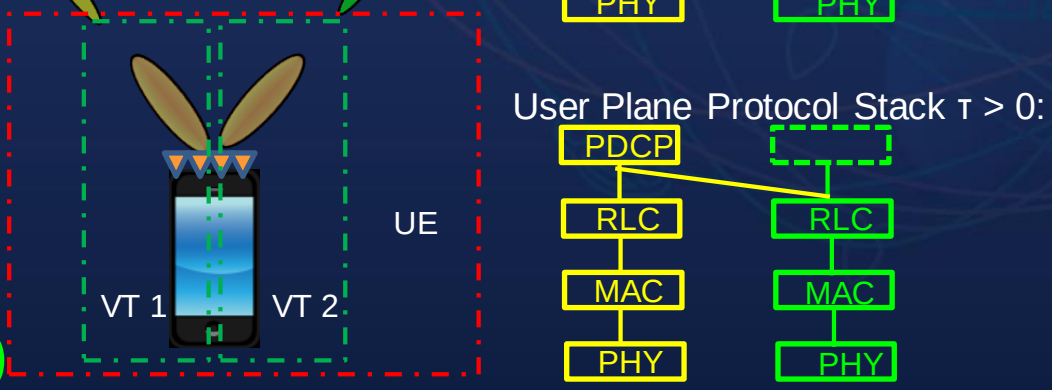


Baseline LTE Codebook (1 DFT ray) Beam Space MIMO (N DFT rays) Reduced Beam Space (M<<N DFT rays)

Non-coherent JT for low load

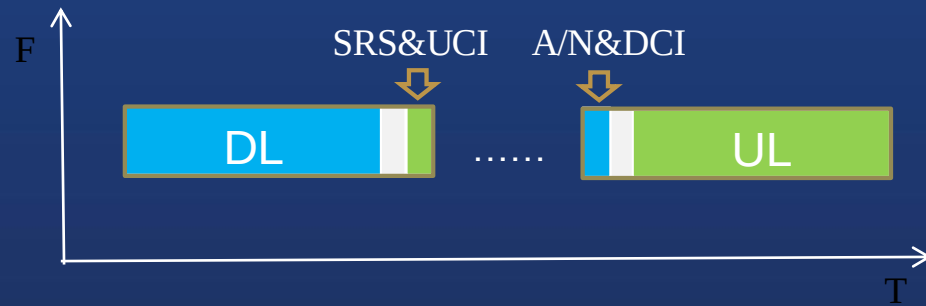


Non-coherent JT



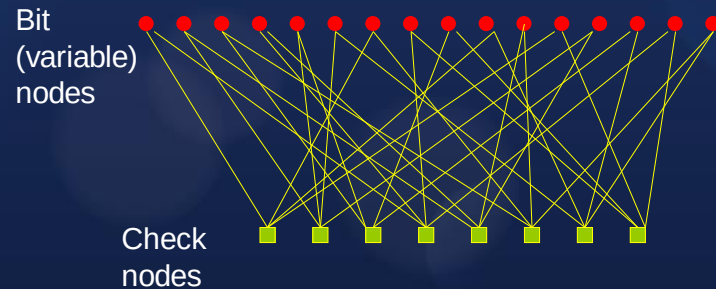
Native Low Latency

Self-contained SF



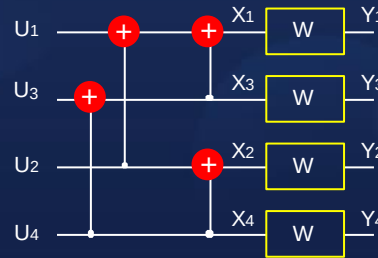
LDPC (for eMBB data)

- Much Lower Complexity and parallel decoding suitable for low latency

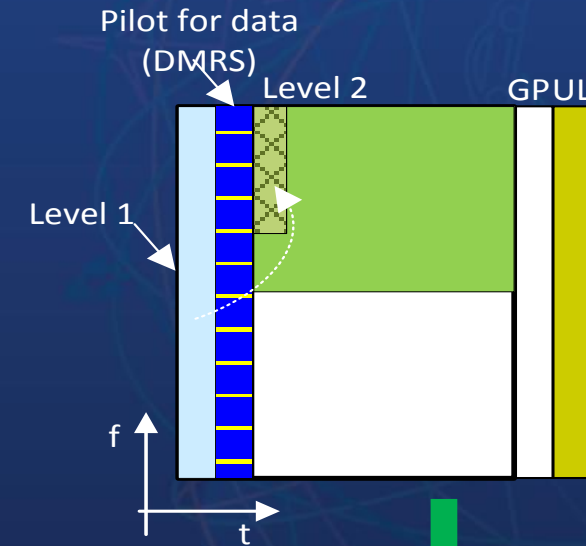


Polar (for eMBB control)

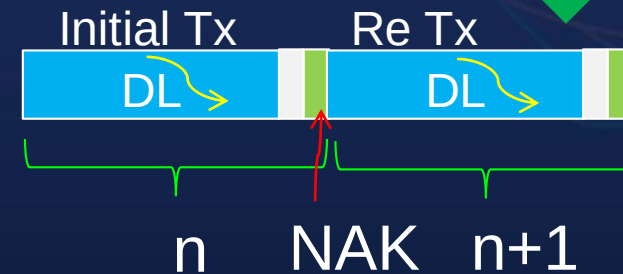
- PC-Polar
- CA-Polar



2-Stage DCI

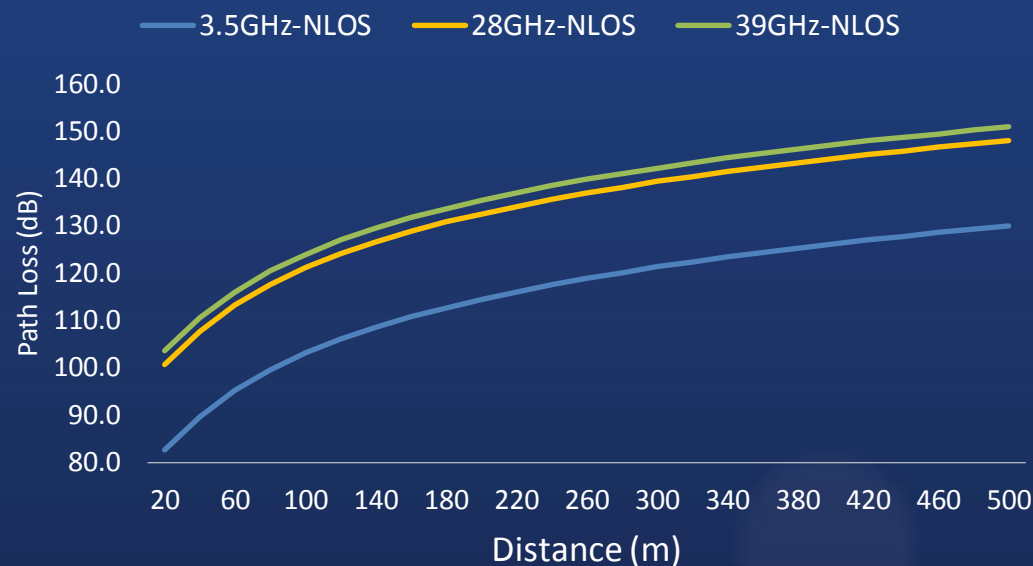


Super Short RTT



mmWave with High Penetration Loss & Propagation Loss

Providing Fiber Class Speed in Specific Scenarios



Path Loss	3.5GHz	28GHz	39GHz
100m	103.1	121.1	124.0
200m	114.5	132.5	135.4
300m	121.3	139.4	142.2
400m	126.2	144.2	147.1
500m	129.9	148.0	150.9



Glass Door



Glass Wall



Hollow Metal Wall



Hybrid Glass Wall

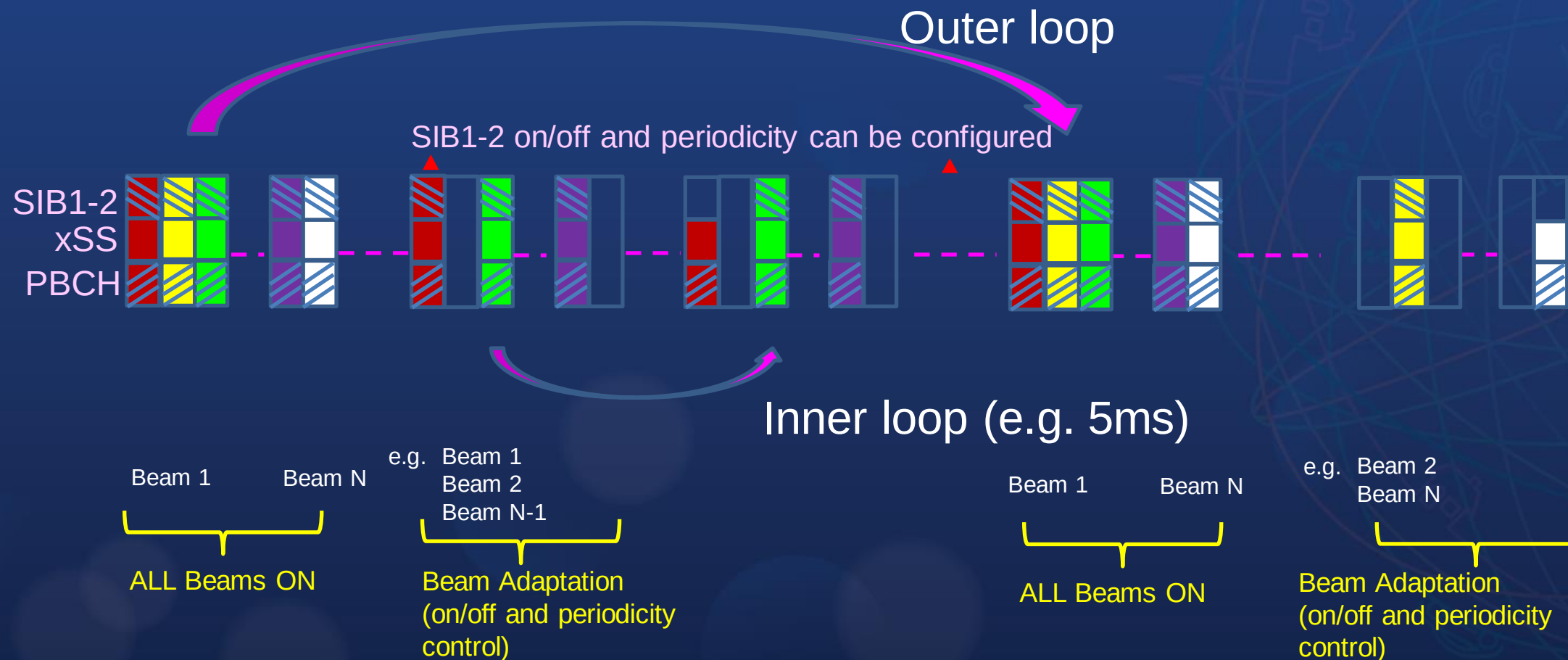


Uniform Concrete Wall

Penetration Loss	28GHz	39GHz
Glass Door(0.8cm)	3.5	4.5
Standard multi-pane glass(1.8cm)	14.6	20.9
IRR Hybrid Glass Wall	36.2	41
Hollow Metal Wall(5cm)	63	68.5
Uniform Concrete Wall(28cm)	64.9	78.8
Uniform Concrete Wall(42cm)	69.1	68.5

Challenge: How to deal with high losses on mmW

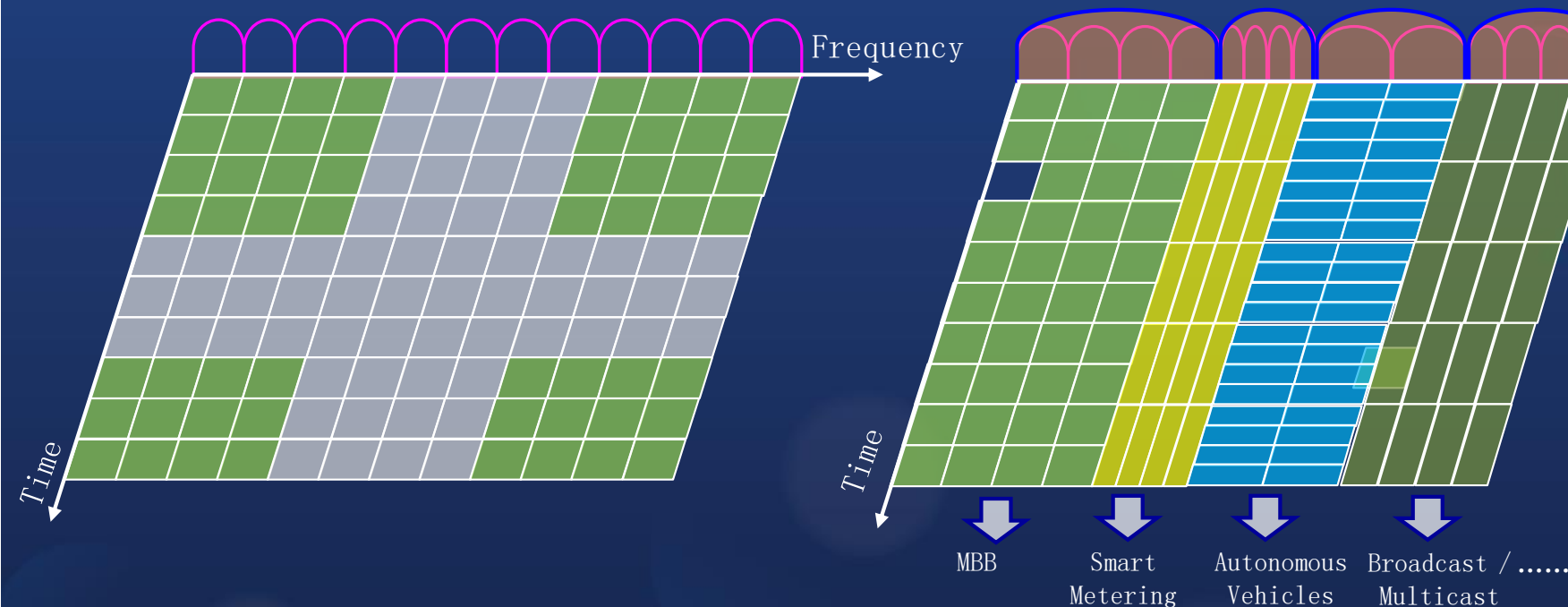
Beam Based Access



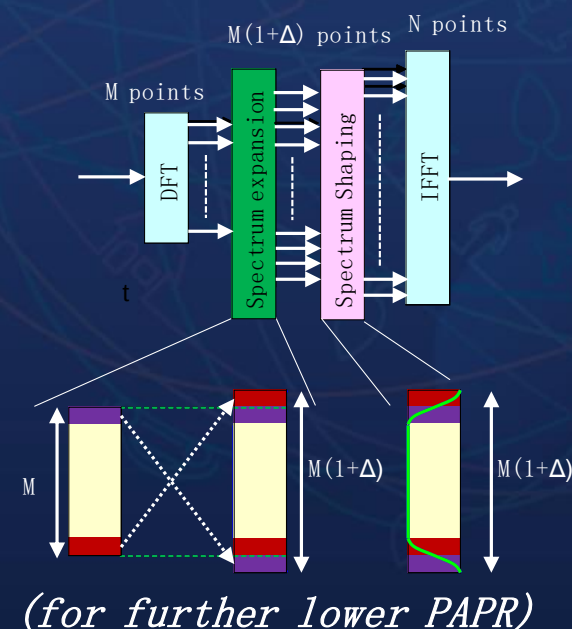
Low PAPR 5G Waveform

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
($\Delta=0$), standard transparent



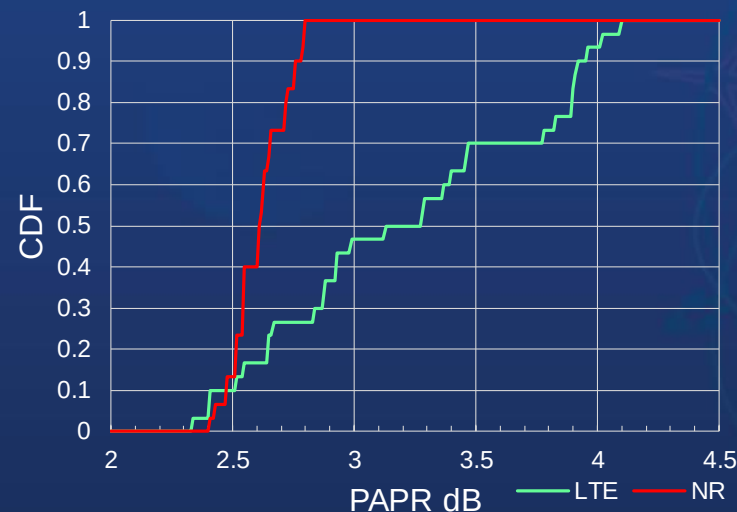
UL waveform is OFDM or DFT-S-OFDM
QPSK/16QAM/64QAM/256QAM
 $\pi/2$ BPSK is also supported for DFT-S-OFDM
(for lower PAPR)

Low PAPR 5G UL Pilot: new Computer Generated Sequences

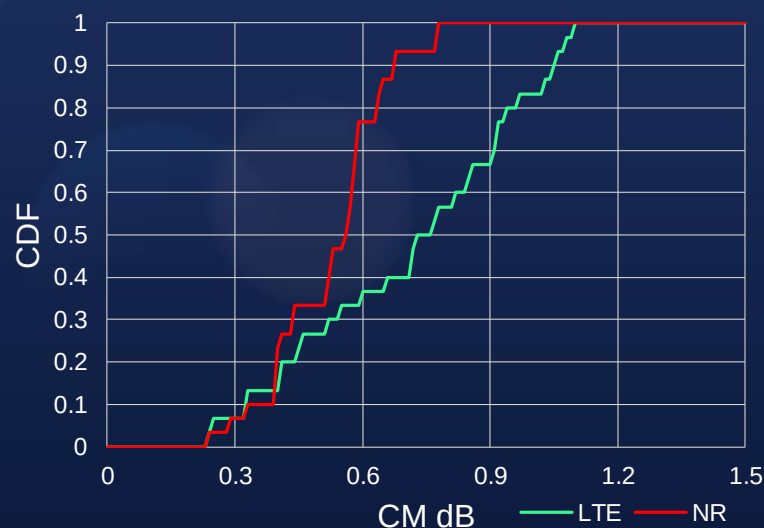
$$r_k(n) = \exp(j\pi\phi_k(n)/4)$$

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	-3	-1	-3	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
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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	-3	-1	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

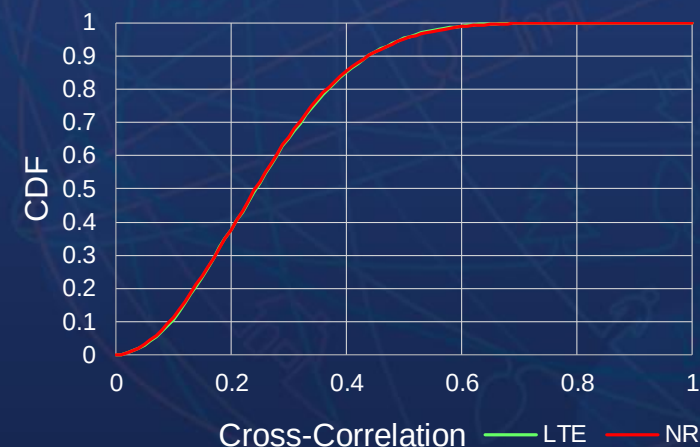
Peak to Average Power Ratio



Cubic Metric



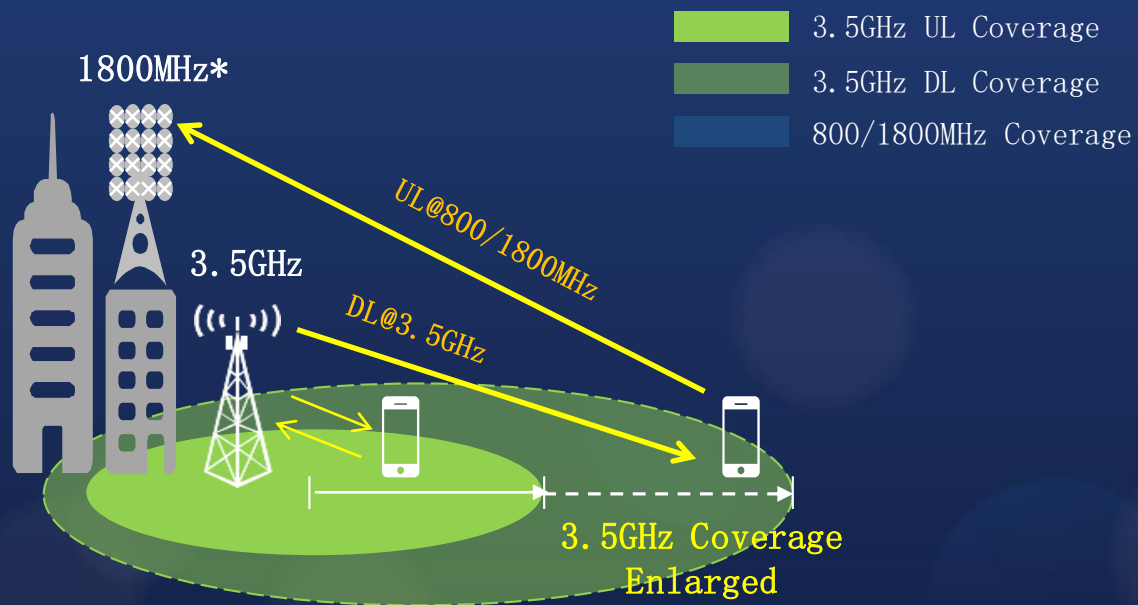
Cross-Correlation Coefficient



UL&DL Channel Decoupling Enlarges Cellular Coverage

Will comply with 3GPP Release 15.

Implement 3.5GHz Large-Scale Deployment



* Could be any low band frequency

UL@1800MHz + DL@3.5GHz



~2X Coverage Extended

How to deal with coverage gap? This is one way.

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



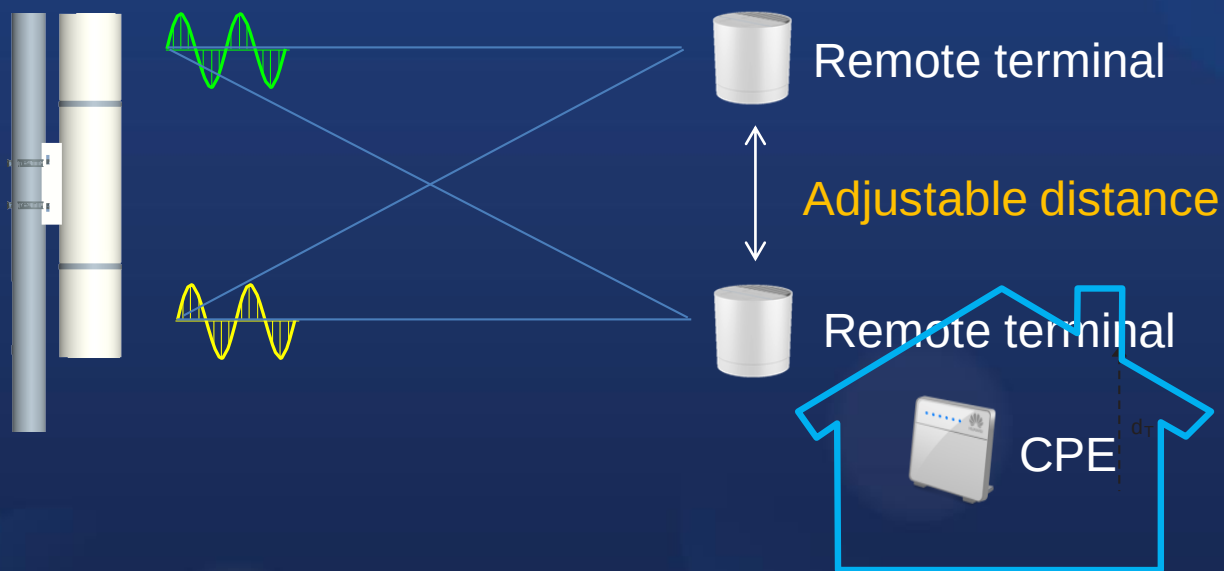
gNB

(*3.5GGz/28HGz)

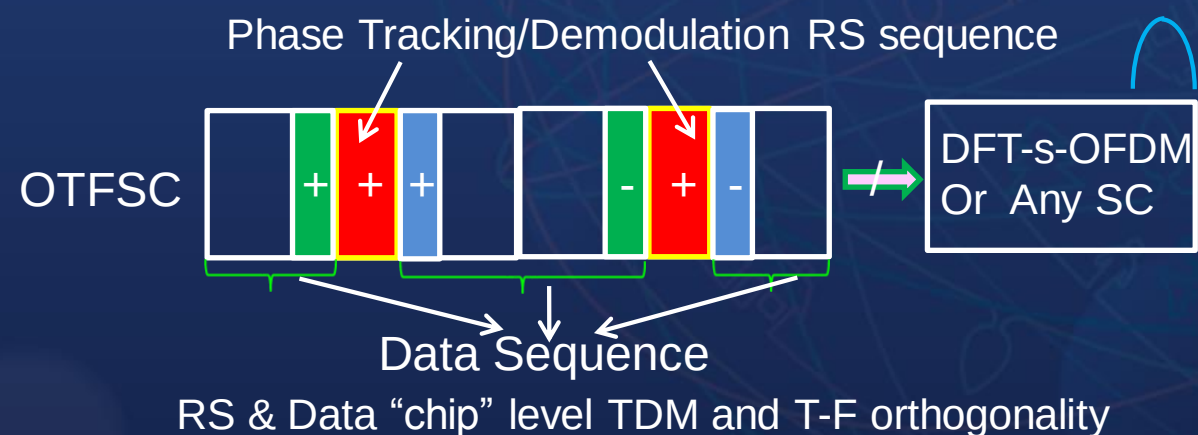
299m/220m

133m/74m

WTTx: Advanced Techniques



LTE



Adaptive LOS MIMO for throughput boosting @ LOS channel

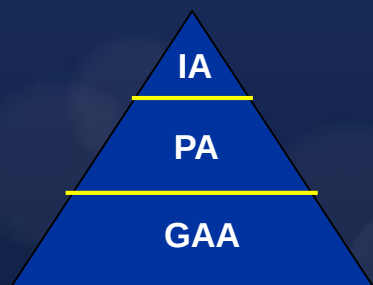
Orthogonal Time-Frequency SC (OTFSC) waveform for good PAPR @ NLOS channel

Network/Spectrum Sharing for reasonable performance/cost tradeoff

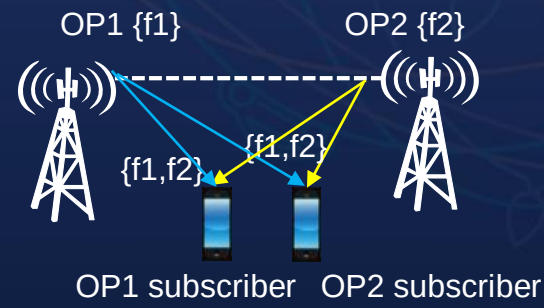
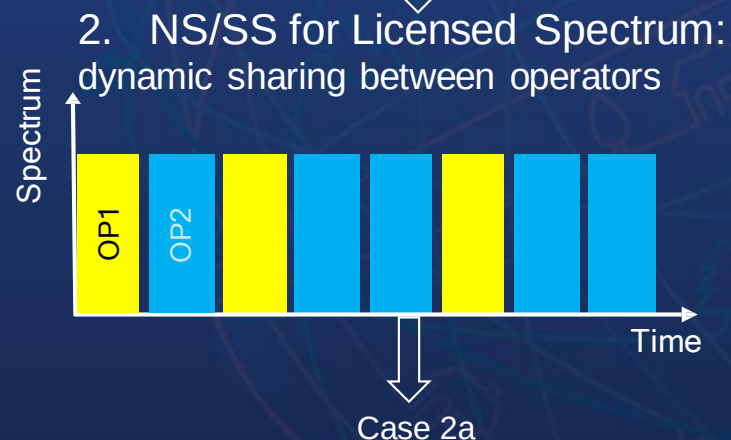
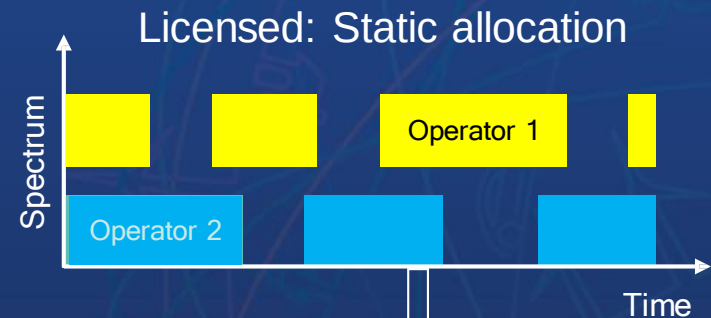
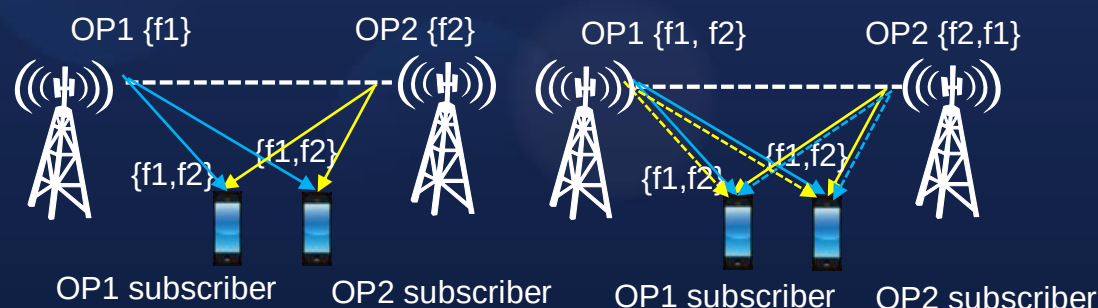
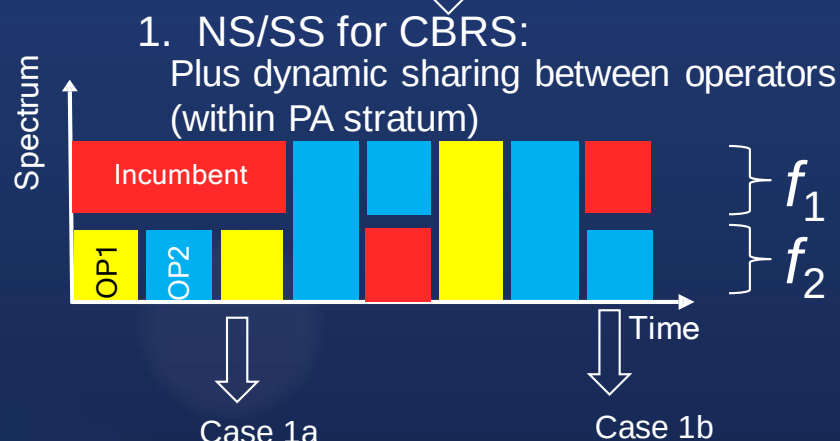
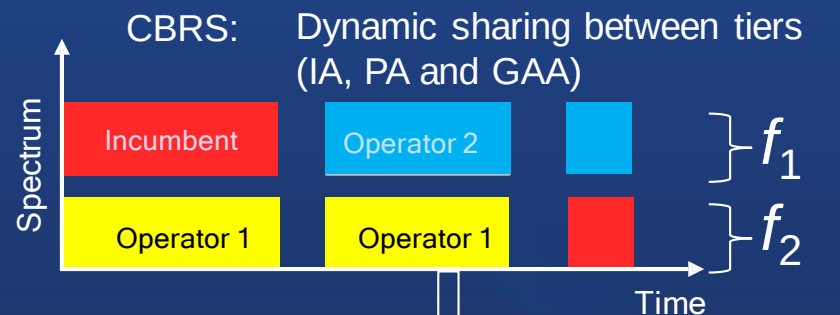
Licensed spectrum
Exclusive use

Unlicensed spectrum
Shared use
Example: 2.4 GHz / 5 GHz / 60 GHz

Shared spectrum
New spectrum sharing paradigms
Example: 2.3 GHz Europe (LSA) / 3.5 GHz USA (CBRS¹)



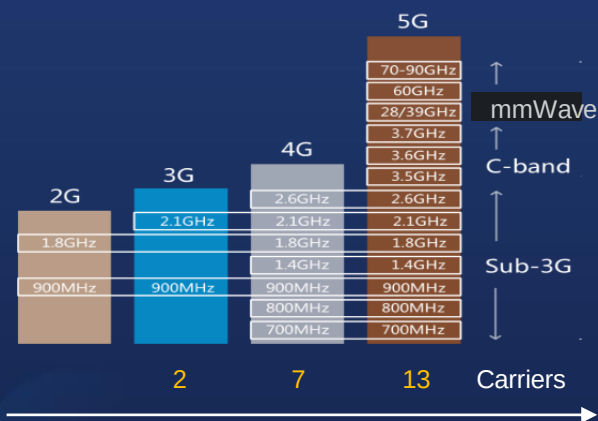
¹: 3 tiers model of CBRS



5G Network Calls for Cloud Architecture

More Bands...

5G Will be Full Spectrum Access.



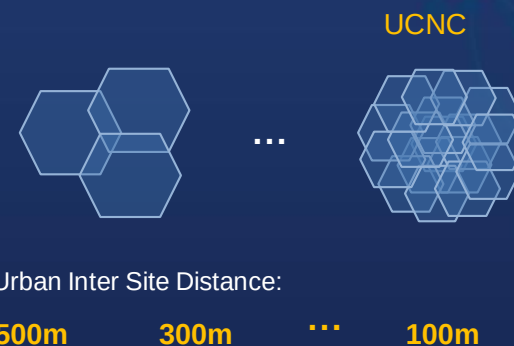
Higher MIMO...

Massive MIMO is the trend.



Denser Site...

More sites to meet traffic challenges.



More Complicated O&M...

Simplified O&M Hosted in CloudRAN.

~10,000 parameters
Per gNodeB

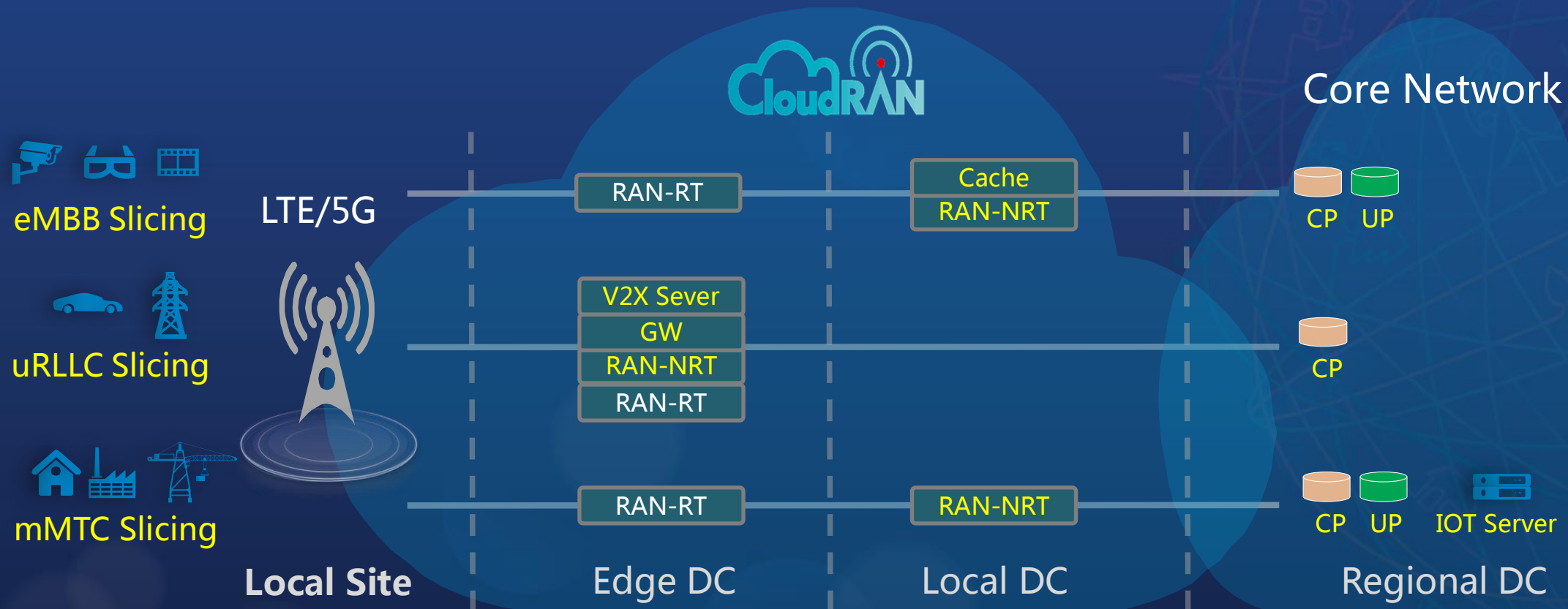
4 Layers
5G&4G&2/3G

~X
Ng/Xn interface

CloudRAN as 5G-oriented architecture will support (manage, orchestrate, ...) an ultra complex network

Key domains: AI, NFV, SDN, Cloud Native, TelcoCloud, etc. Most importantly, what do these mean in the context of RAN and network Cloudification?

Flexible On-demand Deployment for Diversified Services



RT – Real time
NRT – Non-RT

Better
Experience

CloudRAN On-demand Tradeoffs

Cost-
Efficiency

Thank You
