Security Level:

Engineering Antenna Arrays for mmWave 5G Systems

R&S 5G & IoT Seminar

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HUAWEI

Christian Mazzucco
System Engineer, Wireless Dept.
MWCC Milan

Evolution AND Revolution
Leveraging on one unified standard

2014 2015 2016 | 2017 | 2018 | 2019 | 2020

RAN

Rel-12 | Rel-13 | Rel-14 | Rel-15 | Rel-16

Phase1.1
None-Standalone
NR

Phase1.2
Standalone
NR

Phase2
Full IMT-2020
NR

5G
Global
Launch

Huawei

First stage accelerated to meet early demands

1st Version for commercial use

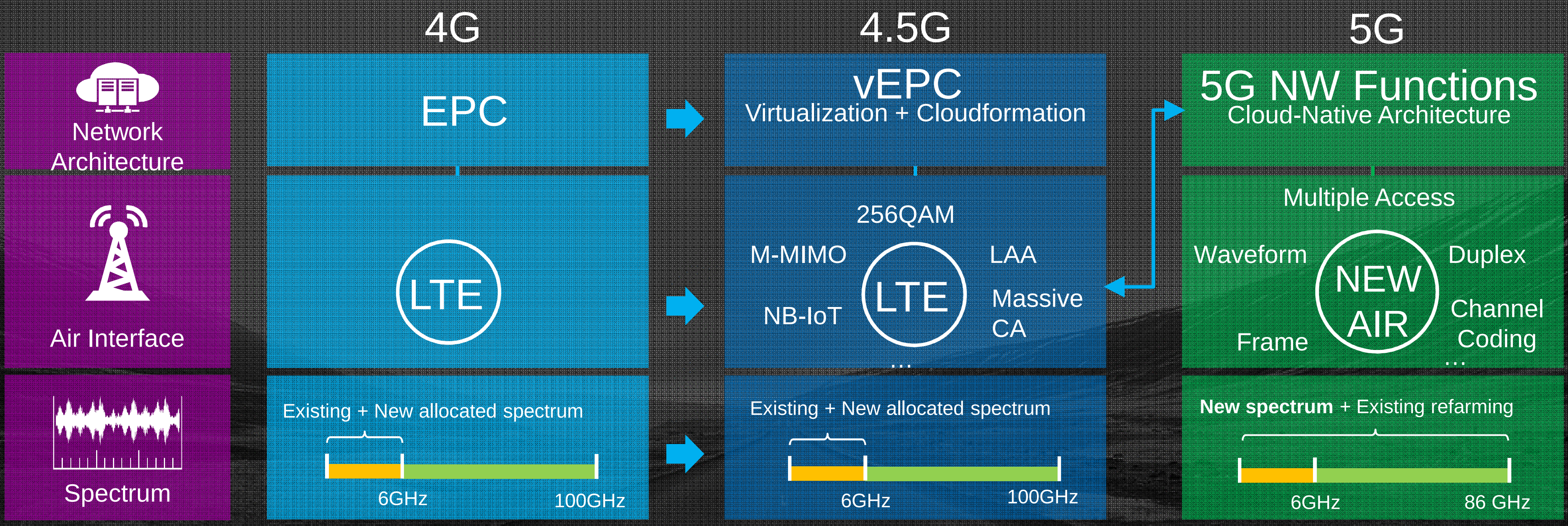
Winter Olympic Games in South Korea in February 2018

Version for all 5G scenarios

5G comprises:

- New Radio (NR)
- Evolution of LTE Advanced Pro
- NextGen Core
- Evolution of Evolved Packet Core (EPC)

5G Revolutionary Road



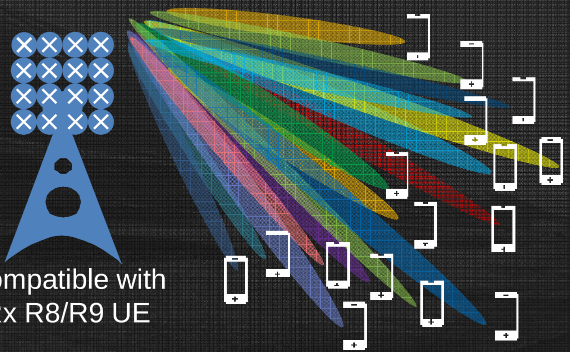
50 ms		10 ms		1 ms
600 Mbps		1 Gbps		10 Gbps
IoT:10K / Km^2 Site:<300m	⇒	IoT:100K /KM^2 Site:<100m	⇒	IoT:1Million/KM^2 Site:<50m
CoMP; CA (5CC) ;4*4 MIMO		FDD 8T8R / TDD 16T16R		SCMA; f-OFDM; Polar Code

Enabling Technologies
C and Ka-band M-MIMO Boosts Capacity with *Affordable* Complexity

C-Band + M-MIMO
boosts capacity with affordable complexity

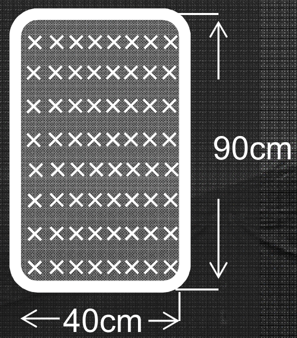
Sub6
(3.5GHz 100MHz, 1.8GHz 20MHz)

64T64R: 16+ Layers MU-BF



Compatible with
2Rx R8/R9 UE

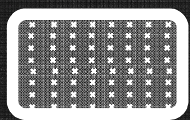
3.5GHz
Massive MIMO



40kg

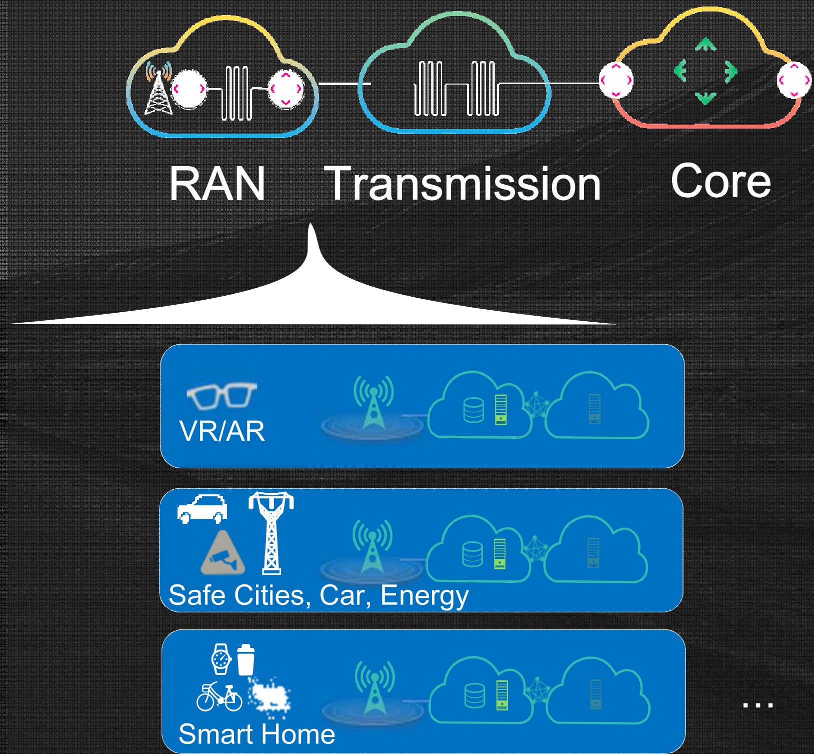
\+ mmWave
(28GHz/40GHz 400/800MHz)

Ka-Band + BF
boosts capacity



12 x 10cm 30GHz
array size

Cloud-native architecture for E2E Slicing



5G Use Cases
AR/VR and WTTx

AR/VR market has huge potential by 2025

TV
$99bn

AR/VR
$110bn

Source: Goldman Sachs, AR&VR Report

More speed/capacity required for AR/VR

Normal experience: 48.94 Mbps
3960(pix) X 2160(pix); 60fps

Excellent experience: 1.29 Gbps
12000(pix) X 7800(pix); 120fps

Source: Huawei wireless X Labs

"WTTx"
last-mile "fiber in the air" for households

Households with Internet globally

> 10Mbps	0.3 B
< 10Mbps	0.4 B
No Access	1 B

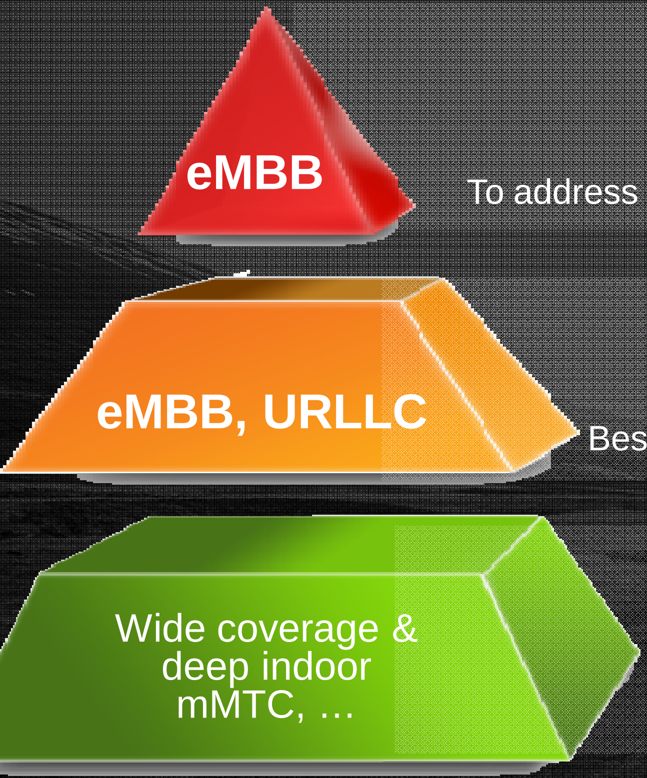
Source: ITU 2015 ICT Facts

WTT*x* provides

Fiber-like experience

Fast TTM & ROI

Spectrum for 5G



High Frequencies

Super Data Layer

To address specific use cases requiring extremely high data rates

Above 6GHz

N x 100 MHz assignments

Medium Frequencies

Coverage & capacity Layer

Best compromise between capacity and coverage

2100 / 2300 / 2600 / 3x00-4x00 MHz

up to 100MHz assignments (contiguous when possible)

Low Frequencies

Coverage Layer

Wide and deep coverage

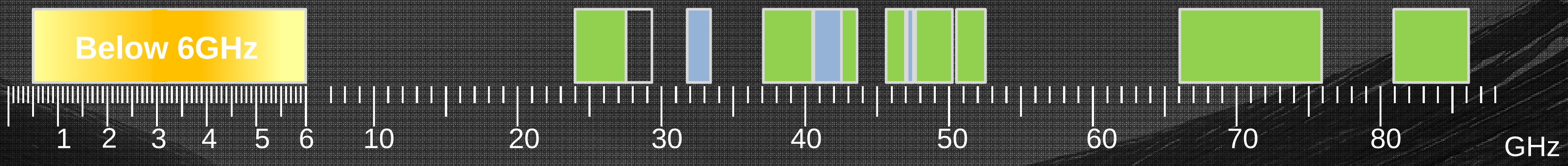
Sub-700 / 700 / 800 / 900 / 1400 / 1800 MHz

(up to 20MHz paired / unpaired)

5G requires spectrum from the three layers in parallel.
Each Mobile-Network-Operator will identify its specific most suitable combination of bands.

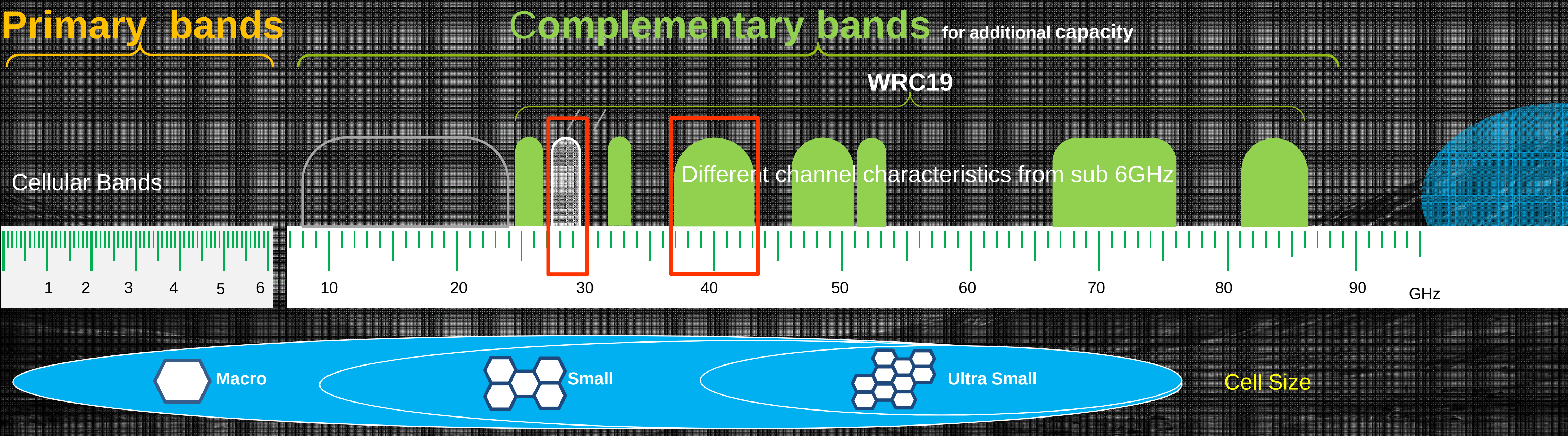
5G Needs Spectrum BELOW AND ABOVE 6GHZ

- Higher and lower frequencies are both needed to meet multiple use case scenarios



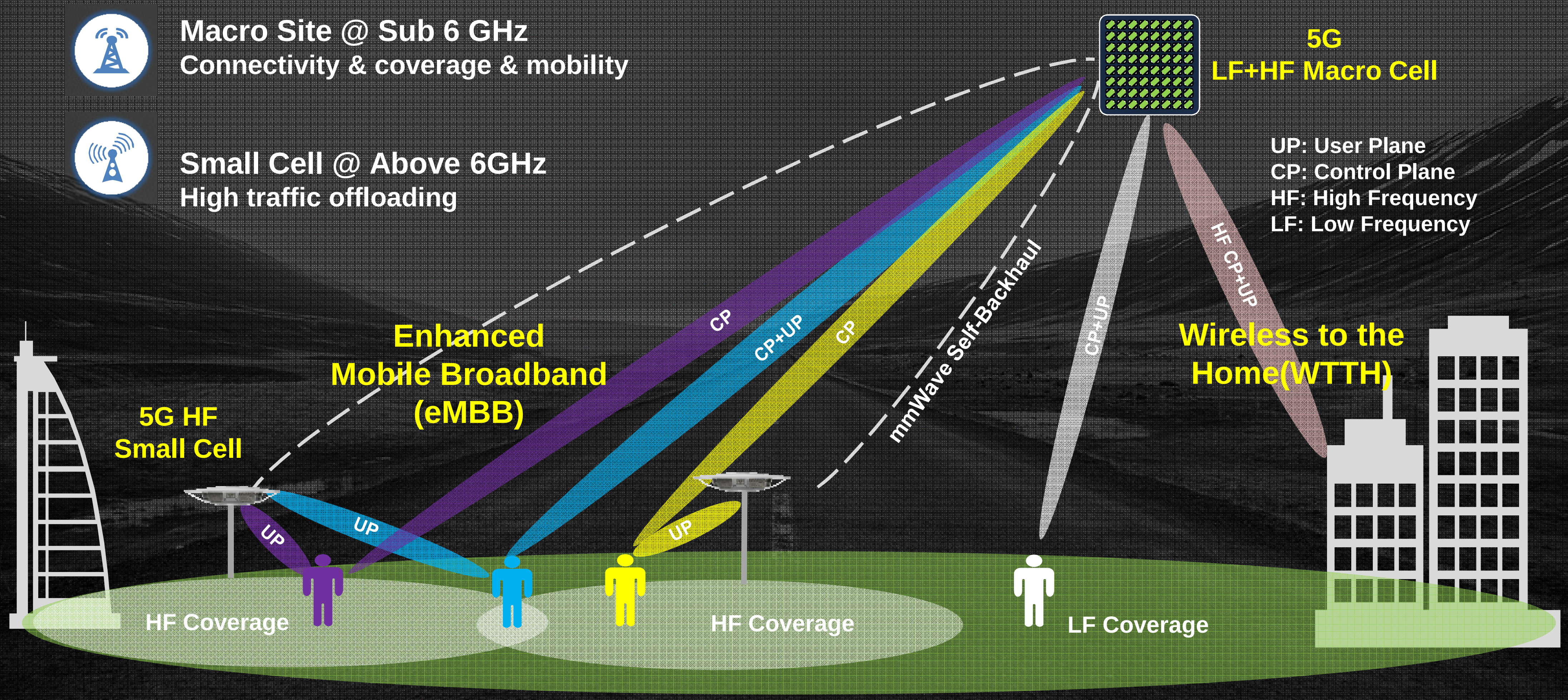
- Spectrum below 6GHz
  - Wider coverage allowing cost effective delivery of mobile services
  - Bandwidths considerably wider (in the order of 100s of MHz) than those of today, providing a combination of capacity and coverage
  - New bands below 6GHz should be made available for 5G
- Spectrum above 6GHz
  - Needed for applications requiring extremely high data rates
  - May accommodate wider channel bandwidths (e.g. up to 1GHz per MNO) within a coverage area that may reach 100s meters
  - Propagation characteristics may lead to higher spectrum reuse and may facilitate sharing with existing services

Complementary Bands for 5G



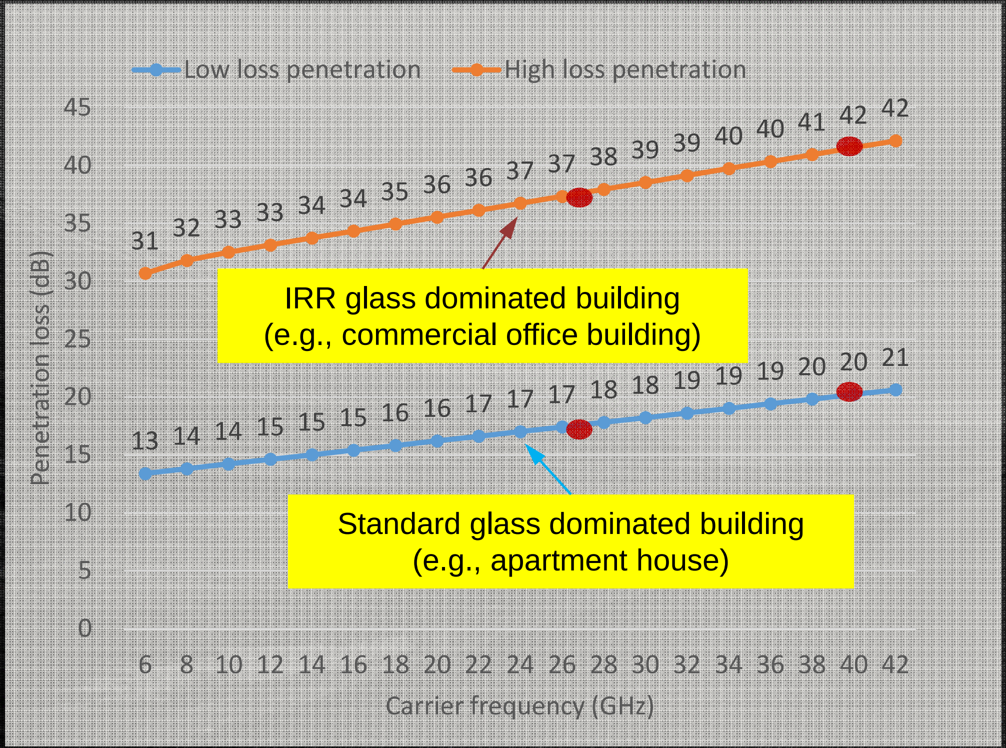
Group 30	Group 40	Group 50	Group 80
•24.25 - 27.5 GHz	•37.0 - 40.5 GHz	•45.5 - 47 GHz	•66 - 76 GHz
•27.5 - 29.5 GHz	•40.5 - 42.5 GHz	•47.0 - 47.2 GHz	•81 - 86 GHz
•31.8 - 33.4 GHz	•42.5 - 43.5 GHz	•47.2 - 50.2 GHz	
		•50.4 - 52.6 GHz	

High Band Non-standalone & Low Band Standalone

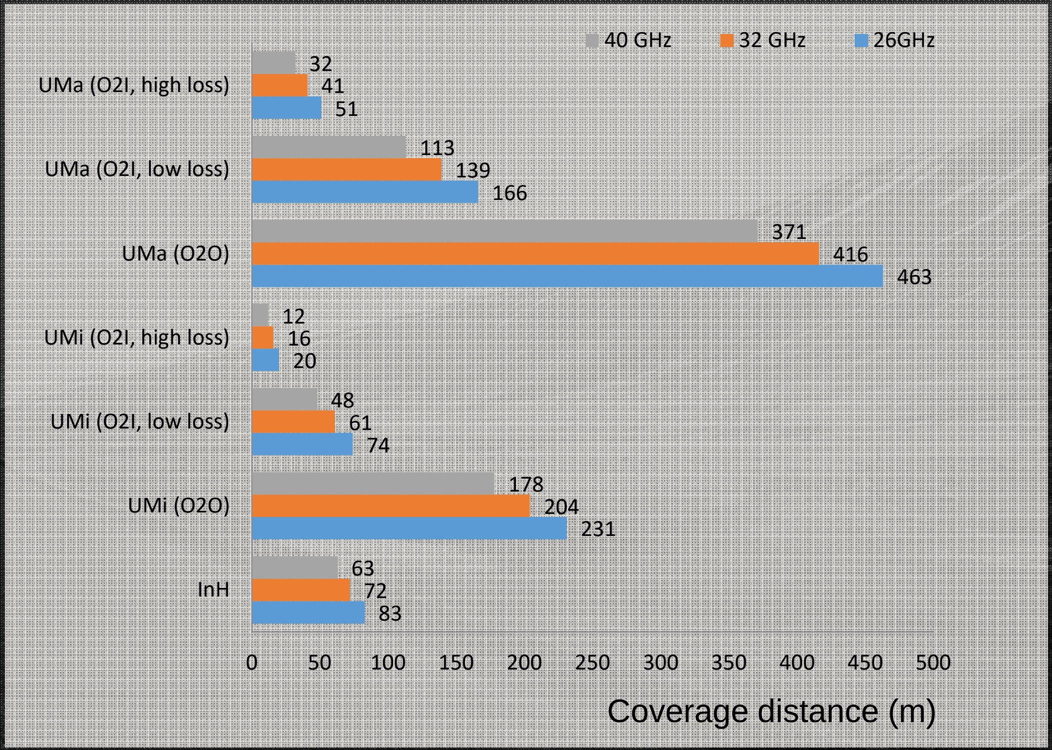


5G spectrum above 6 GHz
Propagation and link budget

Penetration & O2I



Link budget performance (meters)
For 1 Gbps downlink data rate



150dB System Budget
(85% coverage)

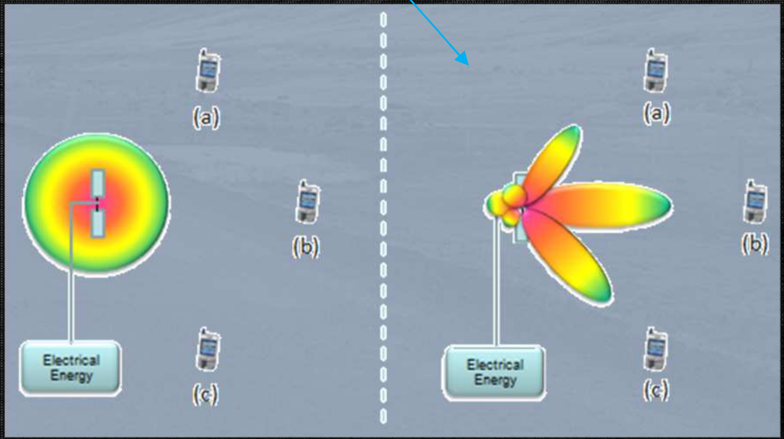
UMa:	Urban macro	O2I:	Outdoor-to-indoor
UMi:	Urban micro	O2O:	Outdoor-to-outdoor
InH:	Indoor hotspot		

Free Space Path Loss

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r$$

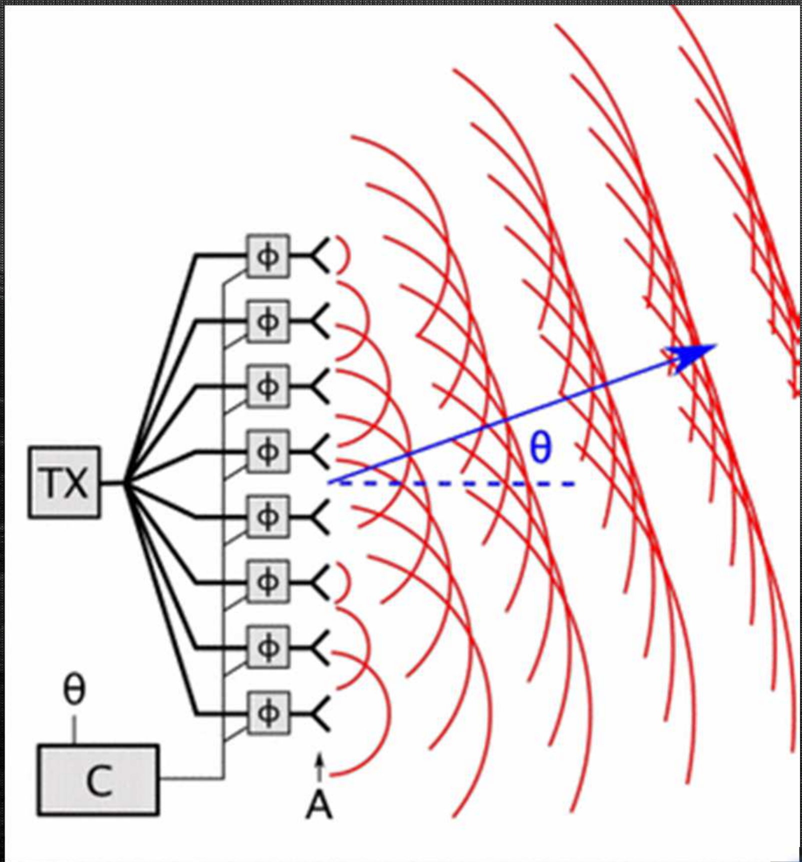
At least 20dB increased PL between sub-6 and mmWave link

More antenna gain required



Phased Array concept

Source Wikipedia



- **Phased array**
  - Usually refer to an electronically scanned array
  - It is an array of equally spaced antennas that creates a radio waves , which can be steered to maximize the gain in different directions
  - Relay on the coherent combining of the TX/RX wave
- **Wanted characteristics**
  - No need of mechanism to move the antenna
  - Behavior consistent over a wide spectrum of frequencies
  - Accurate phase shifters control system
  - It can create nulls in specific directions to suppress interference

$$F(\theta) = \sum |a_n| \exp[jnd_x k_0 (u - u_0)]$$

$$u_0 = \sin(\theta_0)$$

$$k_0 = \frac{2\pi}{\lambda_0}$$

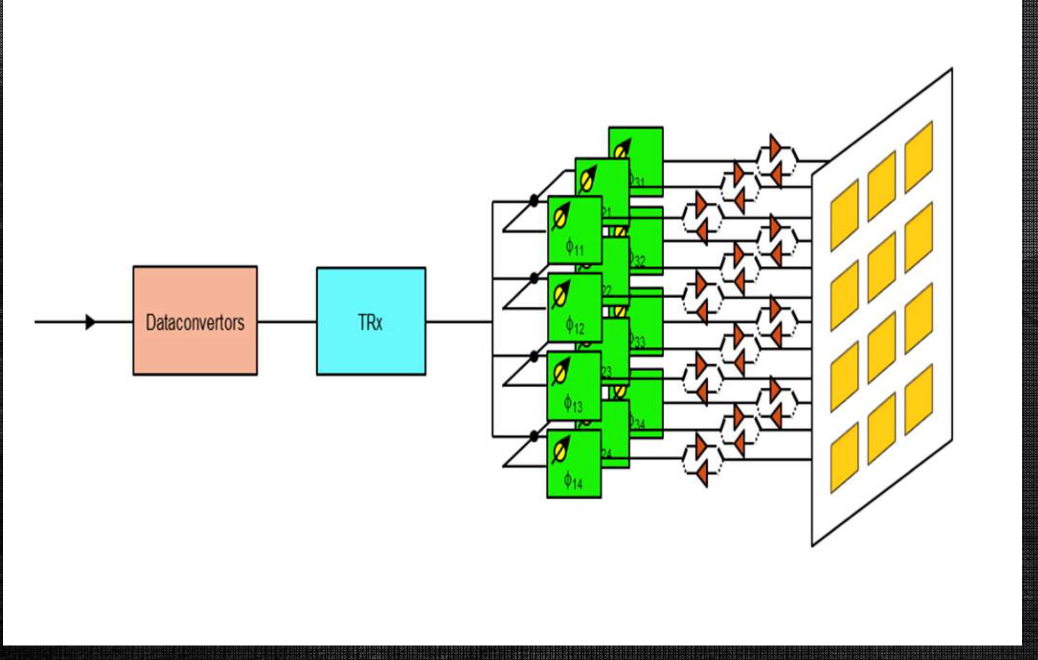
$$\Delta\varphi = \frac{360° d_x u}{\lambda}$$

Gain increase Log(N)
Angular BW decrease with element spacing

Analog and Digital BeamForming

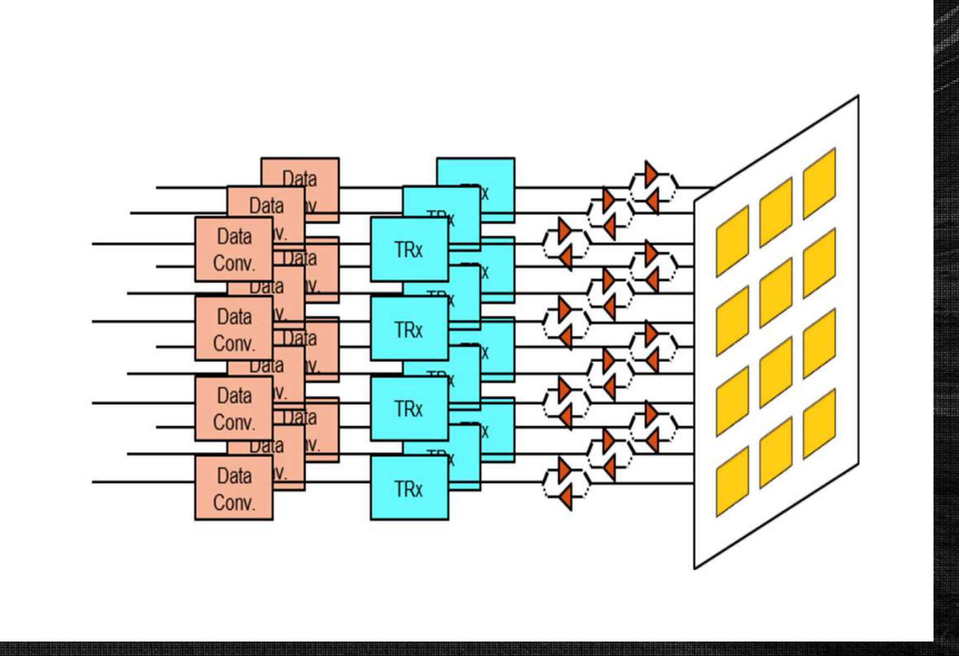
Single ADC/DAC

Analogue phase shifters



High number of ADC/DAC

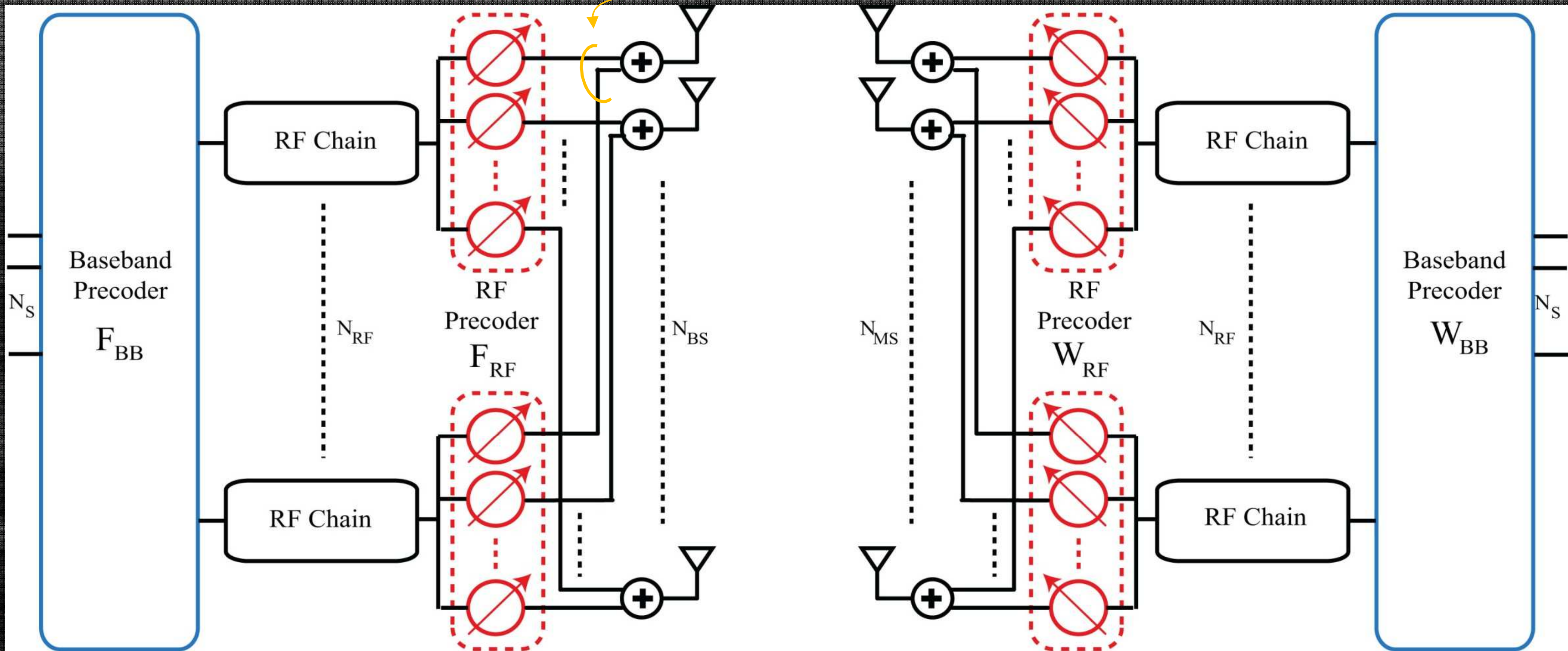
Phase shifters in digital domain



Hybrid BF

Balanced digital/analog functions

- **Can be "clustered" or "Full Connected"**



Hybrid Precoding

Received signal Transmitted signal Noise

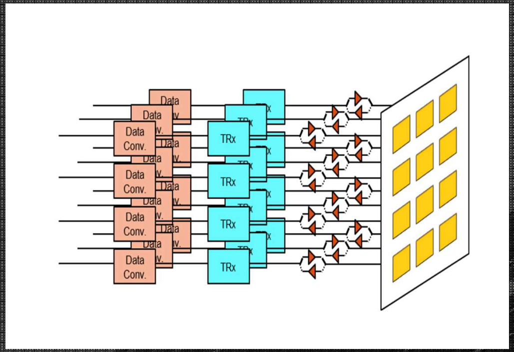
$$\mathbf{y} = \mathbf{W}_{\mathbf{BB}}^{*}\mathbf{W}_{\mathbf{RF}}^{*}\mathbf{H}\mathbf{F}_{\mathbf{RF}}\mathbf{F}_{\mathbf{BB}}\mathbf{s} + \mathbf{W}_{\mathbf{BB}}^{*}\mathbf{W}_{\mathbf{RF}}^{*}\mathbf{n}$$

RF Combiner BB Precoder

BB Combiner RF Precoder

- **Hybrid Precoders**
  - Allows multi-stream MIMO gain with less hardware
  - Hybrid structure introduces additional constrains on precoding (i.e. channel estimation)
  - Gain depends on dimensionality (#BB chains)
  - Hybrid precoding has low loss in channels that are not “rich scattering”

ADC in Full Digital Array



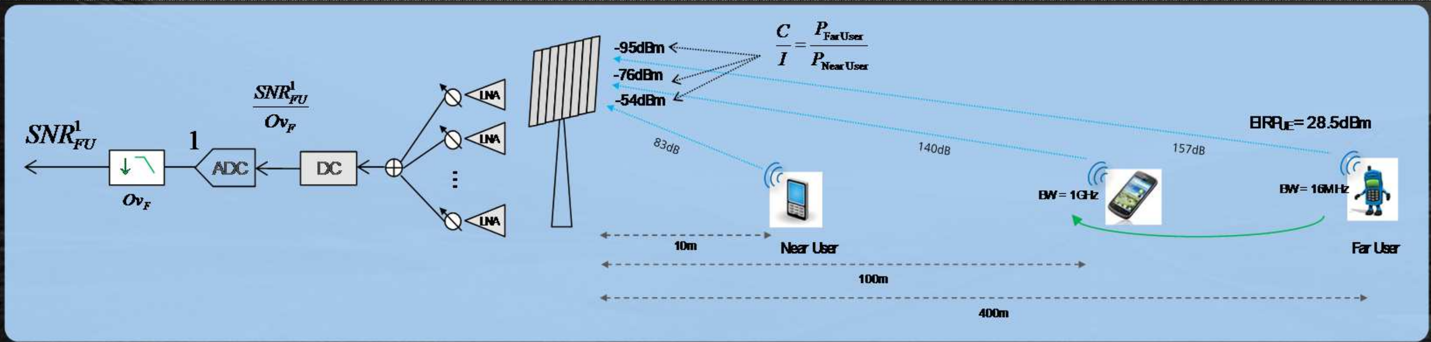
- # of ADC bits impacts
  - Processing complexity
  - Power consumption
  - Chip-to-chip data rate
  - Perfomance in case of interference
- ADC can be viewed in two ways
  - As an impairments:
    - Quantization noise is a non linear effect which effects can be modeled
  - Part of the design
    - Take into account ADC in the system design and explicit in RX algorithms
    - Use digital pocessing to take advantage of DAC qualtization noise
- Ultra low power ADC (&DAC) technologies are available
  - 14nm FinFET CMOS
  - Low resolution
  - Ultra Gsps rates (RF sampling/synthesis)

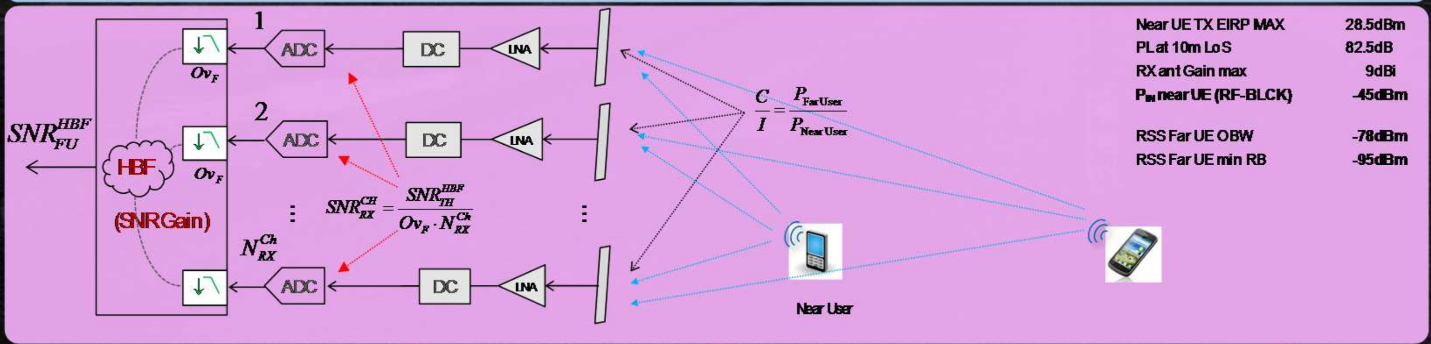
Low resolution ADC

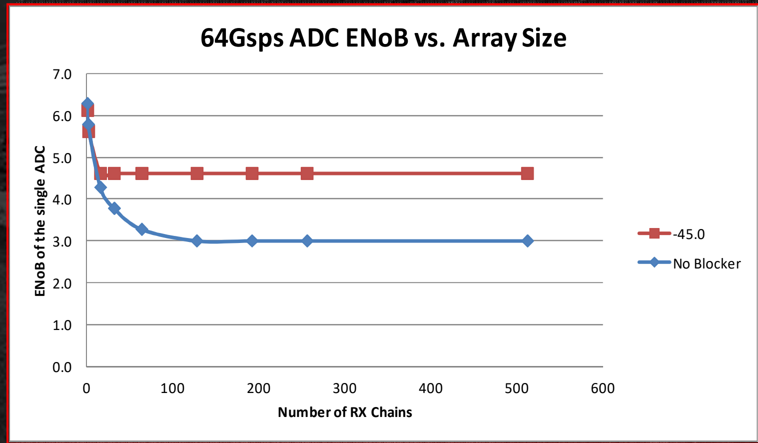
- Number of N bits required with oversampling gain *and* processing gain (multiple receiver chains)

$$SNR_{ADC} = 6.02N + 1.76dB + \underbrace{10\log_{10}\frac{f_S}{2\cdot BW}}_{\text{Oversampling Gain Factor }(Ov_F)} + \underbrace{10\log_{10} N_{RX}^{Ch}}_{\text{Reduced SNR requirements over the single ADC}}$$

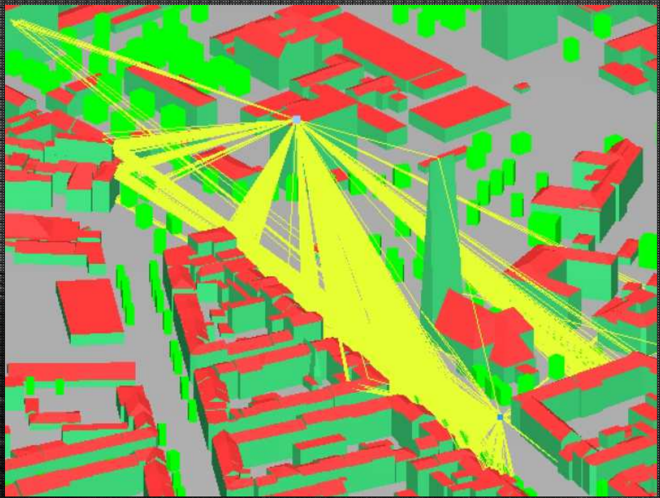
- Constant C/I over each antenna element assumption







mmWave Channel



- Conventional MIMO channel estimation cannot be applied
  – Physical channel model very preliminary
  – High number of antennas leads to high channel dimensionality
  – Direct access to the channel is affected by RF pre-preprocessing
  – Need to exploit channel structure to enable efficient channel estimation

Source Rappaport et al. IEEE Trans.

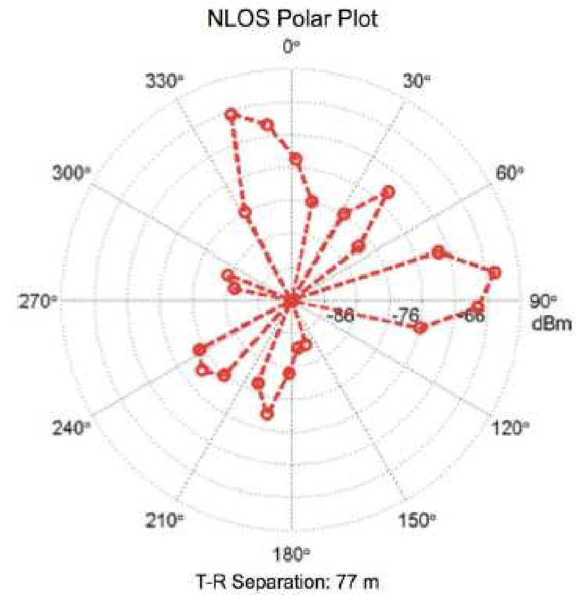


Fig. 18. 28 GHz NLOS polar plot for a T-R separation distance of 77 m showing that energy arrives at distinct AOAs, motivating the use of beamforming and beam combining in mmWave MIMO systems.

- mmWave channel structure can be exploited in CE
  – Low rank
  – Only a few clusters exist due to the propagation characteristics at mmWavve
  – Concept of “sparsity”

mmWave massive MIMO

- Massive MIMO implementations is different at *mmWave*
  - Both *hybrid precoding* and *low resolution ADC* concepts can be used
  - Number of users allocated in spatial domain is limited/fixed by the *RF configuration* choosen
- Array at UE side?
- *mmWave* Massive MIMO engineering
  - Needs to balance the requirements between:
    - Coverage
    - Network deployment (Small-cell, demanding FH/BH, DAS, ...)
    - Power consumption & cost
- Unreliable mmWave link due to the “beam instability/failure” can be mitigated by:
  – BTS density
  – Sub-6 assisted
- Up to now is more “technology-driven” than “algorithm-driven”
    - Efficient technolgies need to be further developed both RF and DSP

BTS Technological trends

- Antenna array
  - Synthesis and integration
    - Higher scan-view and gain with lower controls
- Hardware
  - High efficiency PA (GaN + DHT + ET +DPD)
  - High integrated SiGe/CMOS RFIC
  - Low resolution ADC/DAC (≤14nm FinFET)
- Algorithms
  - Low complexity channel estimation
  - Hybrid precoding
  - Low/High frequency joint managment (CP + UP + BH)

Ready for 5G?

Thank You.