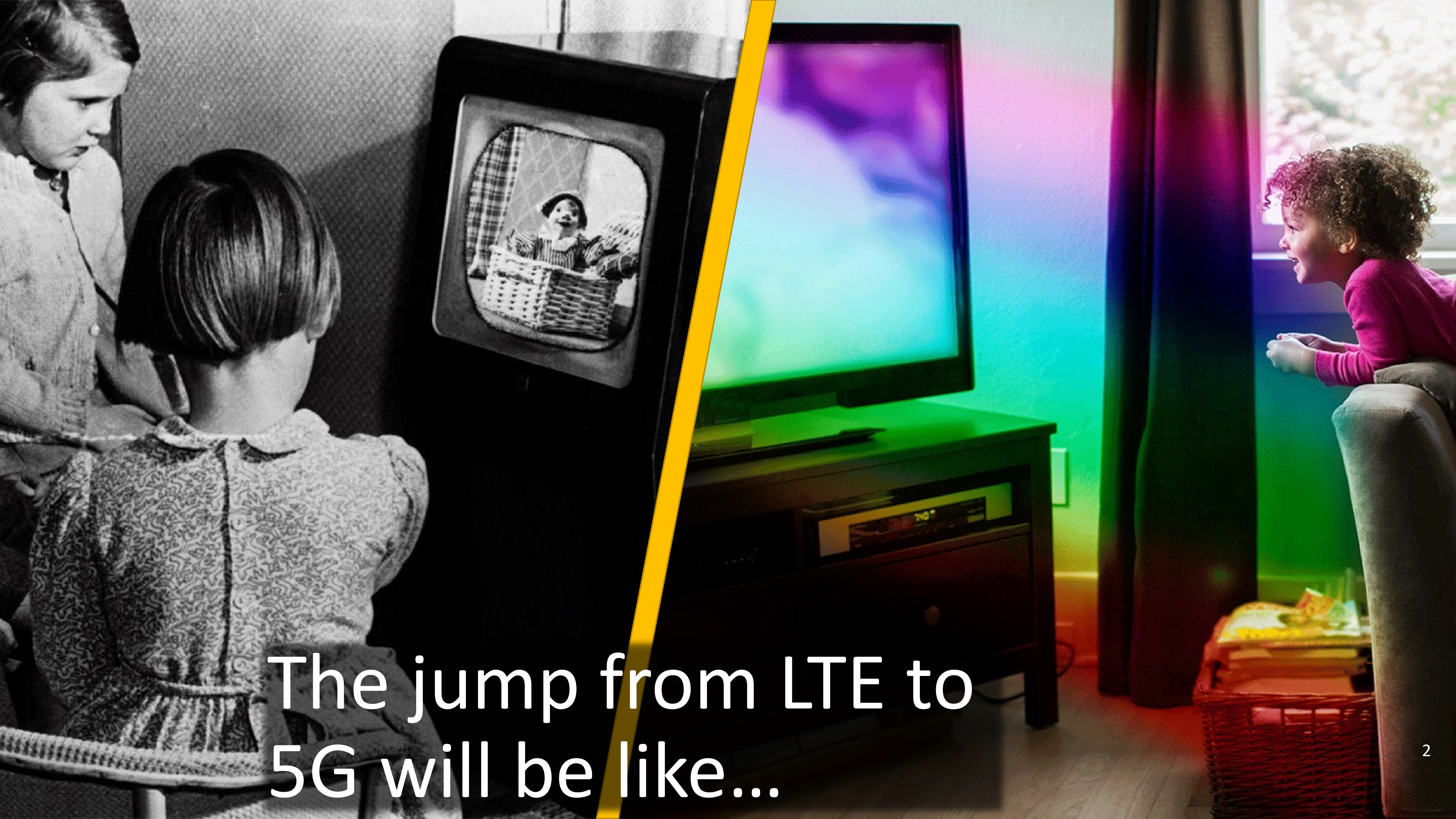
Spectrum and its application to 5G and the Power of Massive MIMO

March 30th 2019

Tajit Mehta



The jump from LTE to 5G will be like…


AMERICA
Online
Connecting...
Macintosh SE/30

Existing networks & technology must evolve to handle the demands of the connected future

Between 2018 and 2022, the traffic generated by smartphones will increase by **10 times**

5G IS TRULY REVOLUTIONARY

…

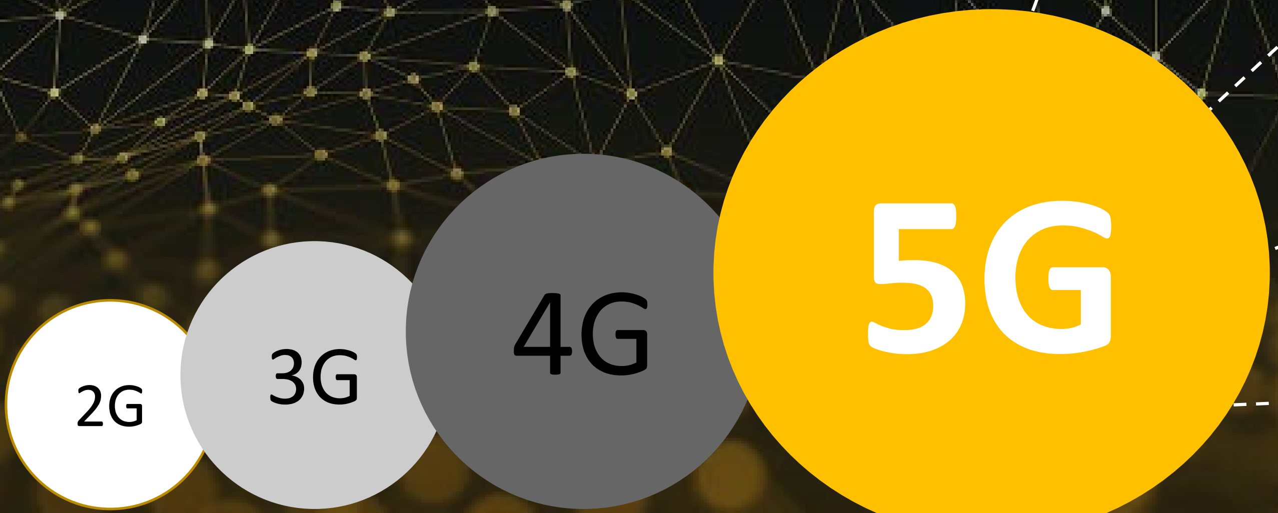
& will satisfy customer demands

10X
5G will handle 10X connection density

10X
5G will deliver 10X experienced throughput

100X
Increased area traffic capacity

10X
Lower latency



Source: ITU, IMT-2020

Even more important – 5G can deliver a MASSIVE economic benefit

3 Million
new US jobs
(800K in construction)

UNTOLD POTENTIAL
for innovation

5G

$275 Billion
investment

$500 Billion
economic growth

Source: CTIA

EM Intro video

Electromagnegtic Sprectrum

Current Wave

Electric field to give a direction

Magnetic Wave

To give the field

7 Types of wave

Radio wave

Microwave

Infrared

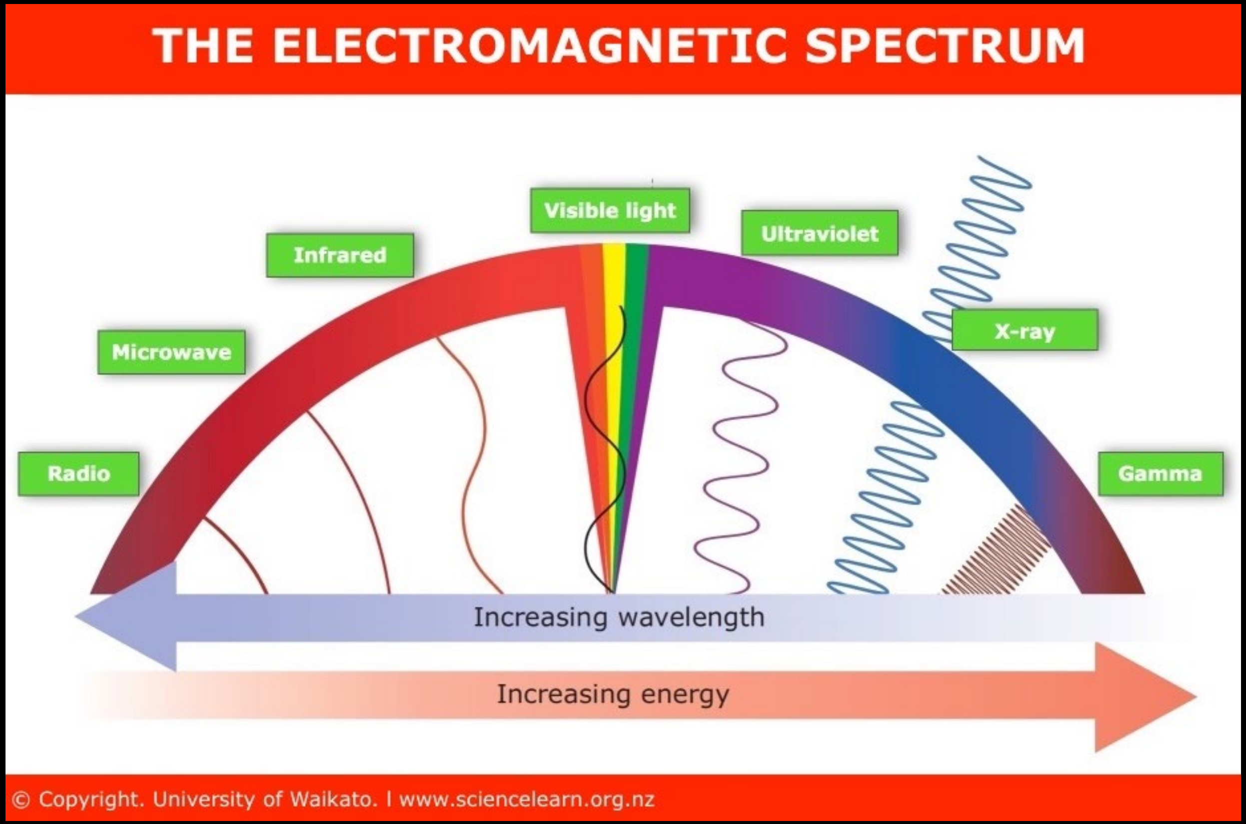
Visible

Ultraviolet

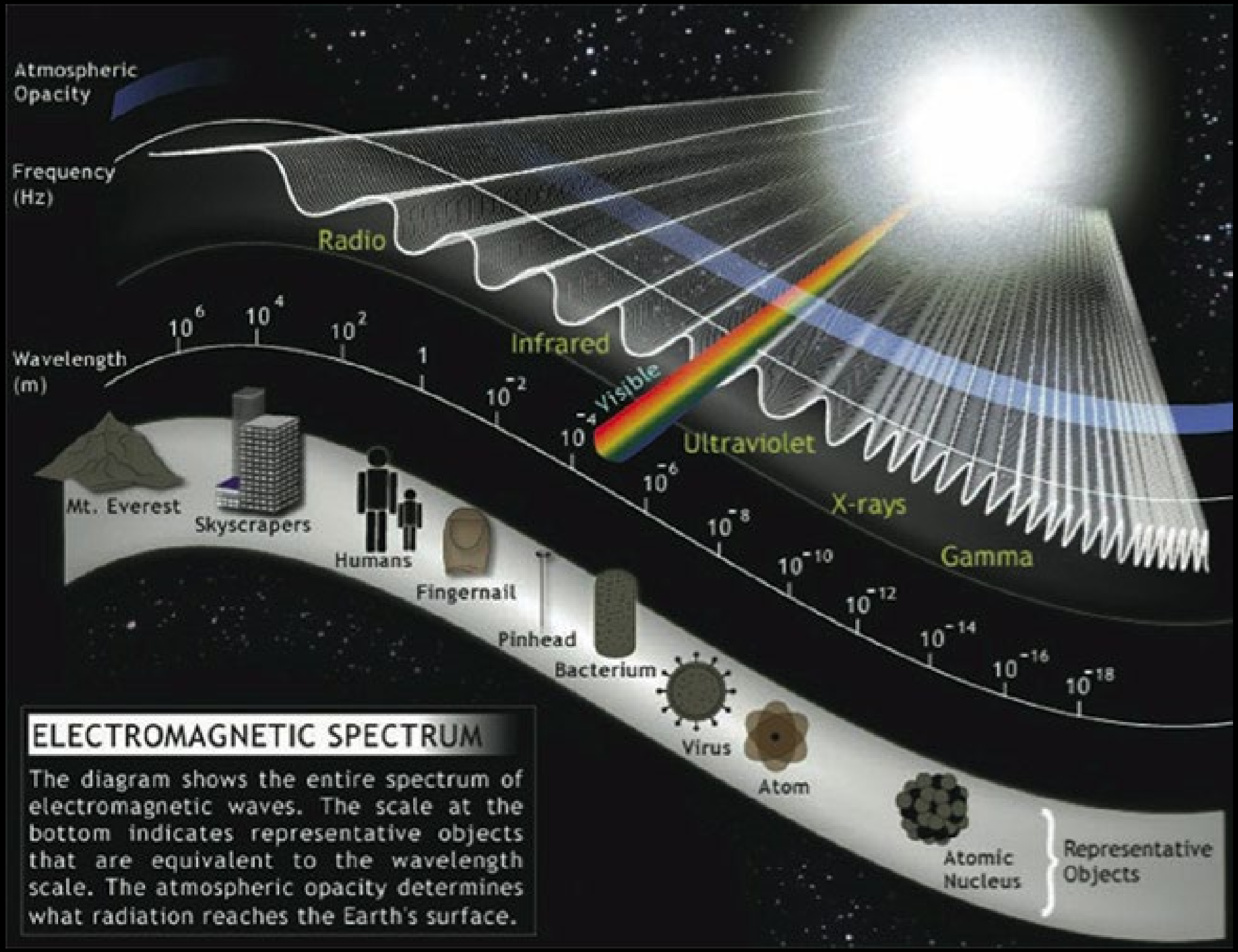
X-ray

Gamma

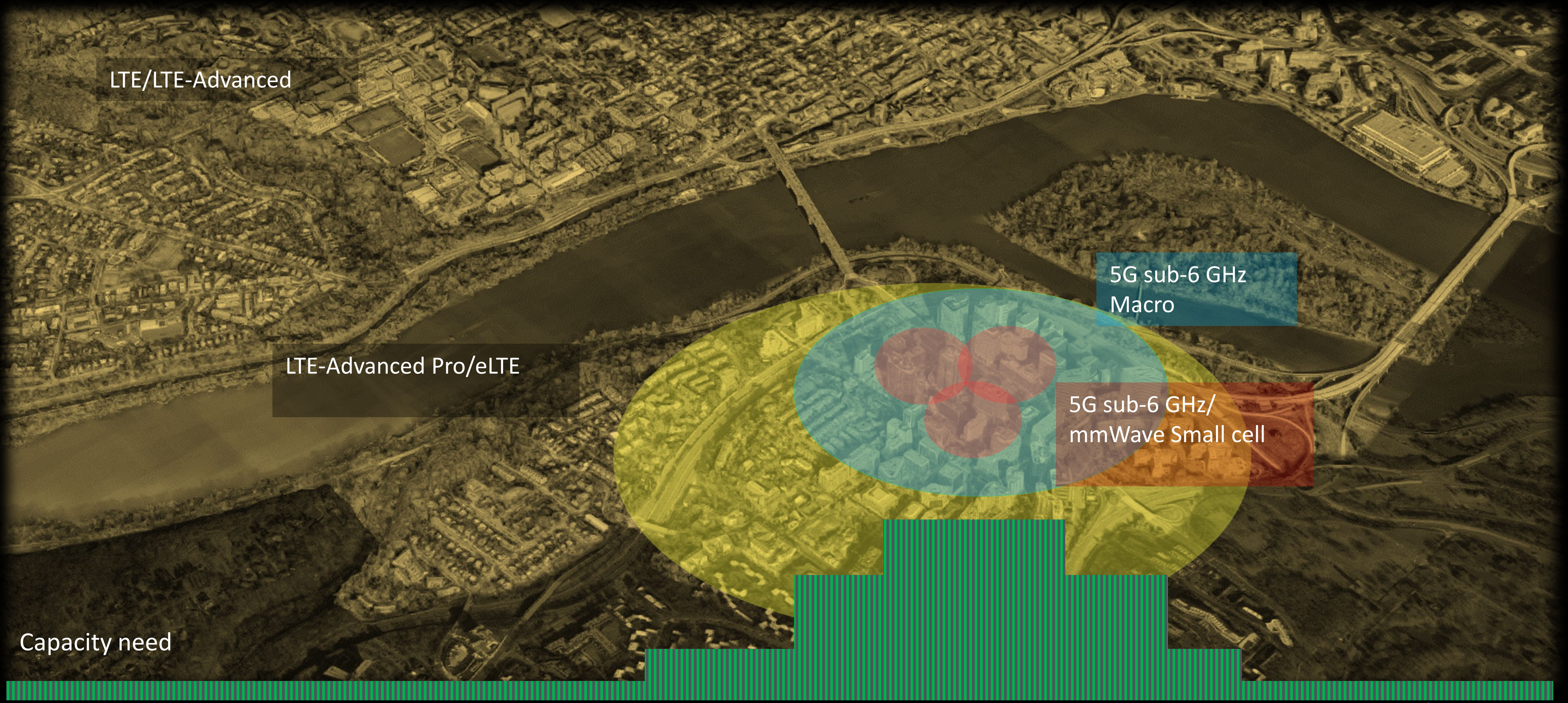
Spectrum Waves and Output



The Sweet Spot



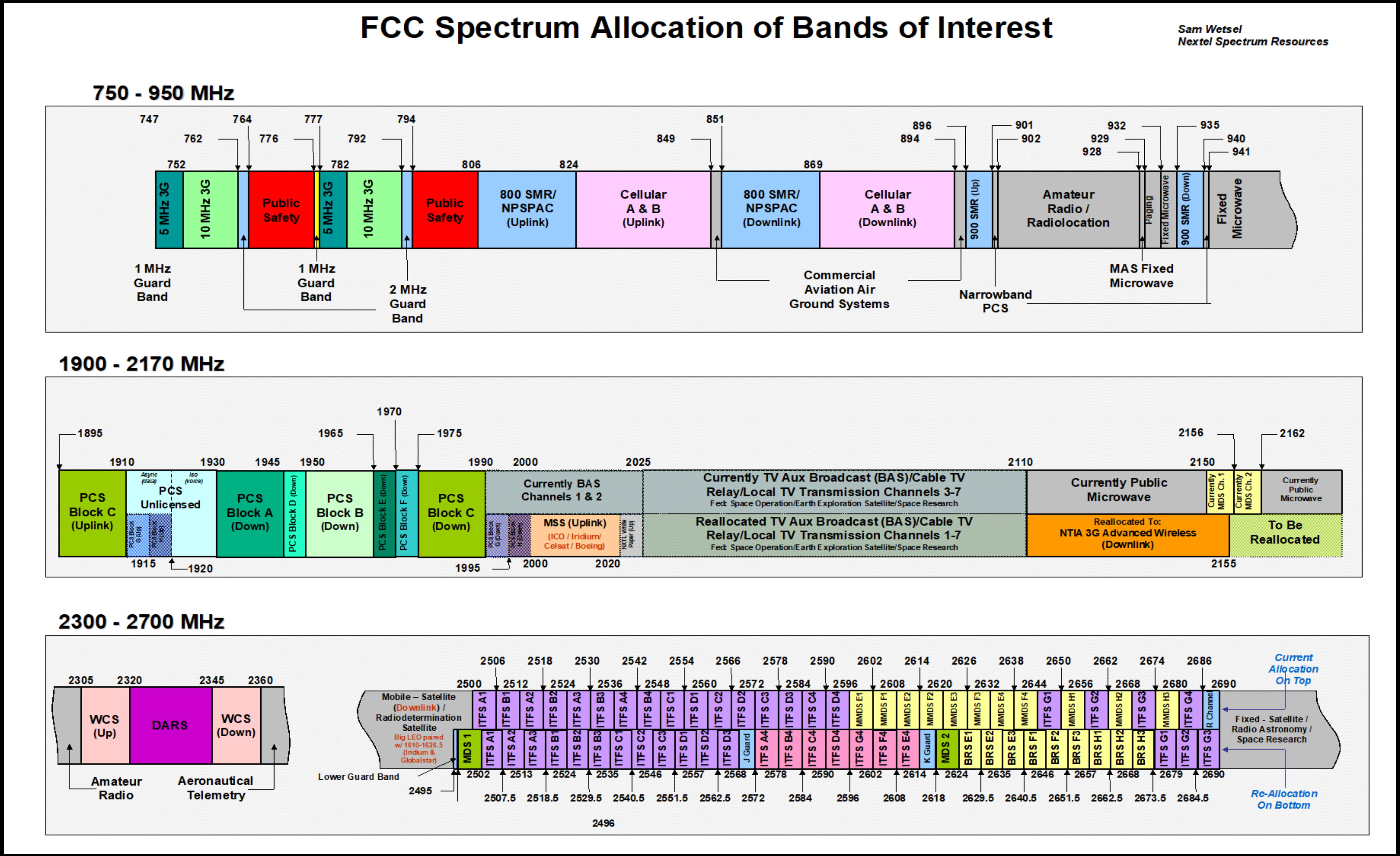
Capacity Demands and Deployment



Map data: Google

Coverage shown is for illustrative purposes only

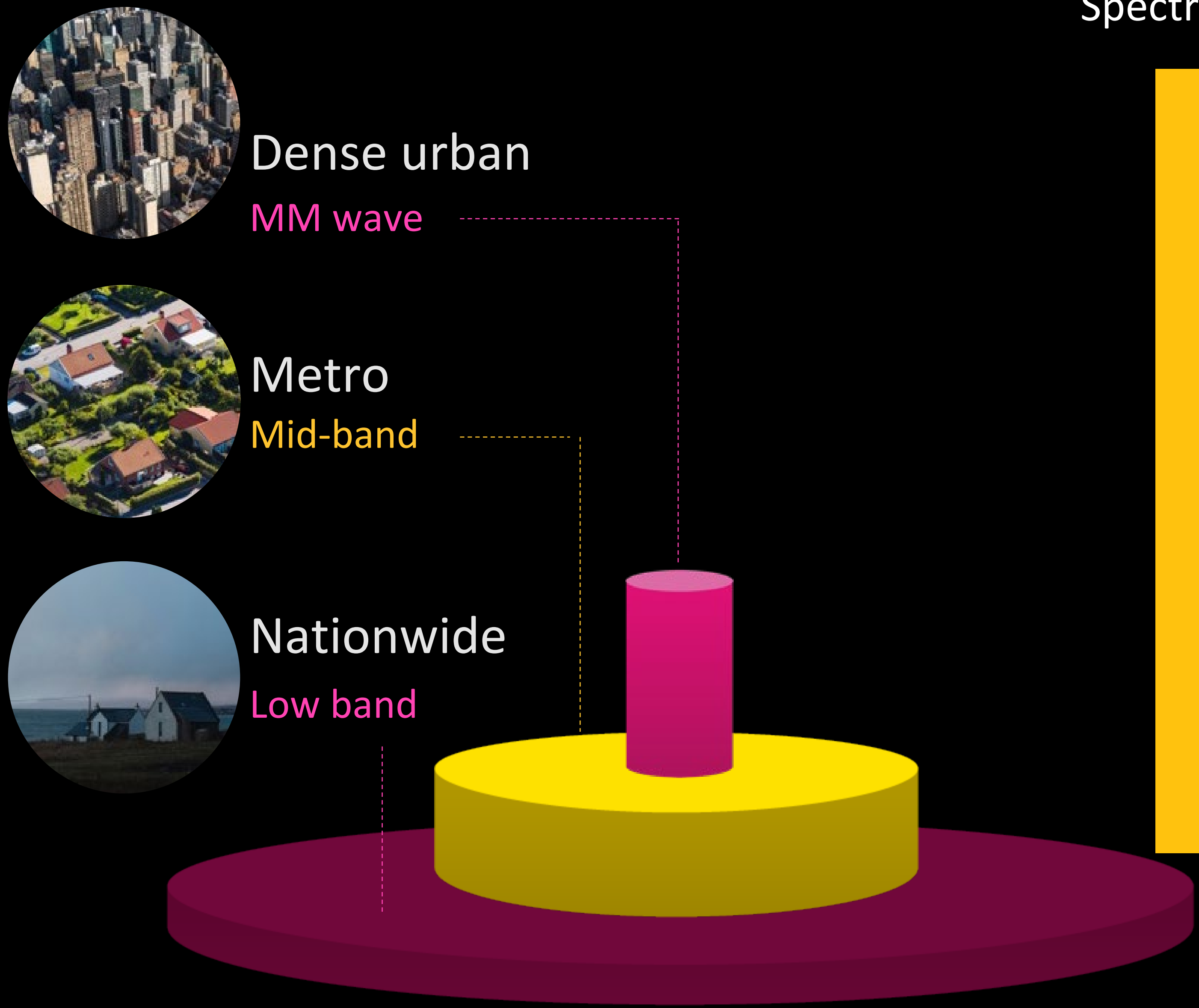
Sample Intra-band breakouts



The Three Ps & a Bonus C

- **Power**
- **Propagation**
- **Penetration**
- **Capacity**

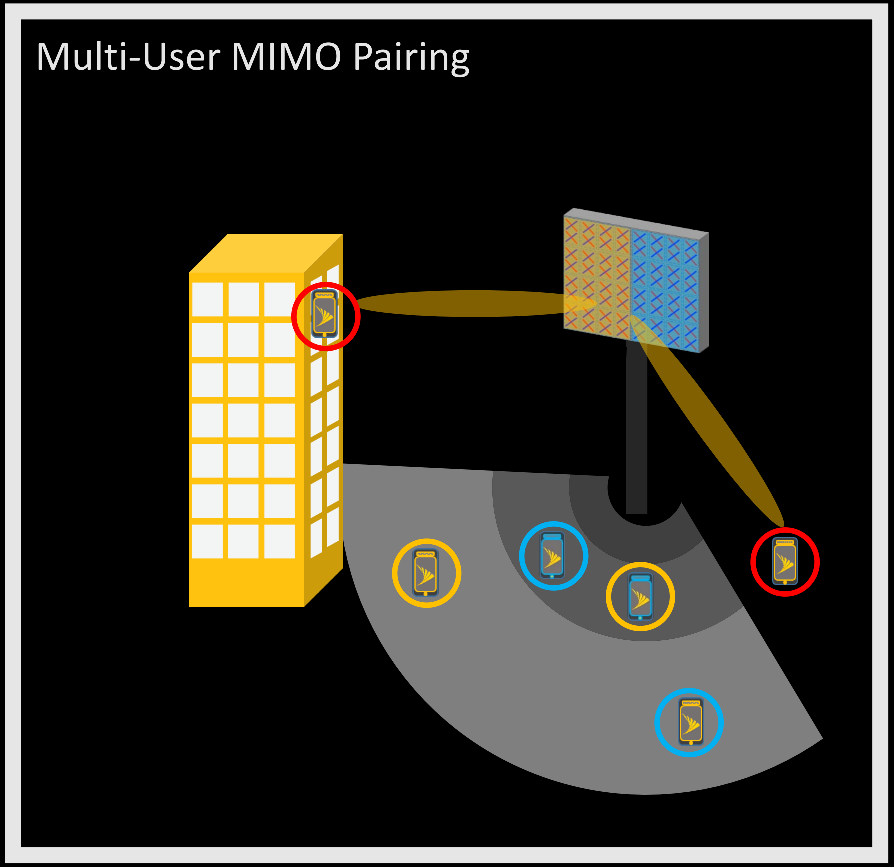
Multi Band
Spectrum use

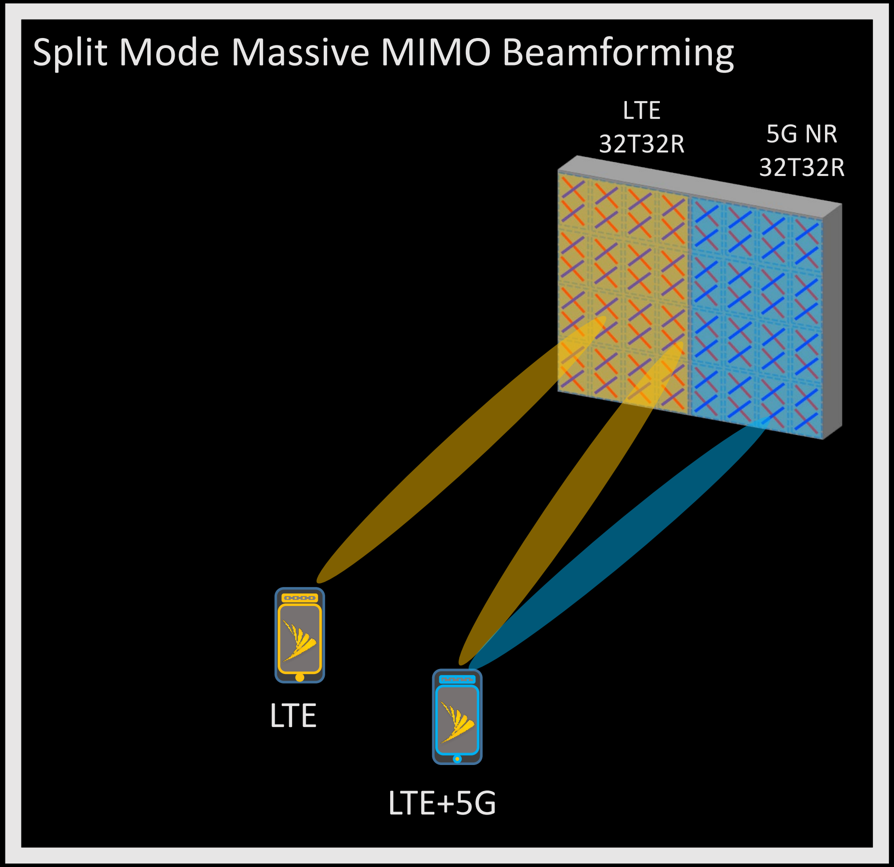


Multi band use requirements met by band not Single band to multi use

MU Mimo video

MU-MIMO and Beamforming





Vertically paired users (red circles)

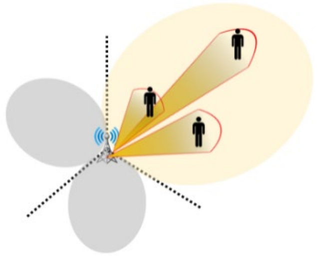
Horizontally paired users (blue and yellow circles)

Massive MIMO Highlights

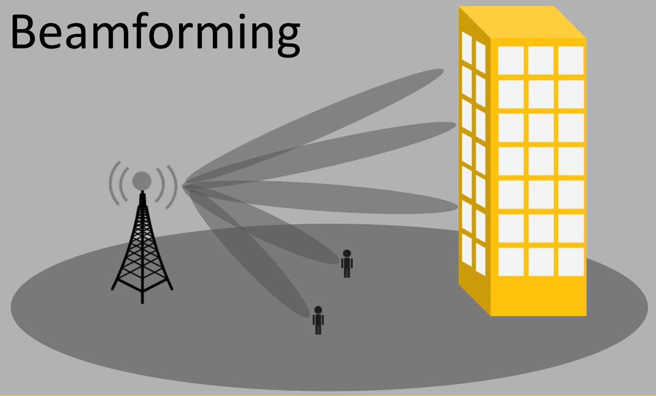
Key building block of

5G Network

Higher Spectral Efficiency



Horizontal and Vertical Beamforming



Better Coverage

Better Capacity

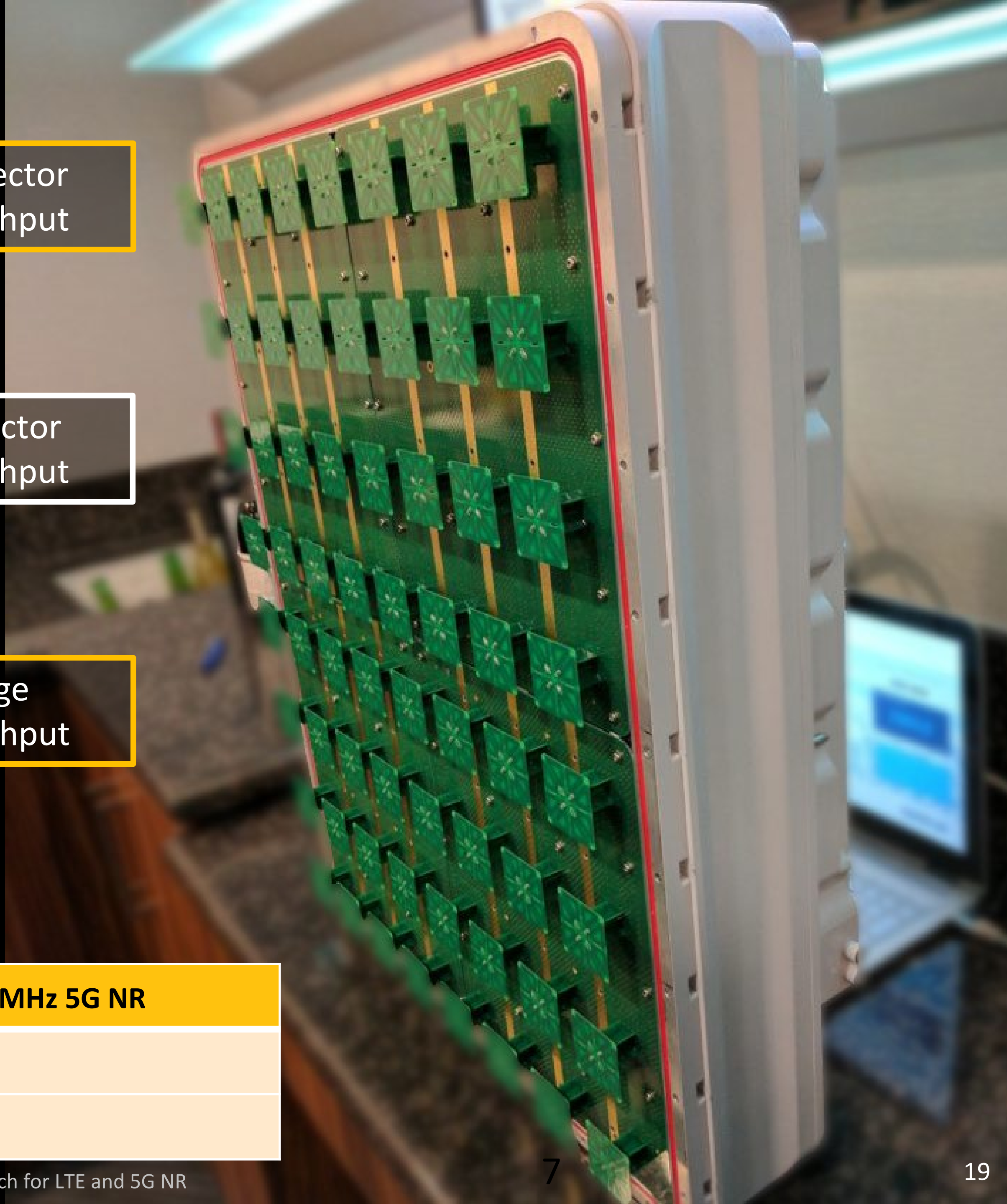
Massive MIMO Performance

Expected
32T32R - Split Mode
Performance over 8T8R

8x Peak Sector Throughput

6x Avg. Sector Throughput

3x Cell Edge Throughput



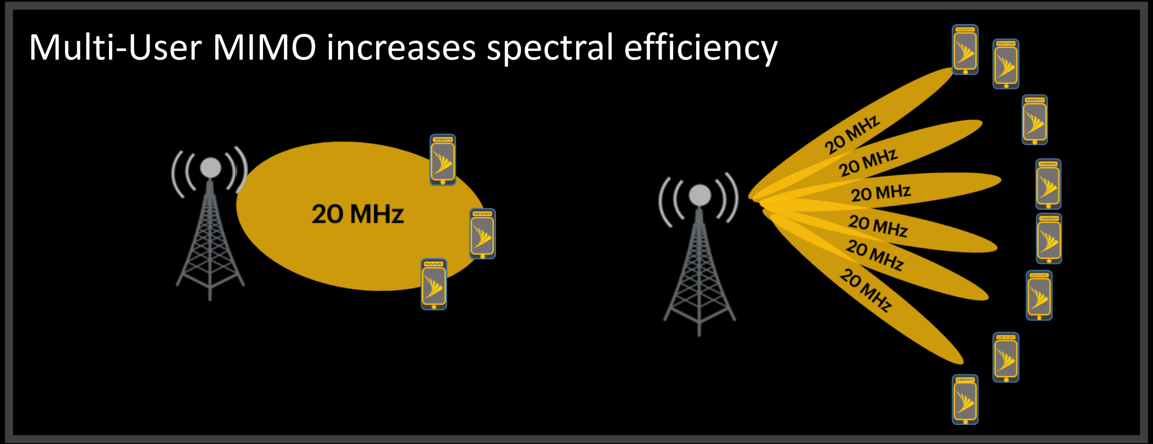
Expected Capacity with LTE + 5G NR

Capacity	**3x20 MHz LTE + 60 MHz 5G NR**
Single Sector (Gbps)	**3**
3-Sector Site (Gbps)	**9**

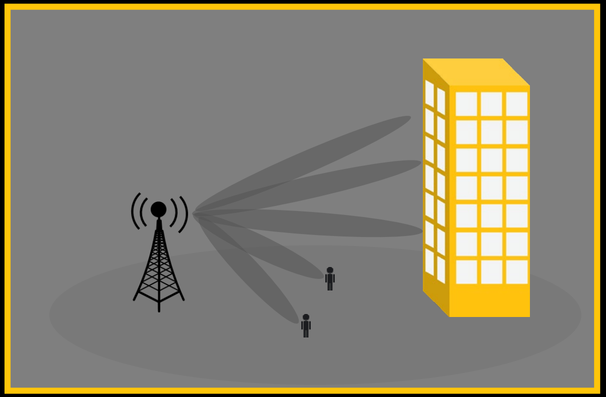
256 QAM, 8 MU-MIMO layers and 32T32R each for LTE and 5G NR

Air Interface Enhancements

Capacity - Massive MIMO Benefits

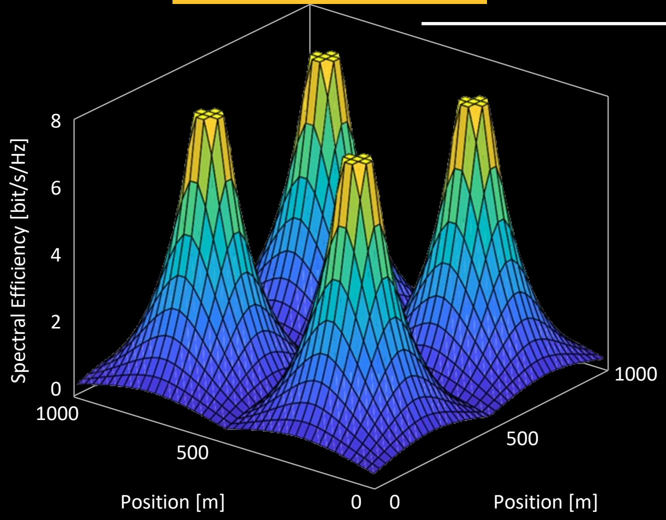


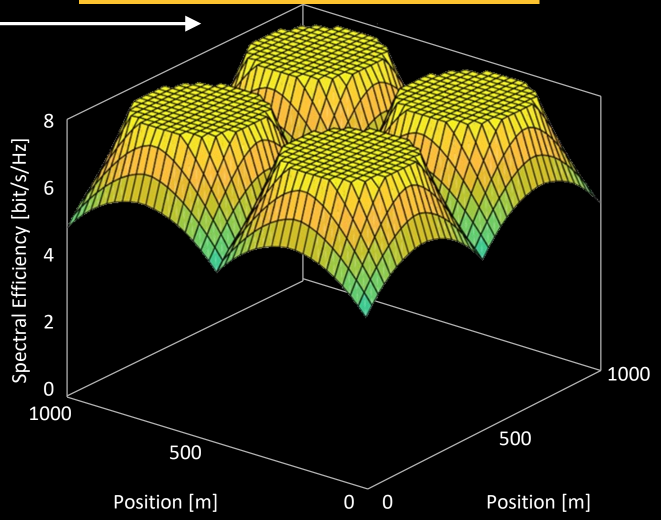
Horizontal and Vertical Beamforming



Legacy Macro

Massive MIMO Macro



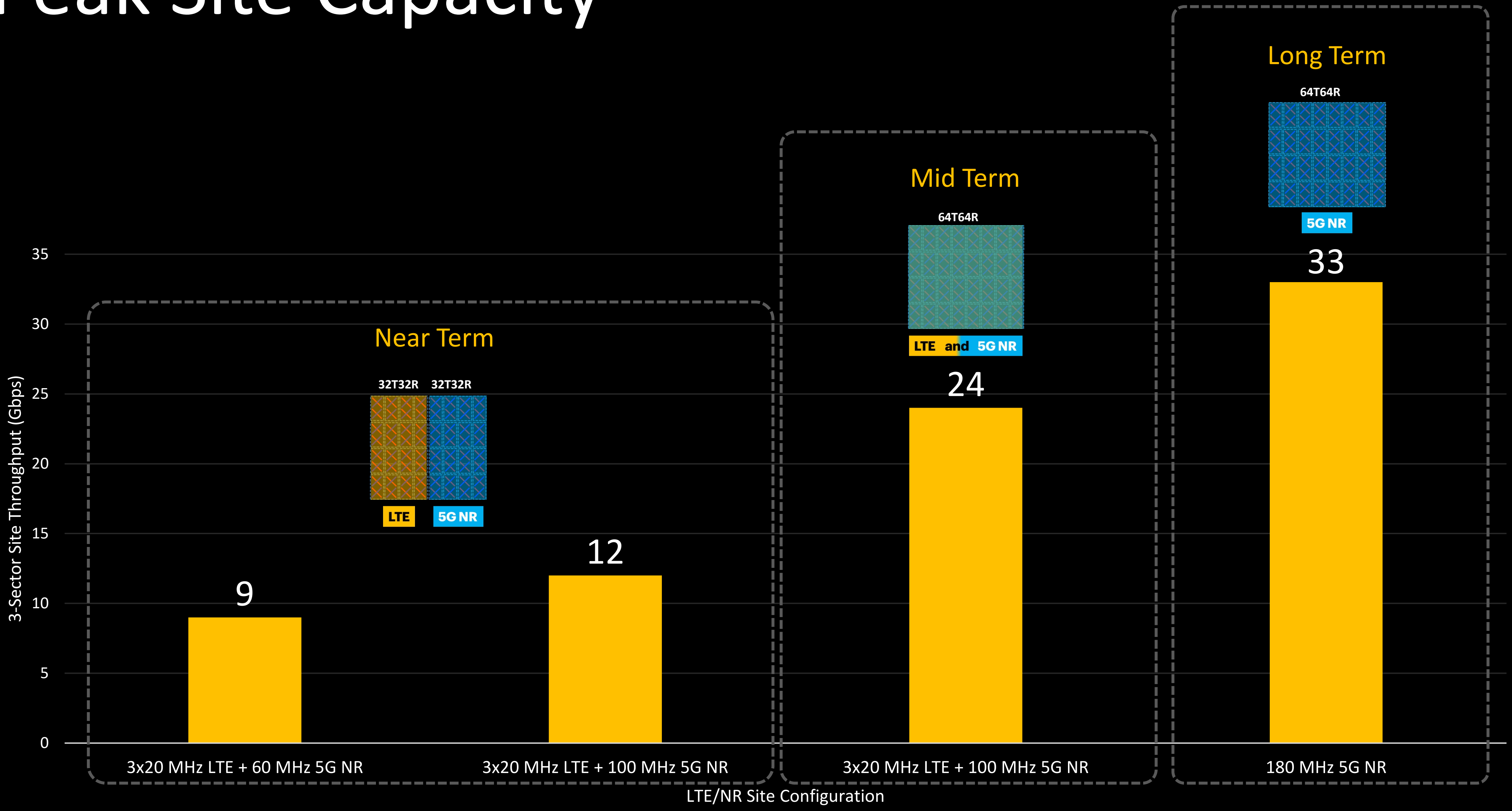


Expected 64T64R 16 Layer Performance over 8T8R

- Network Capacity
- 6x Ave. Sector Throughput
- UL Coverage Gain
- Cell Edge Throughput

Massive MIMO for 5G below 6 GHz, Emil Björnson, Linköping University

Peak Site Capacity



Challenges

- Interference
    - Cross purpose absorption
    - Ducting
    - Seasonal
    - UFO
- Edge of Network handoff
- Network densification
- Market expectation vs market opportunity

Opportunities

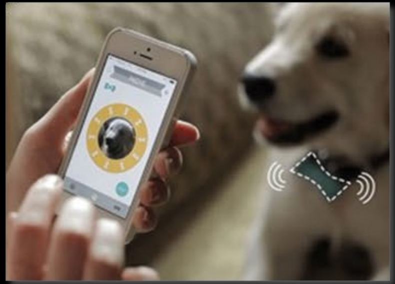
5G Will Enable...









https://www.pbs.org/wgbh/nova/article/thanks-nanoparticle-injections-these-mice-can-see-infrared-are-we-next/

Mouse Video

- https://www.eurekalert.org/pub_releases/2019-02/cp-nmi022019.php

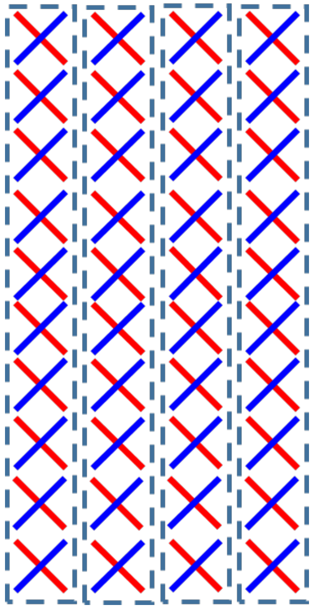
Appendix

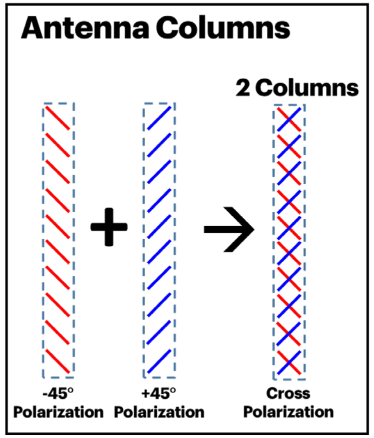
Massive MIMO Antenna Arrays

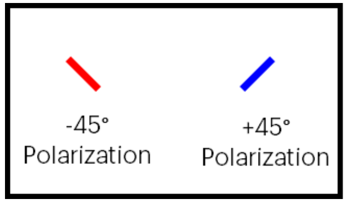
- **Conventional 8T8R Antenna:**
  - Each column uses 8-12 antenna elements to create a vertically fixed directional pattern.
  - The 8 columns, each used with a single transceiver for signal transmission, are designed for horizontal beamforming only.

- **64T64R Massive MIMO Radio/Antenna:**
  - Has 64 transceiver units, each mapped to 2 antenna elements.
  - All 128 antenna elements create the antenna pattern, with array design enabling both vertical and horizontal beamforming.
  - The addition of the vertical dimension, with per antenna element adjustments, turns a column of antennas into an antenna array allowing many more layers and much finer adjustments.
  - TDD is better than FDD due to channel reciprocity; with FDD, feedback overhead increases with antenna elements.

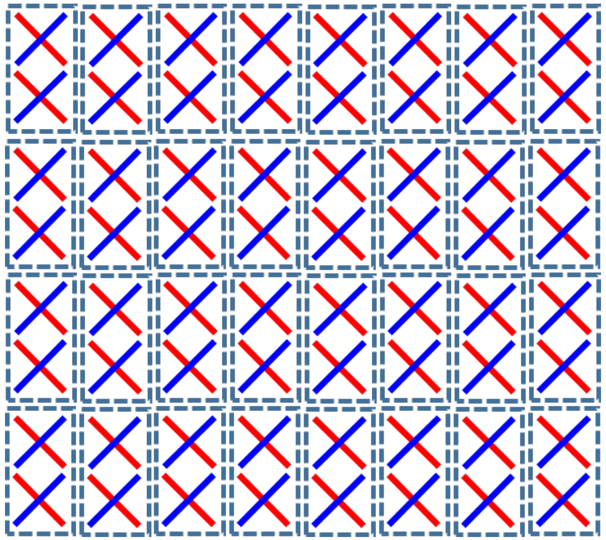
8T8R



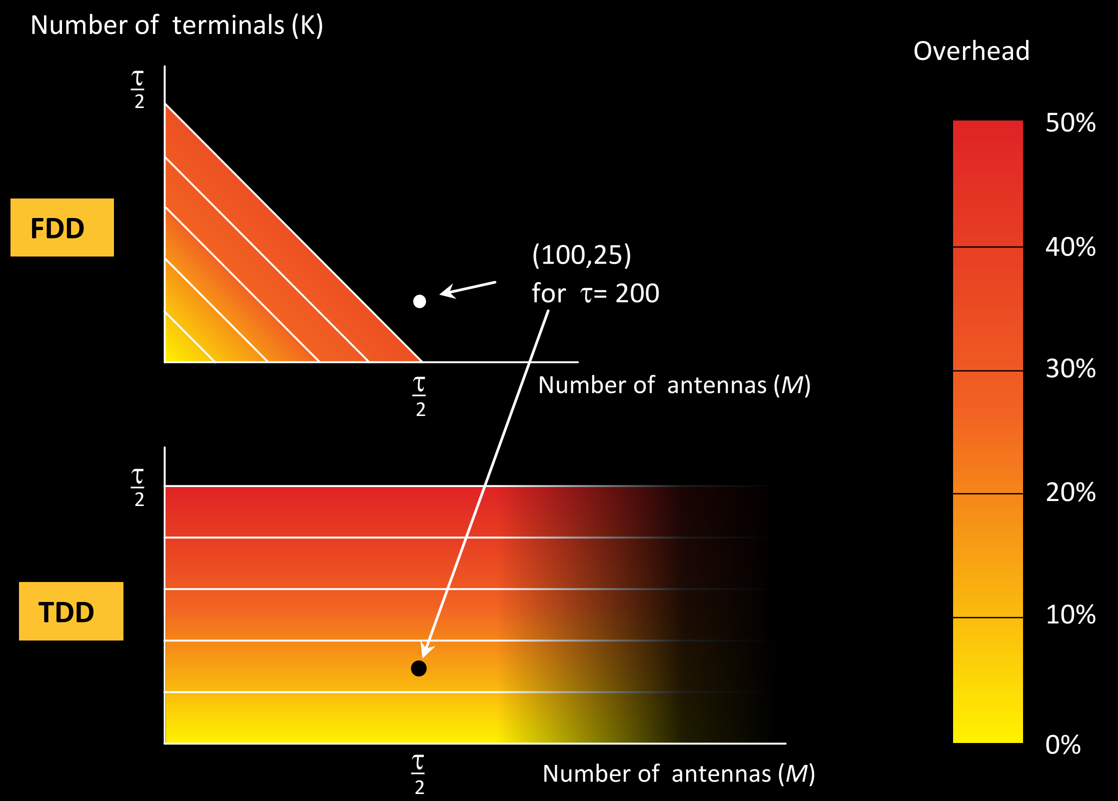




64T64R



Benefits of TDD in Massive MIMO



- To ensure reliable channel feedback, the reference signal symbols should be sent within a coherence block (τ):
  τ = Channel coherent bandwidth x Channel coherent Time
- TDD requires $2K$ UL sounding signal symbols for channel estimation
  $$K < \tau/2$$
- FDD requires $2M$ DL reference signal symbols and $2K$ UL reference signal symbols for channel estimation and feedback
  $$M + K < \tau/2$$

  M is the total number of antennas at the eNB, K is the total number of served UEs.

- TDD operates on the same frequency on DL and UL
  - ⇒ DL/UL channel reciprocity: The channel estimate of the UL at the Tx can be utilized for DL beamforming, thus less overhead
- FDD operates on different frequencies on DL and UL
  - ⇒ No DL/UL channel reciprocity: Two way pilots and feedback needed
    - ➢ Much higher overhead, which greatly limits the total number of allowable antennas in case of high mobility scenario when the coherence block τ is small.

Source: Massive MIMO: Ten Myths and One Critical Question, Emil Bjornson, Erik G. Larsson, and Thomas L. Marzetta

NOW FOCUSED ON 9 MAJOR MARKETS

Sprint

Sprint 5G

Dallas

Atlanta

Chicago

Phoenix

Los Angeles

Houston

New York City

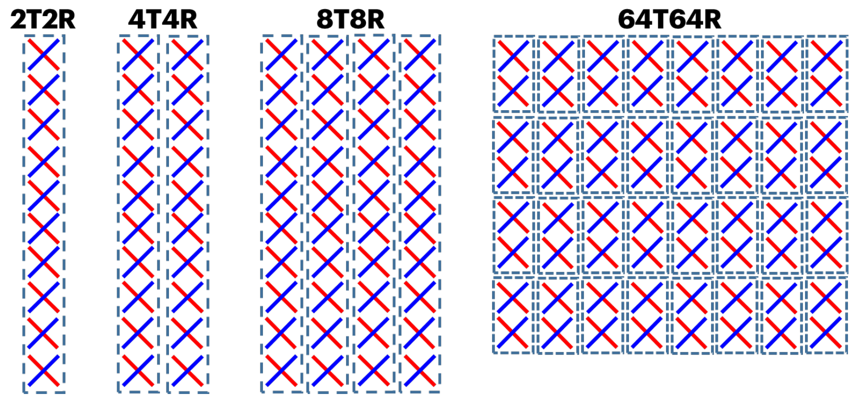
Kansas City

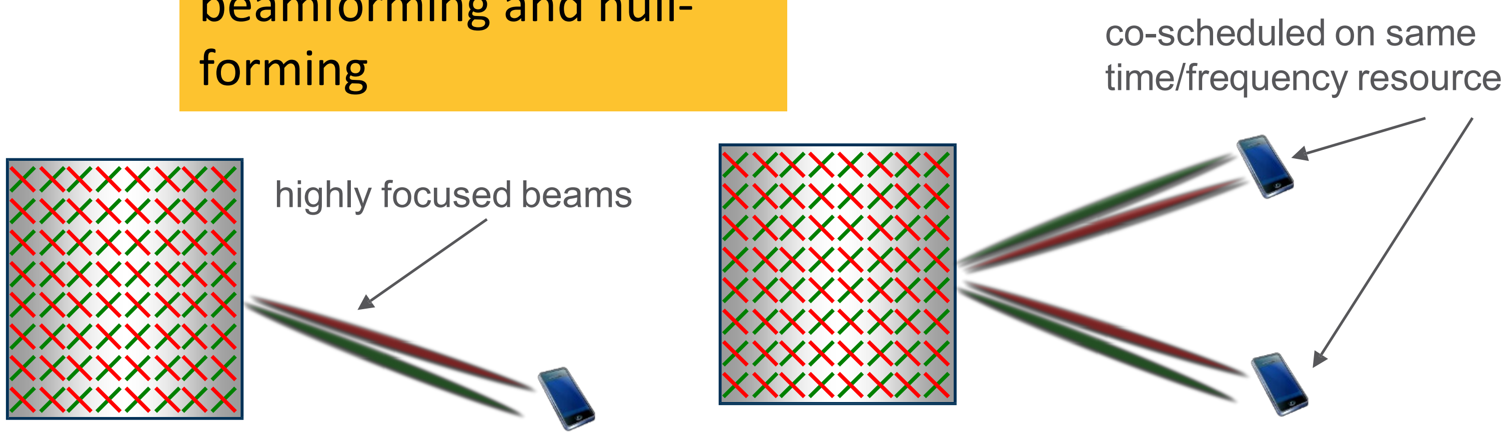
Washington, D.C.

Air Interface Enhancements

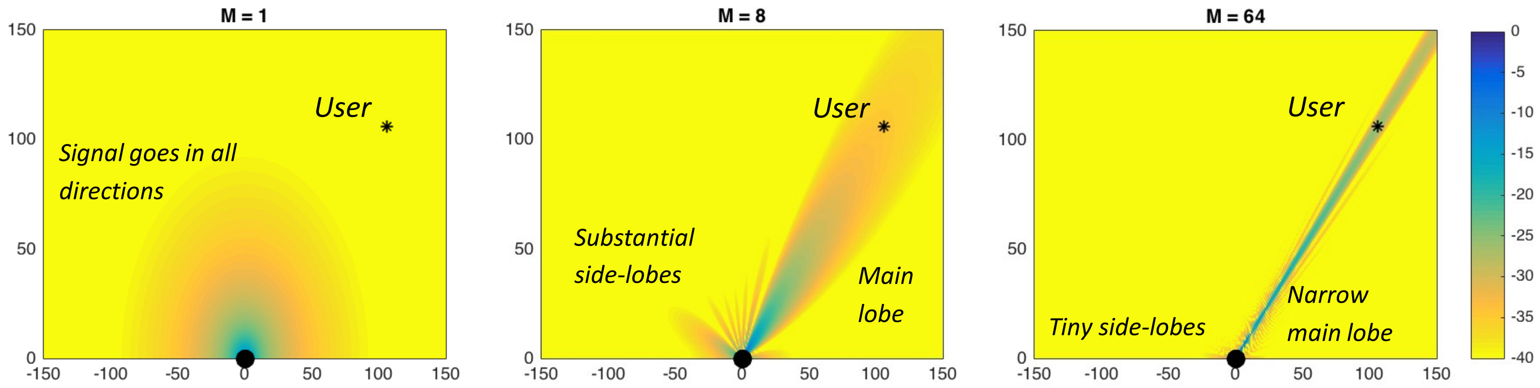
Capacity - Massive MIMO and Beamforming

Massive MIMO systems enable sharper beamforming and null-forming



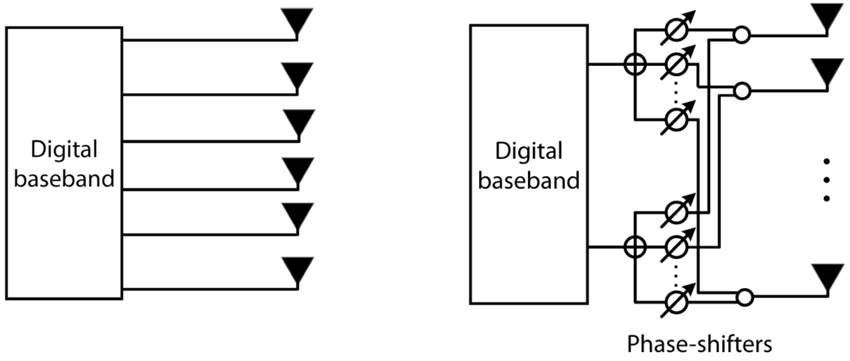


Adapted from Ericsson



M- # of Tx

Massive MIMO for 5G below 6 GHz, Emil Björnson, Linköping University



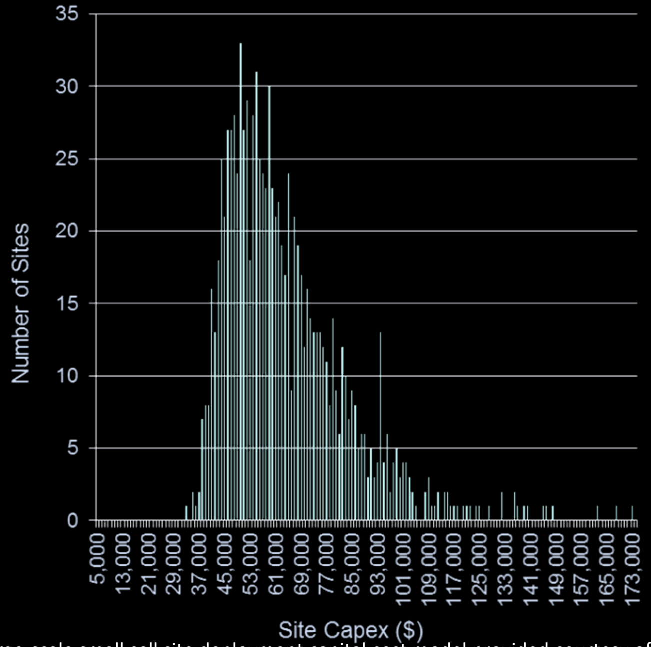
Fully Digital Beamforming > Hybrid Beamforming

Small Cell Deployment Challenges

These remain as open challenges for the Industry today for LTE small cells. 5G will only accentuate the problem.

- Backhaul
- Siting/Real Estate/ Zoning & Permitting
- Sheer # of sites needed

Large variability in local laws, landlord policies, and other site-specific factors result in cost distributions that limit small cell deployments today to the 1,000’s to 10,000’s, and will greatly inhibit the adoption of high-frequency 5G in the US, where 100,000+ units may be necessary per operator (depending on frequencies used, and other company-specific business and technical design criteria).



Large-scale small cell site deployment capital cost model provided courtesy of Nokia.

5G will **NOT** be successful if we cannot adequately address roadblocks to large-scale small cell deployments that exist today.