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Bringing 5G into Reality

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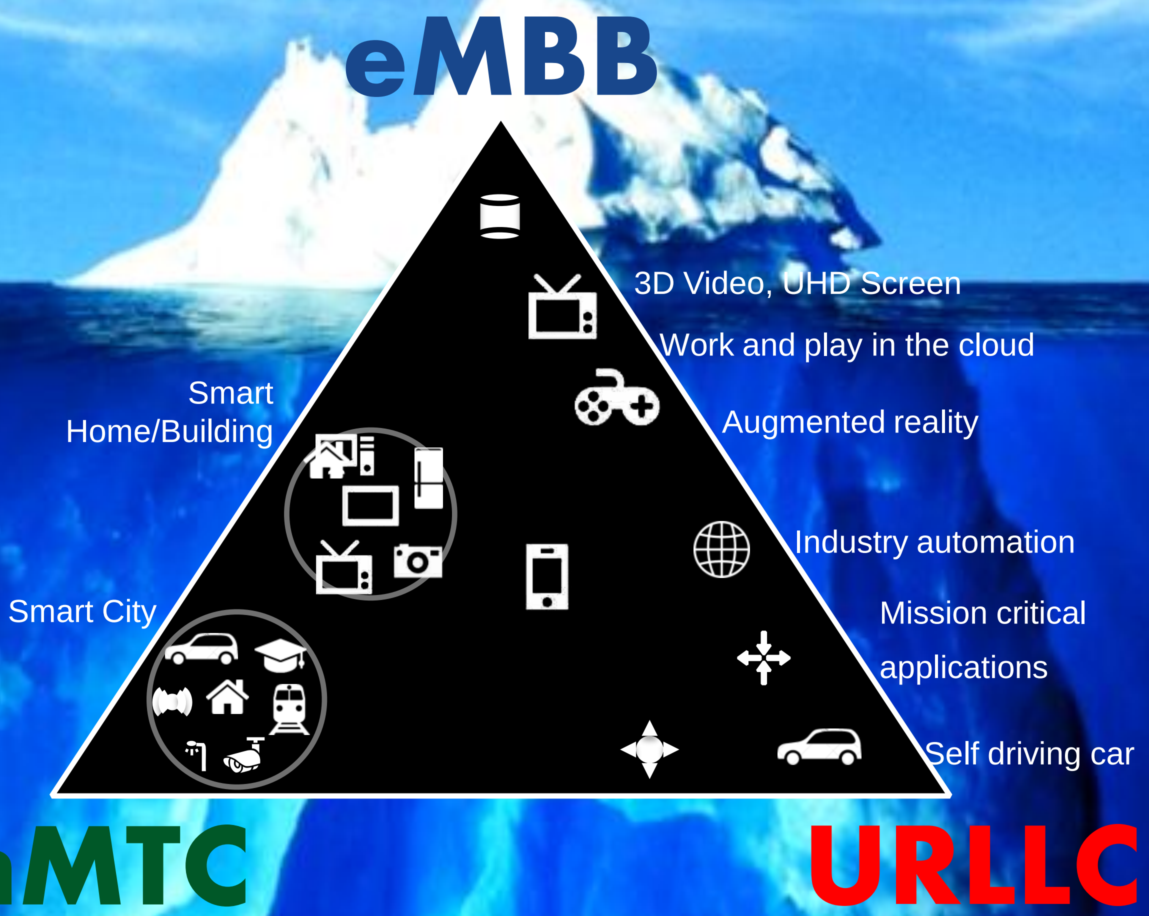
A Tip of Iceberg

Paradigm for Connected People



Paradigm for Connected Things

5G – From Research to Standardization

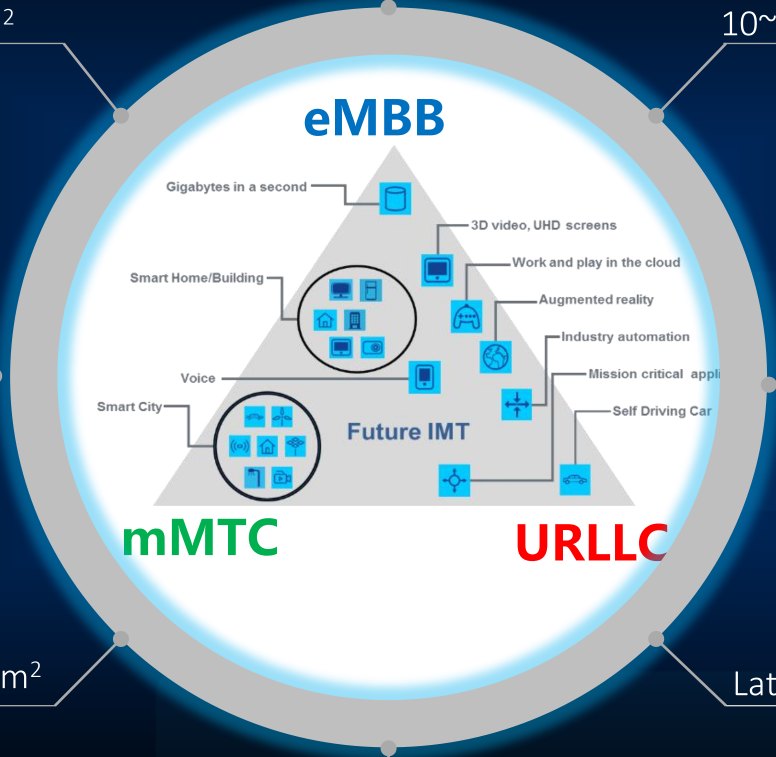
User experienced data rate: 0.1~1 Gbps

Area traffic capacity: 10 Mbps/m^2

Peak data rate: 10~20 Gbps

Network energy efficiency: 100 x

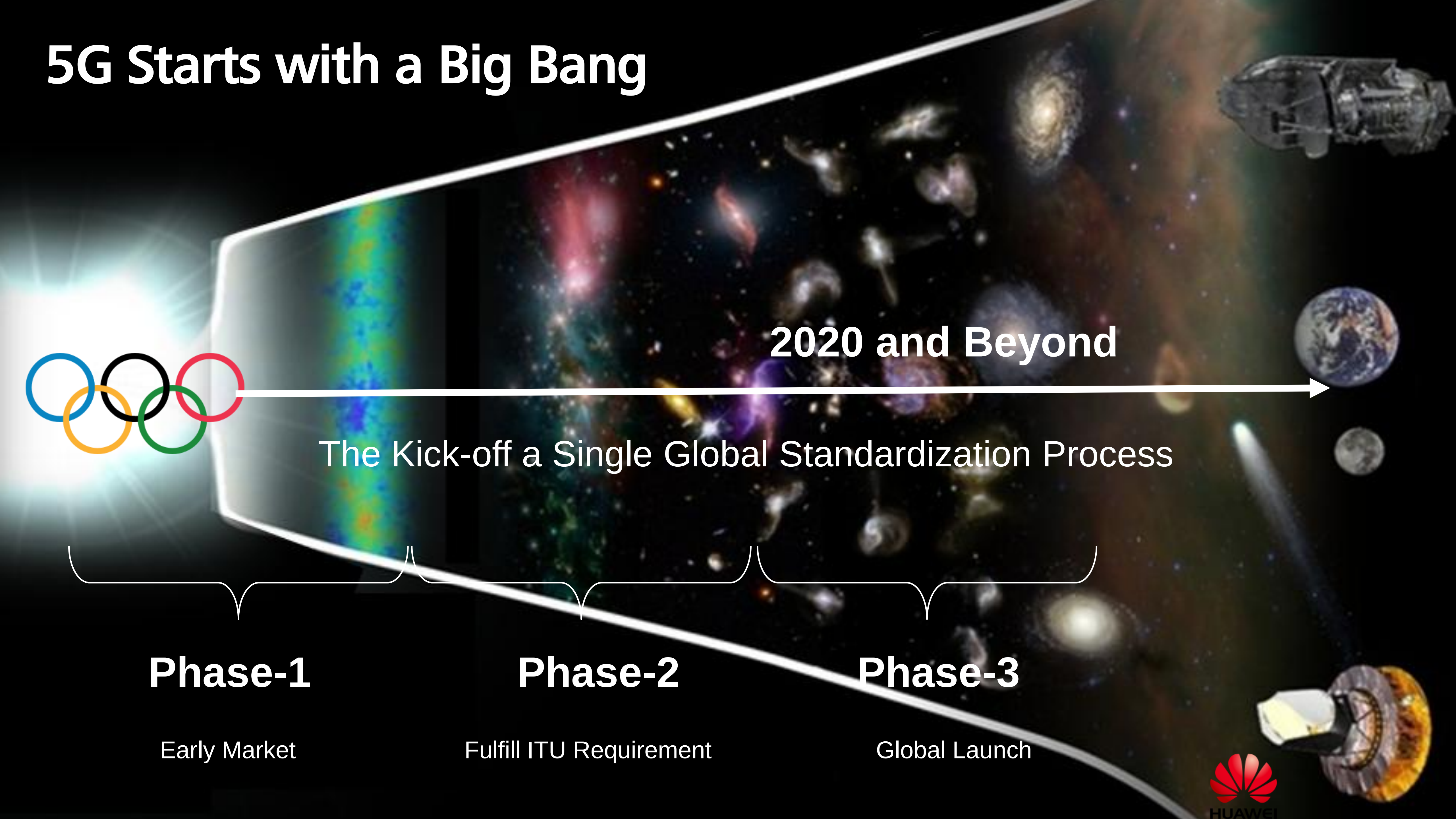
Spectrum efficiency: 3~5x



Connection density: 1M/km^2

Latency: 1 ms (AI)

Mobility: 500km/h


5G Starts with a Big Bang
2020 and Beyond
The Kick-off a Single Global Standardization Process
Phase-1
Early Market
Phase-2
Fulfill ITU Requirement
Phase-3
Global Launch

5G, A Deeper Innovation for the Future

Industry Collaborations

- Cross-industry Communication & Collaboration
- Global Unified Standard

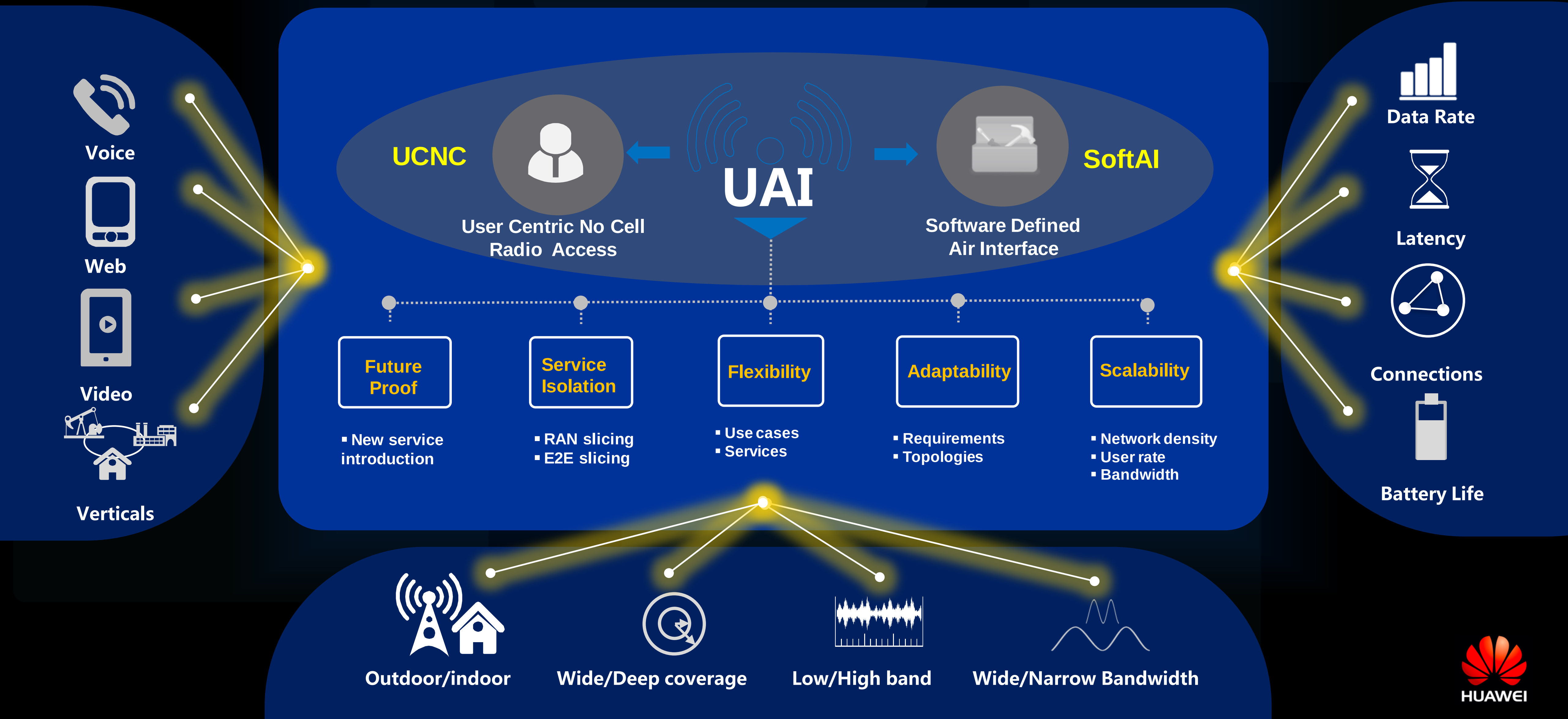
Technology Innovations

- Revolutionary Innovations
- Challenge the Spectral Efficiency Increase by at Least 3 Times

Spectrum Support

- Government & regulators open more spectrum resources
- Technology aggregates all available bands

5G RAT: NR Framework and Characters



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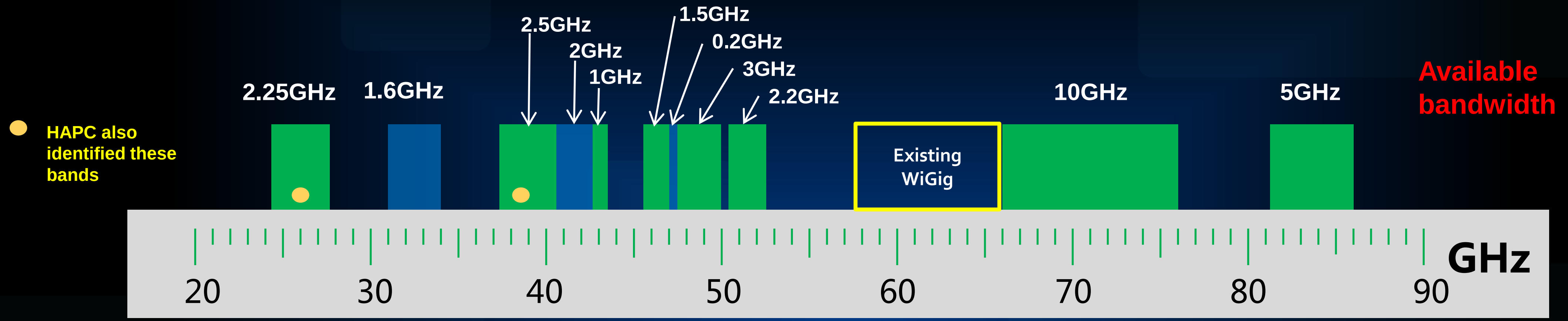
5G, To Explore the New Frontier for New Spectrums



bands have allocations as the "mobile service" on a primary basis

24.25-27.5 GHz
37-40.5 GHz
42.5-43.5 GHz
45.5-47 GHz
47.2-50.2 GHz
50.4-52.6 GHz
66-76 GHz
81-86 GHz

bands may require additional allocations to the "mobile service on a primary basis"

31.8-33.4 GHz
40.5-42.5 GHz
47-47.2 GHz

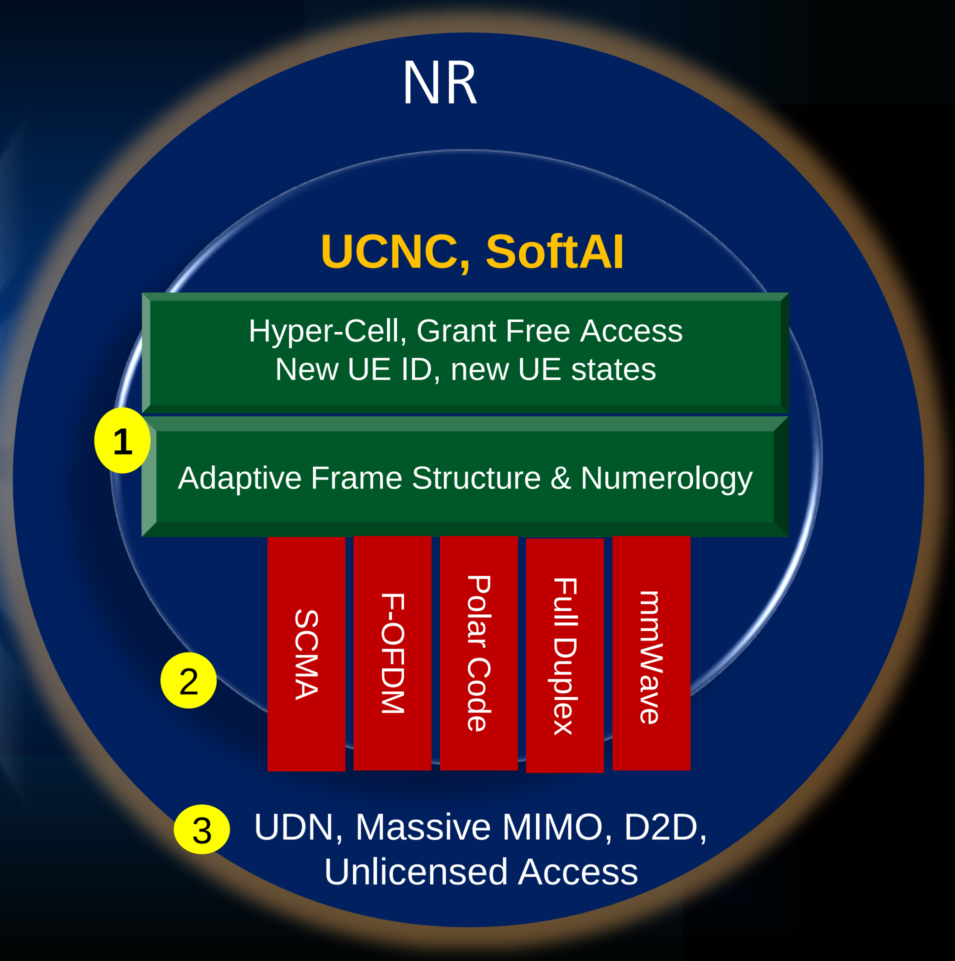
5G NR: Three Technology Categories

New framework enablers
1

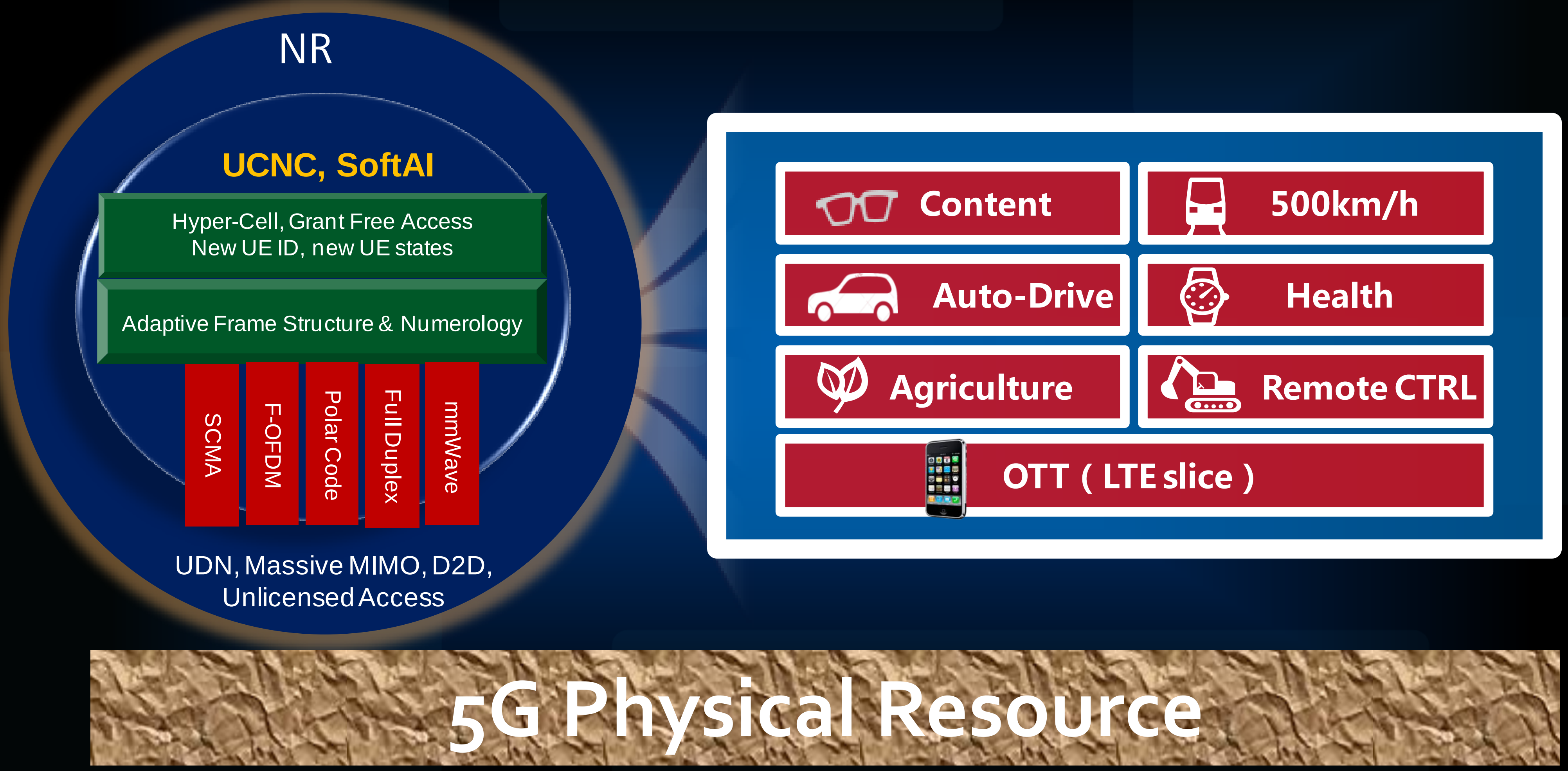
New technologies for new use cases
2

+

Existing LTE technologies + new frameworks
3



5G Network Architecture Concept



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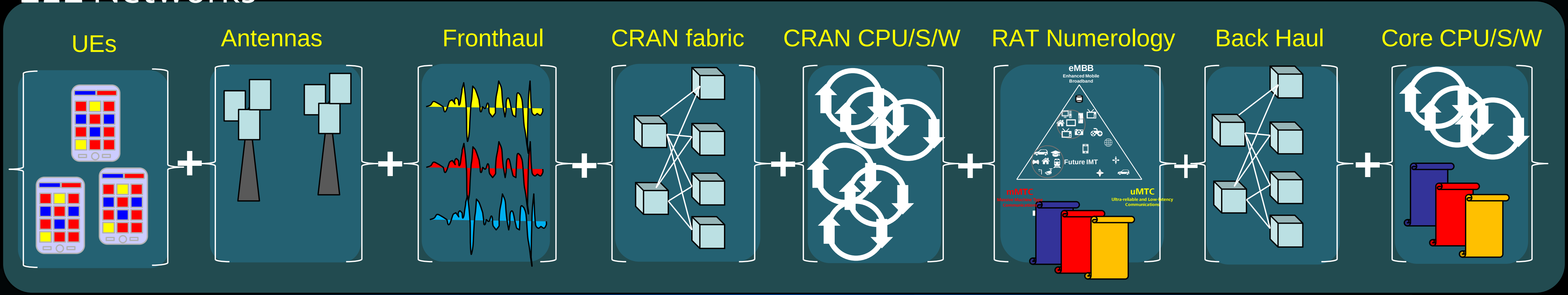
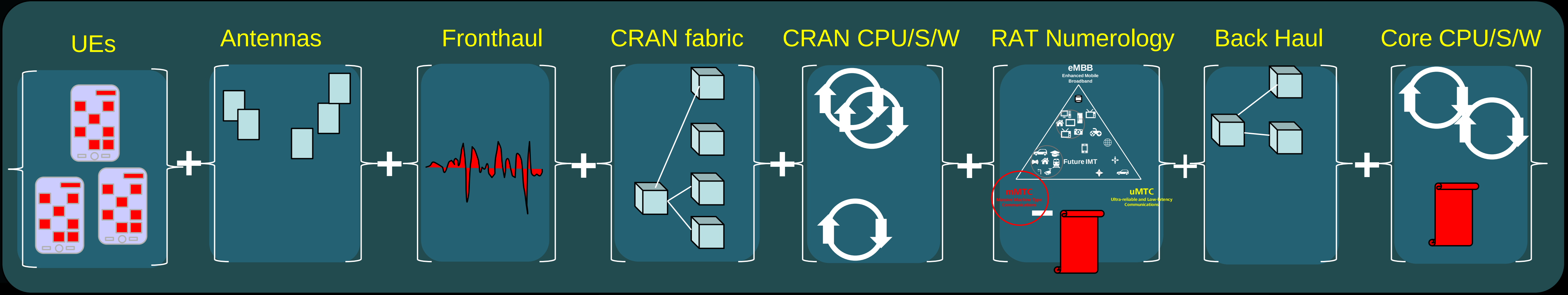
5G concept of an end to end "Slice"

E2E Networks



An E2E Networks Slice

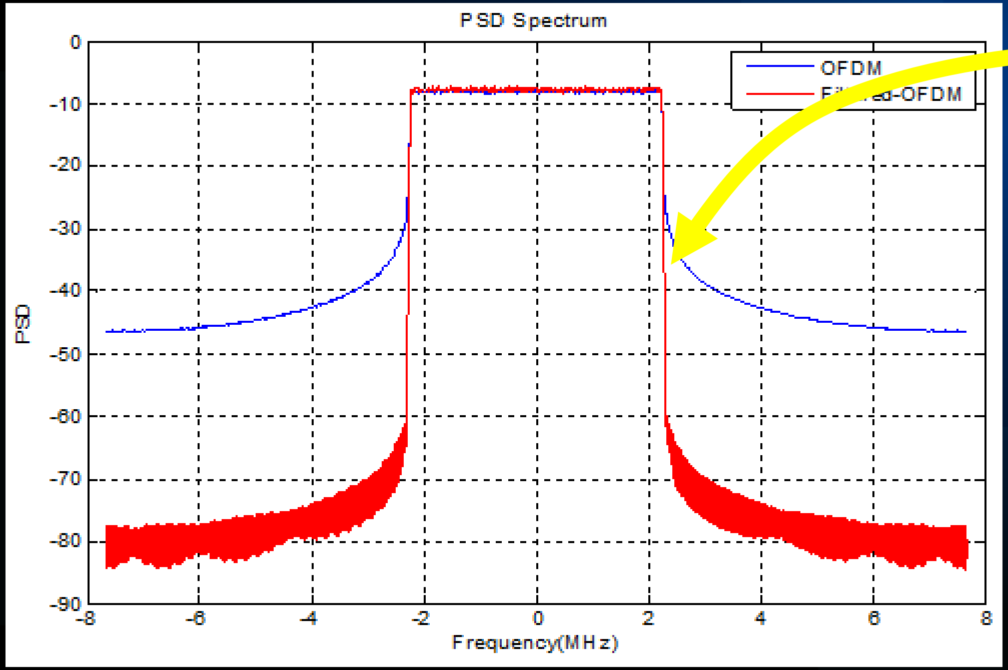


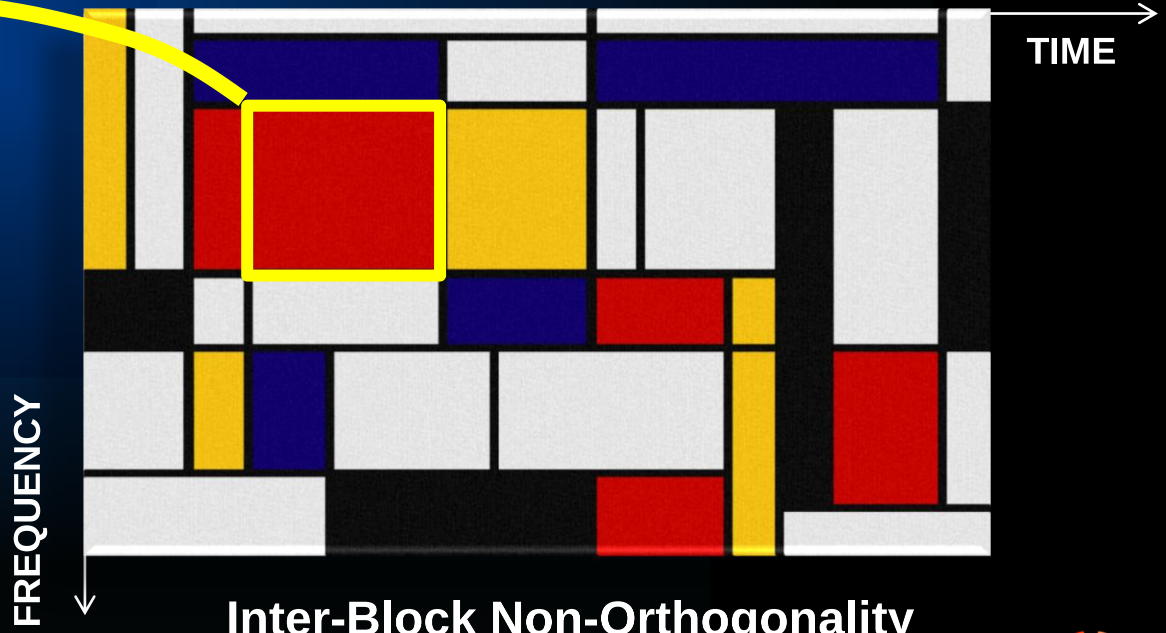
Filtered-OFDM (f-OFDM) Technology

Air-Interface Inter-Slicing

- **Sub-band Filtered OFDM**
  - Good out-of-band leakage rejection
  - Maintain all the benefits of OFDM
  - Future Proof forward compatible to unknown service
  - MIMO friendly
  - Fragmental spectrum utilization

- **Isolation of Radio Resource**
  - Service Driven Dynamic Radio Resource Partition
  - Software Defined Air-Interface
  - Radio Parameters of each f-OFDM block can be re-defined
  - Enable Air Interface Slicing
  - Enable E2E Networks Slicing





Inter-Block Non-Orthogonality

f-OFDM

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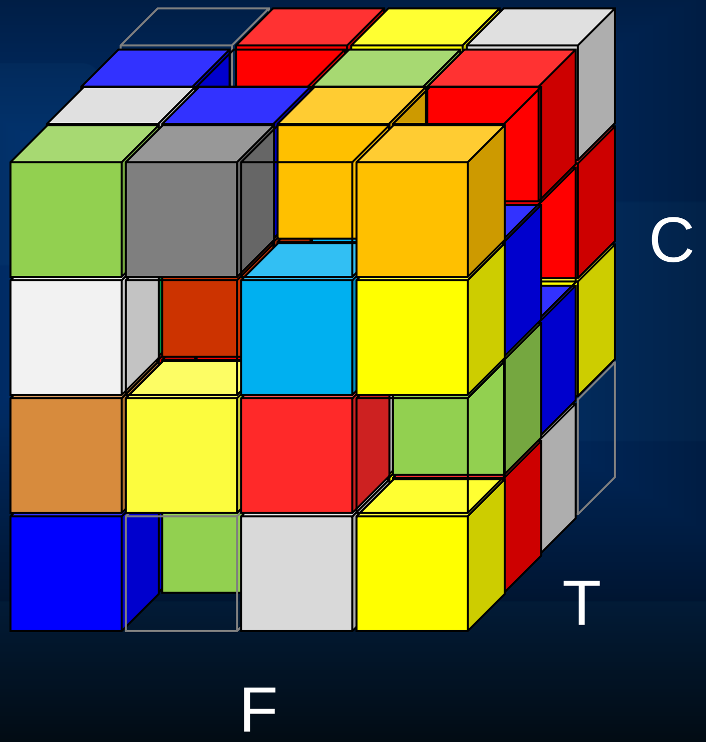
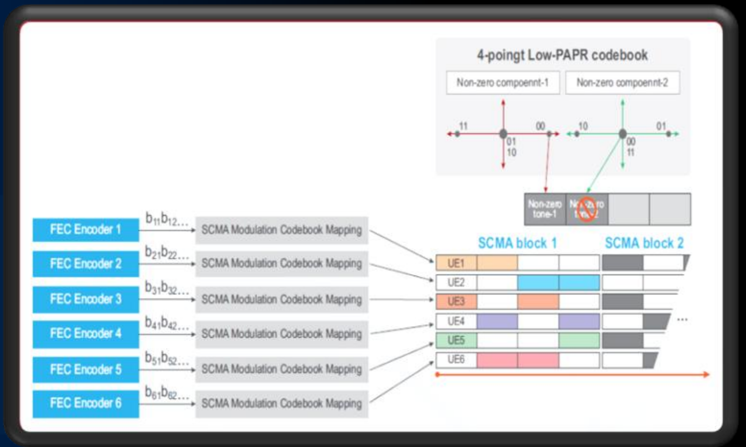
Sparse Code Multiple Access (SCMA) Technology

A Novel Code Domain Non-orthogonal Multiple Access

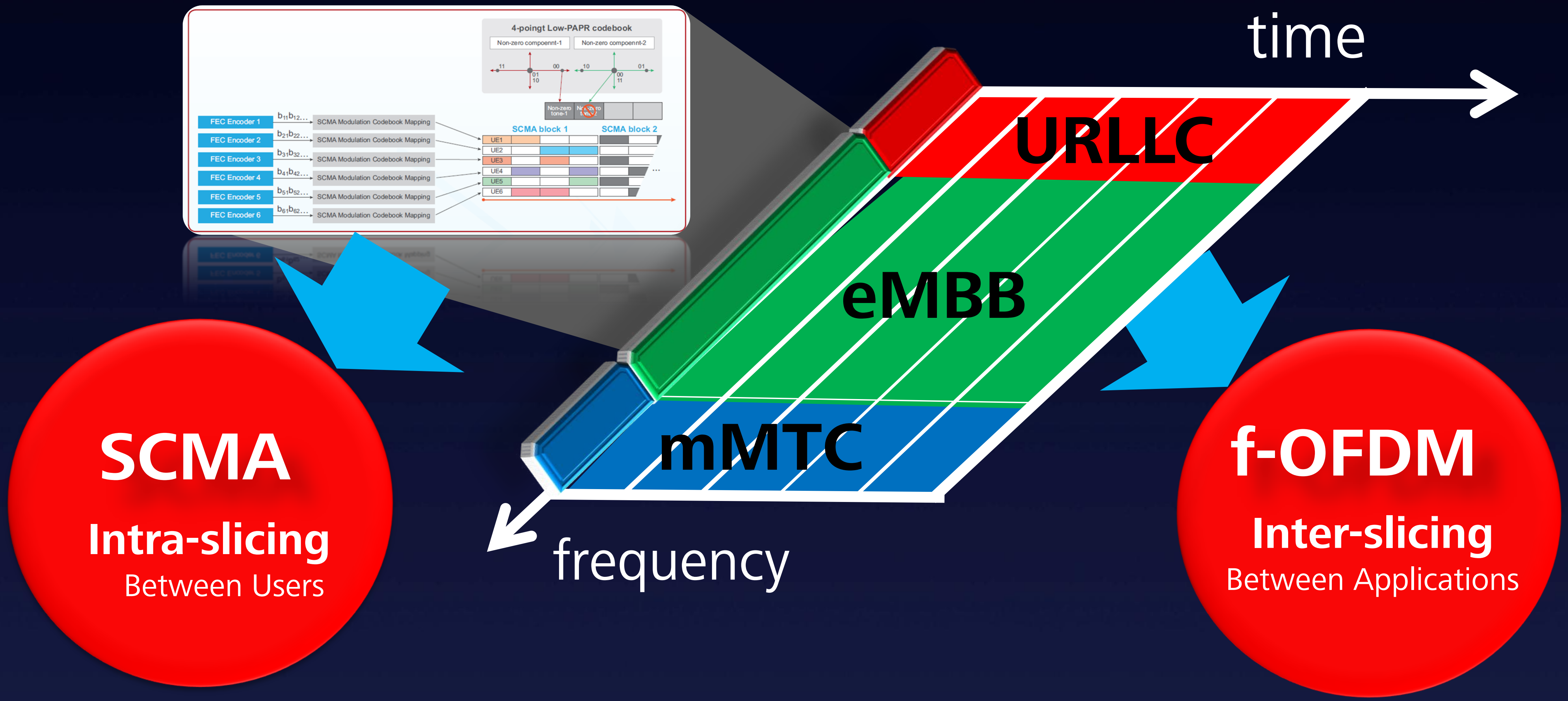
- **Define sparse patterns to minimizes the mutual collision**
  - Allow overloaded superposition with affordable complexity
  - Each sparse spreading pattern corresponds to a codebook
- **For each layer, mapping the incoming bits to non-zero components and modulate them with multi-dimensional constellations**
  - Better spectrum efficiency
  - Enable low projection codebook
    - Lower detection complexity
    - Lower PAPR





Air-Interface Intra-Slicing

5G Air-Interface Slicing



Bringing 5G into Reality

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2015

SCMA

UL 3X connections
DL >1.5X throughput

F-OFDM

Saving guard band
Asynchronous transmission

Polar Code

0.5~2dB gain compared with
LTE Turbo Code

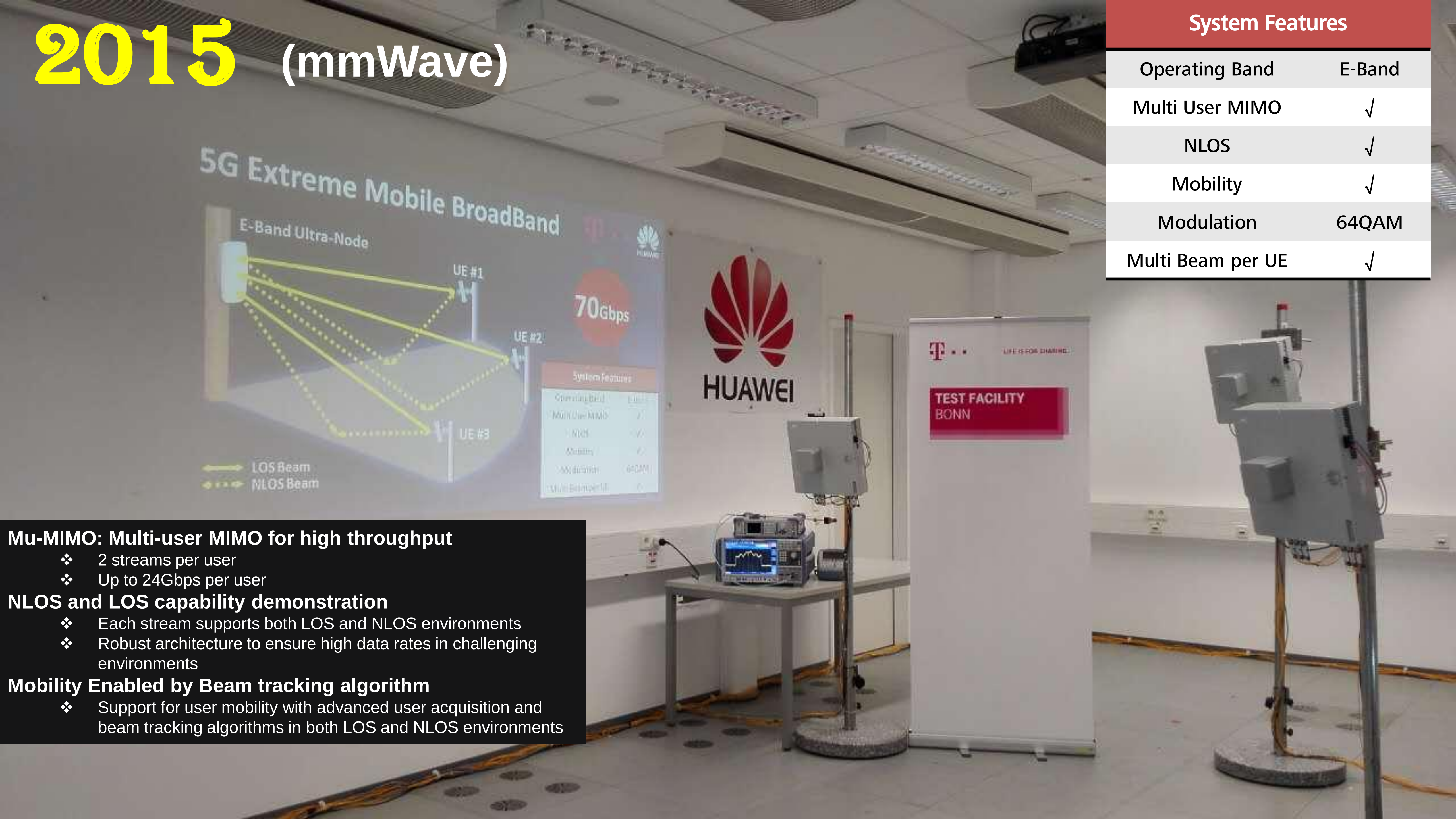
M-MIMO

24 layers

Achieved World First DL/UL Air-Interface Slicing

2015 (mmWave)

System Features	
Operating Band	E-Band
Multi User MIMO	√
NLOS	√
Mobility	√
Modulation	64QAM
Multi Beam per UE	√



Mu-MIMO: Multi-user MIMO for high throughput
- 2 streams per user
- Up to 24Gbps per user

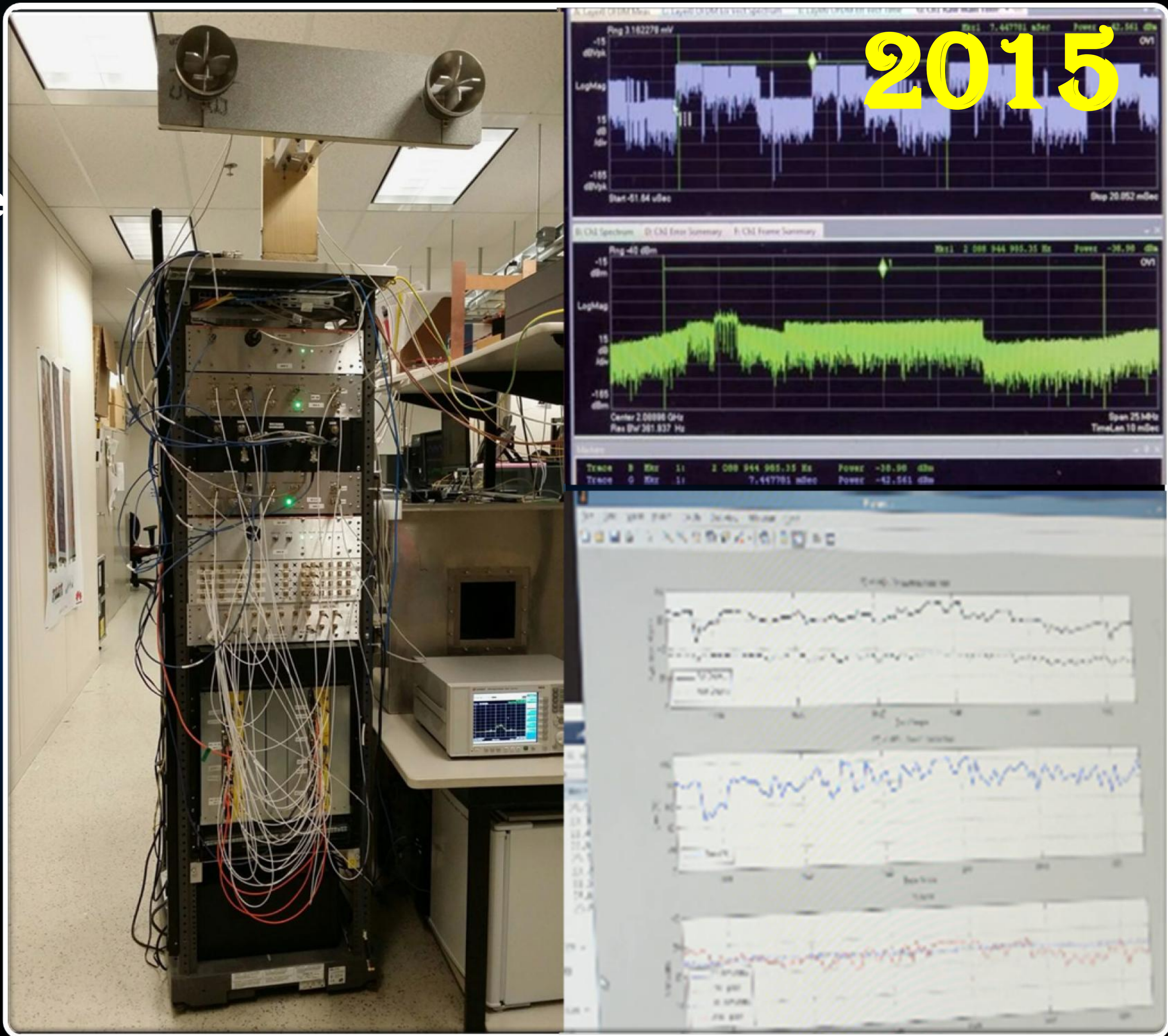
NLOS and LOS capability demonstration
- Each stream supports both LOS and NLOS environments
- Robust architecture to ensure high data rates in challenging environments

Mobility Enabled by Beam tracking algorithm
- Support for user mobility with advanced user acquisition and beam tracking algorithms in both LOS and NLOS environments

Full Duplex:

A Radio Technology Challenge for more than 80 years

Trial Results 1.8 X Spectral Efficiency Gain



Imagine: 5G Powered Car

If autonomous driving car is mandatory in USA, $1.3 Trillions can be saved every year, which includes:

- **$158Billion gas**
- **$507Billion work efficiency improvement**
- **$488Billion accident compensation**

Globally,
5G powered car can save $5.6 Trillion

Morgan Stanley

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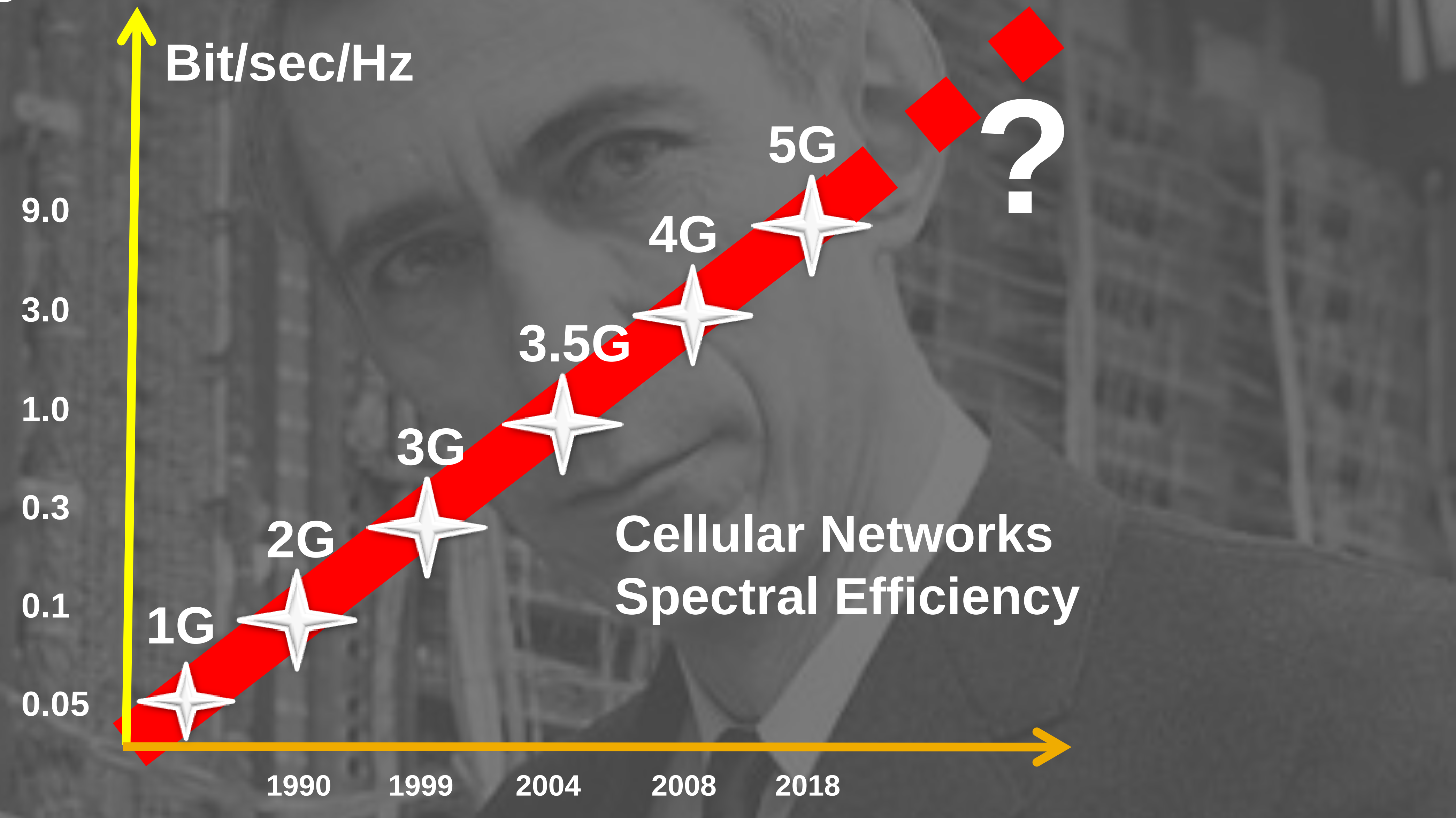
Some Signal Processing Topics for 5G

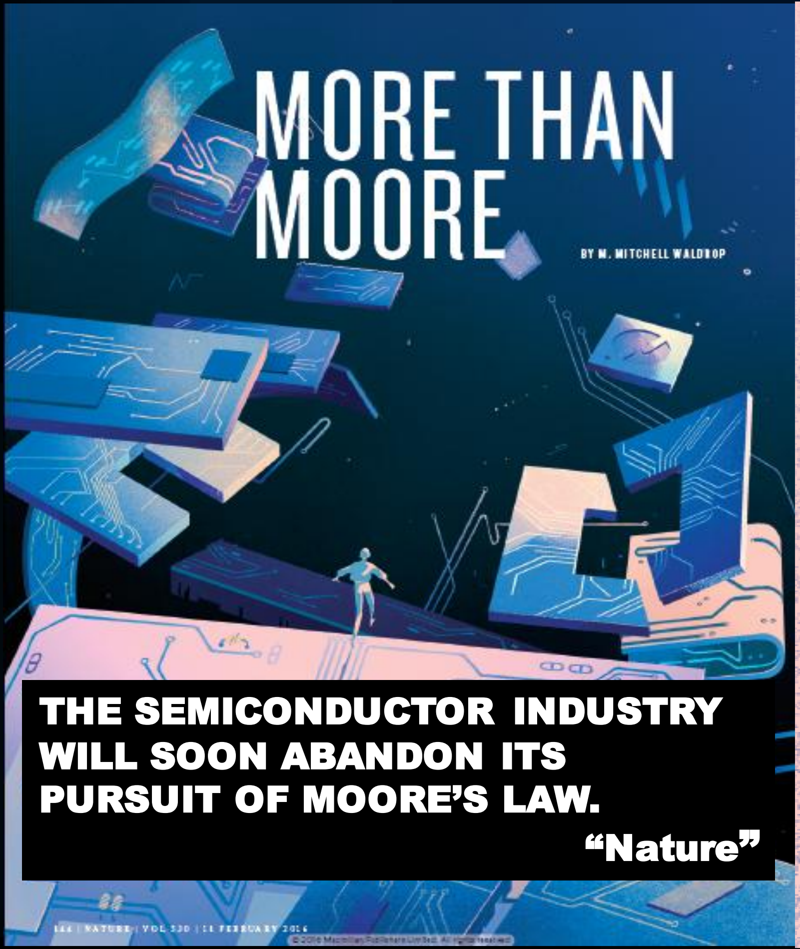
1. Filtered-OFDM ☺
2. SCMA (Sparse Code Multiple Access) ☺
3. Polar Coding ☺
4. Massive MIMO Non-Linear Pre-Code ☺
5. Fast Beam Acquisition and Tracking for mmWave Radio ☺
6. UDN Self-back Hauling ☺
7. FDD m-MIMO with Limited Feedback
8. TDD m-MIMO Large Array Calibration
9. Linear Integer Programming for Network Slicing ☺
10. Time-Limited Bandwidth-Limited Reliable Signal Design

Technology Challenge: Wireless Networks Spectral Efficiency Crunch



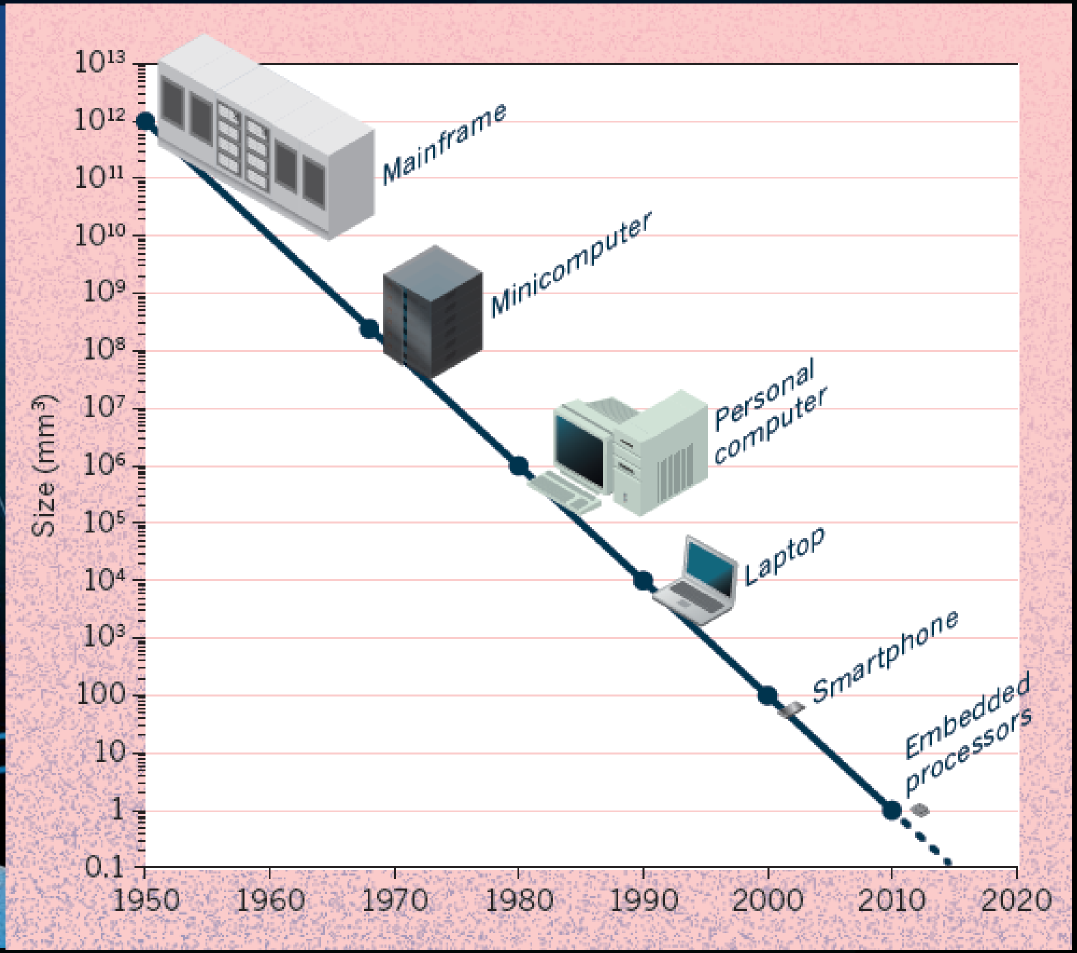
The Renaissance of Algorithm

- Technology Challenge: Moore’s Law Crunch



THE SEMICONDUCTOR INDUSTRY WILL SOON ABANDON ITS PURSUIT OF MOORE’S LAW.

“Nature”



Thank you