

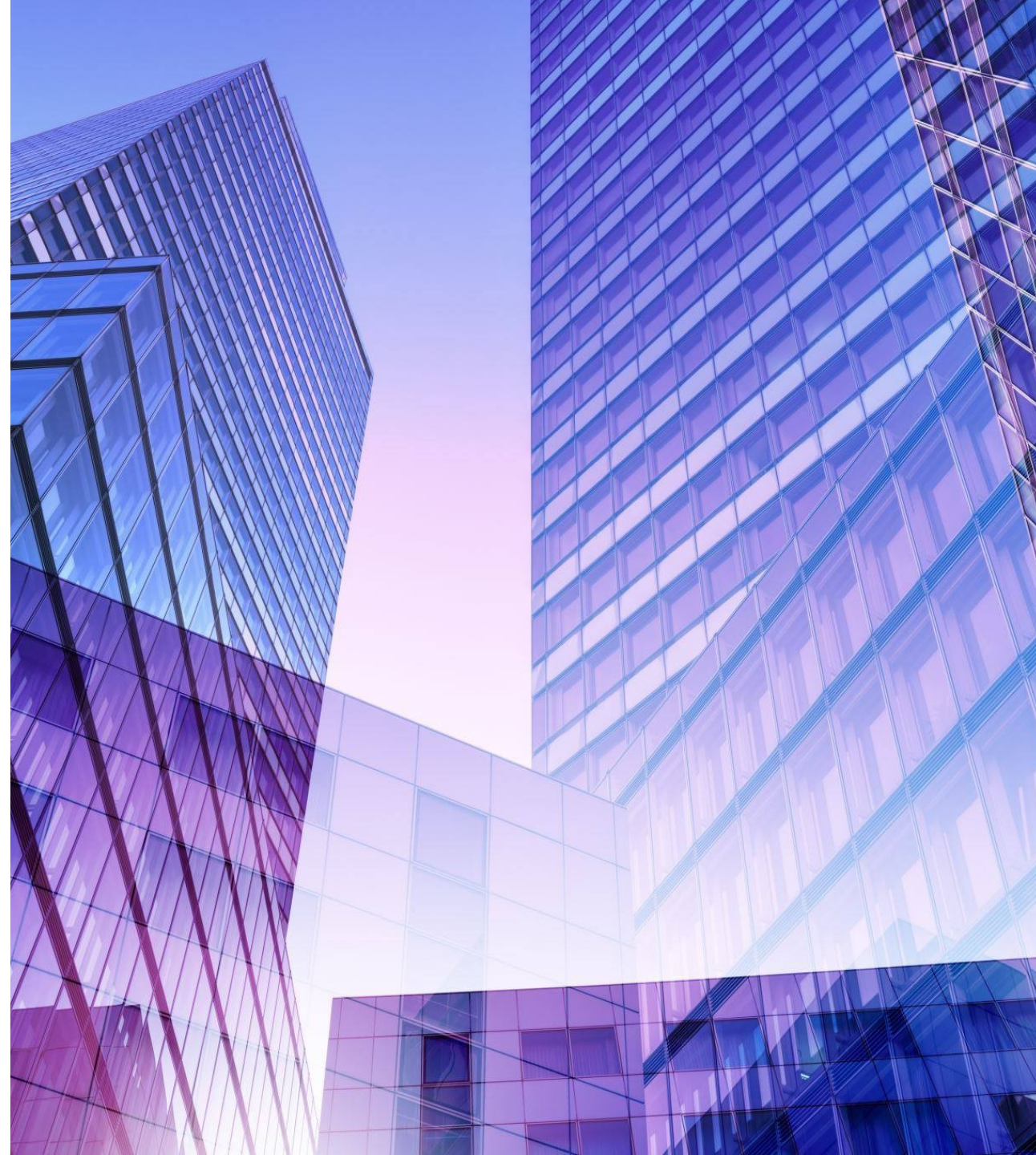
The background of the slide features a silhouette of several 5G cellular towers against a bright, cloudy sky. The towers are made of metal lattice and are equipped with various antennas and satellite dishes. The sky is a mix of light blue and white, suggesting a bright day with some cloud cover. The towers are positioned at different heights and angles, creating a sense of depth and scale.

5G Cellular (Mobile) Communication Systems

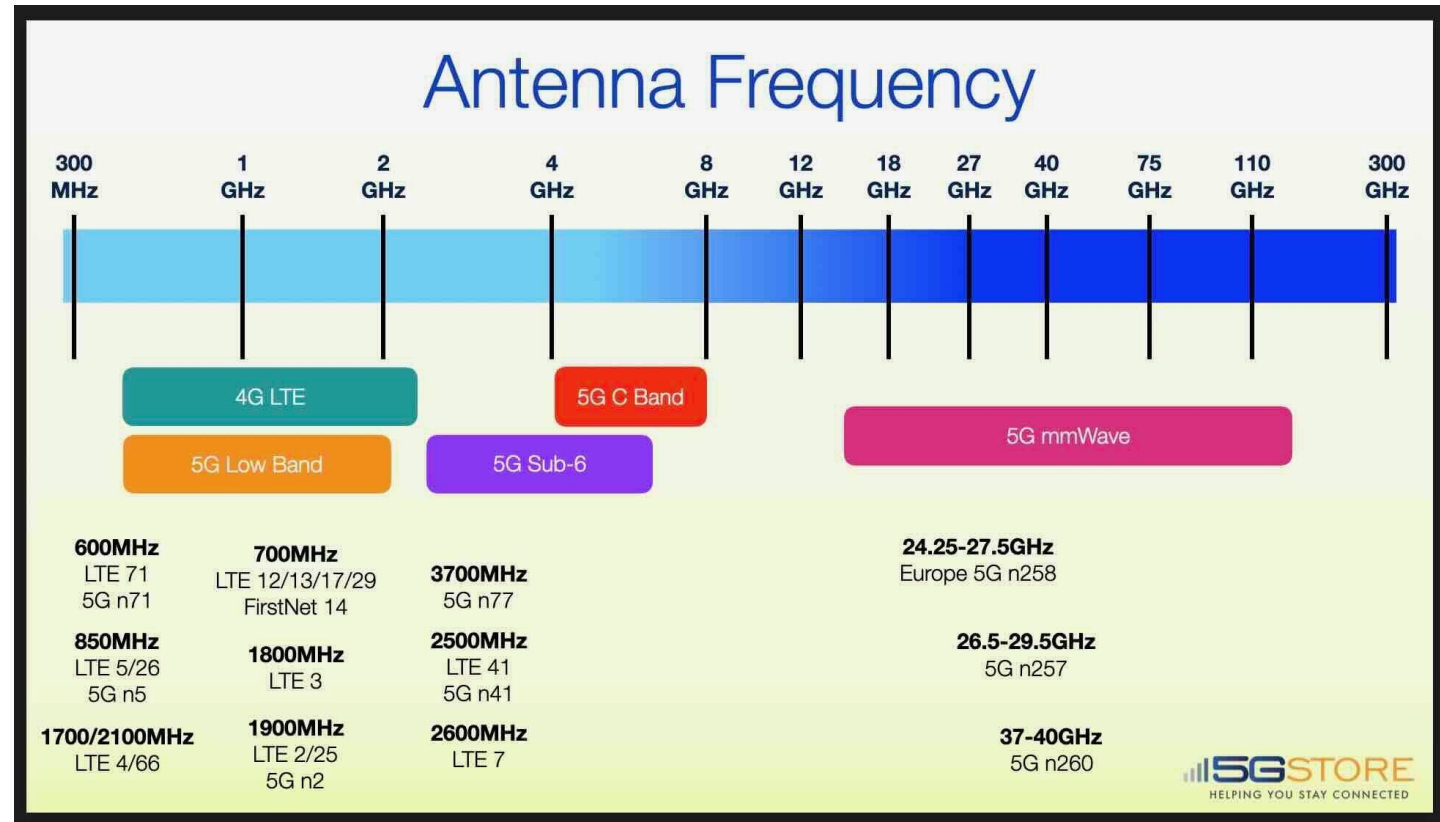
Vincent Cosimano, Andrew Dau, and Anthony DiTano

Agenda

- Introduction & History
- Social, Economic & Environmental Impacts
- Physical Principles
- System Architecture
- Electromagnetics-Focused Components (course tie-in)
- Future Developments & Suggestions
- Q&A



What Is 5G? [1] [2]



Low Band; mid-band; high Band (mmWave) [3]

[4]

Low Band: <2GHz

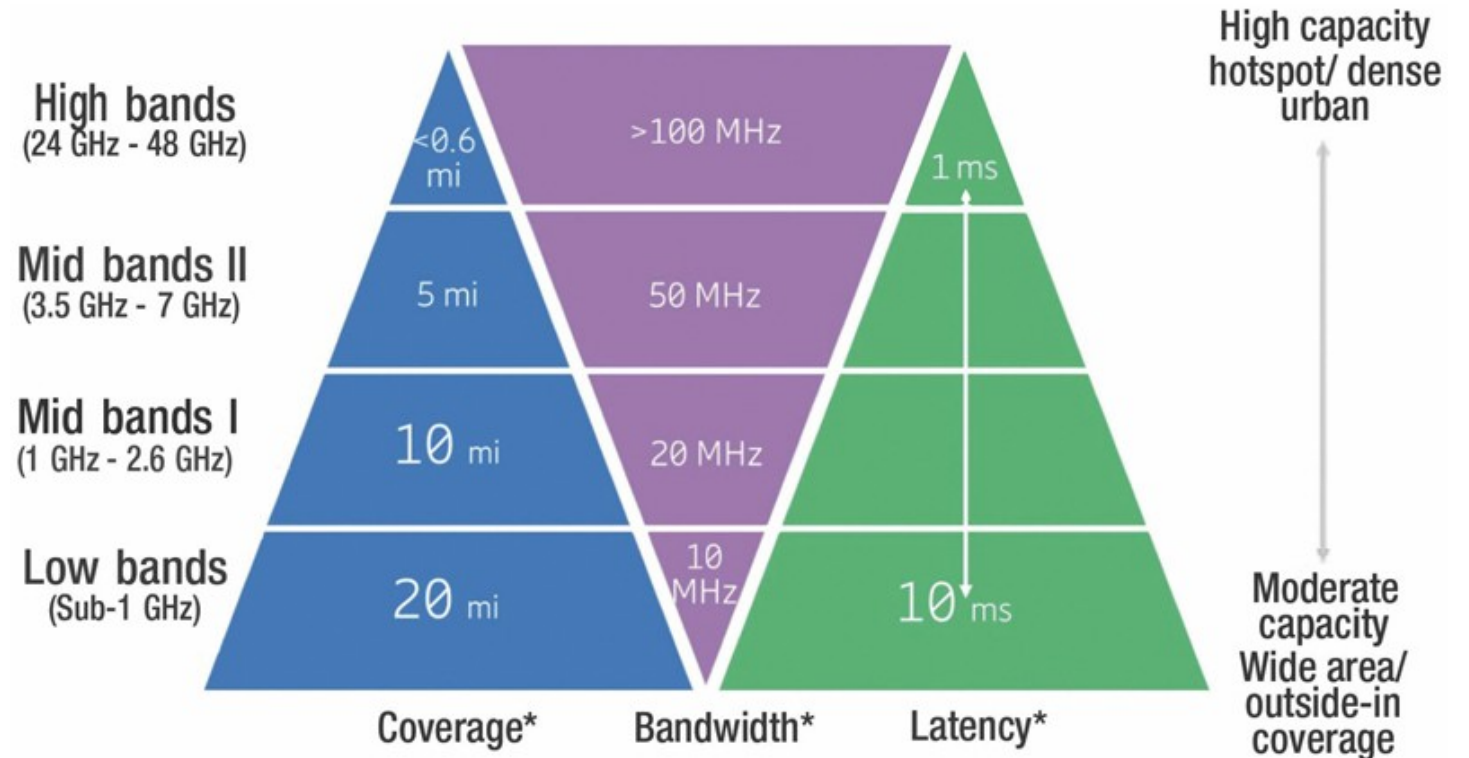
- Strong Coverage
- Long Transmission Ranges
- Overlaps with 4G LTE Networks

Mid Band: 2-6 GHz

- Optimal coverage and capacity

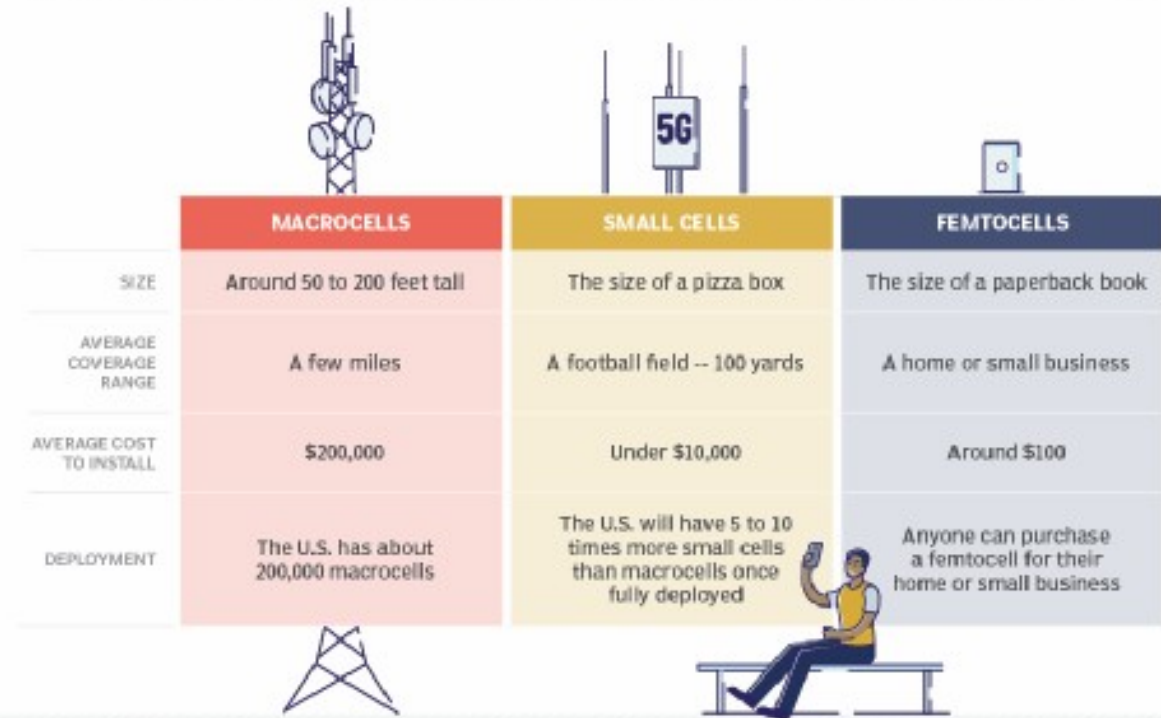
High Band: >24GHz

- High Bandwidth and low latency (5ms)
- Lower transmission distances
- Easily blocked
- Needs many small cells



Macrocells and Microcells [5]

Macrocells vs. small cells vs. femtocells



	MACROCELLS	SMALL CELLS	FEMTOCELLS
SIZE	Around 50 to 200 feet tall	The size of a pizza box	The size of a paperback book
AVERAGE COVERAGE RANGE	A few miles	A football field -- 100 yards	A home or small business
AVERAGE COST TO INSTALL	\$200,000	Under \$10,000	Around \$100
DEPLOYMENT	The U.S. has about 200,000 macrocells	The U.S. will have 5 to 10 times more small cells than macrocells once fully deployed	Anyone can purchase a femtocell for their home or small business

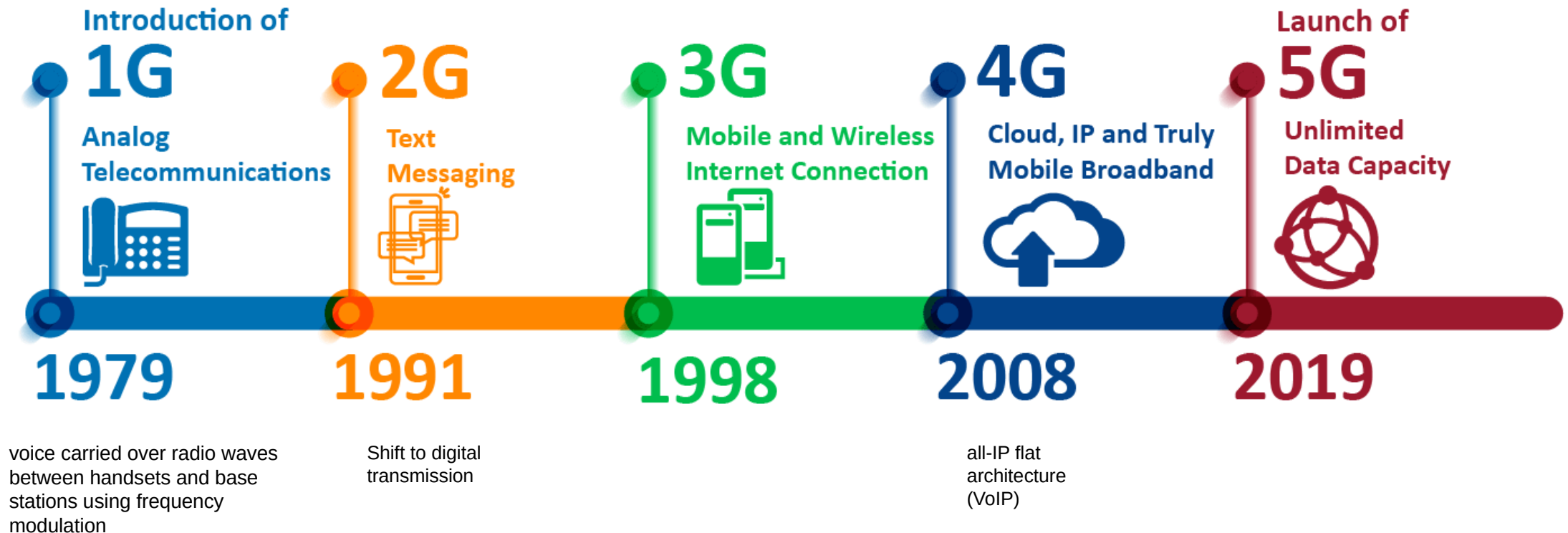
ILLUSTRATION: LARRY AUSTIN FOR ESPEC

REPORT FLOW MARKET. ALL RIGHTS RESERVED

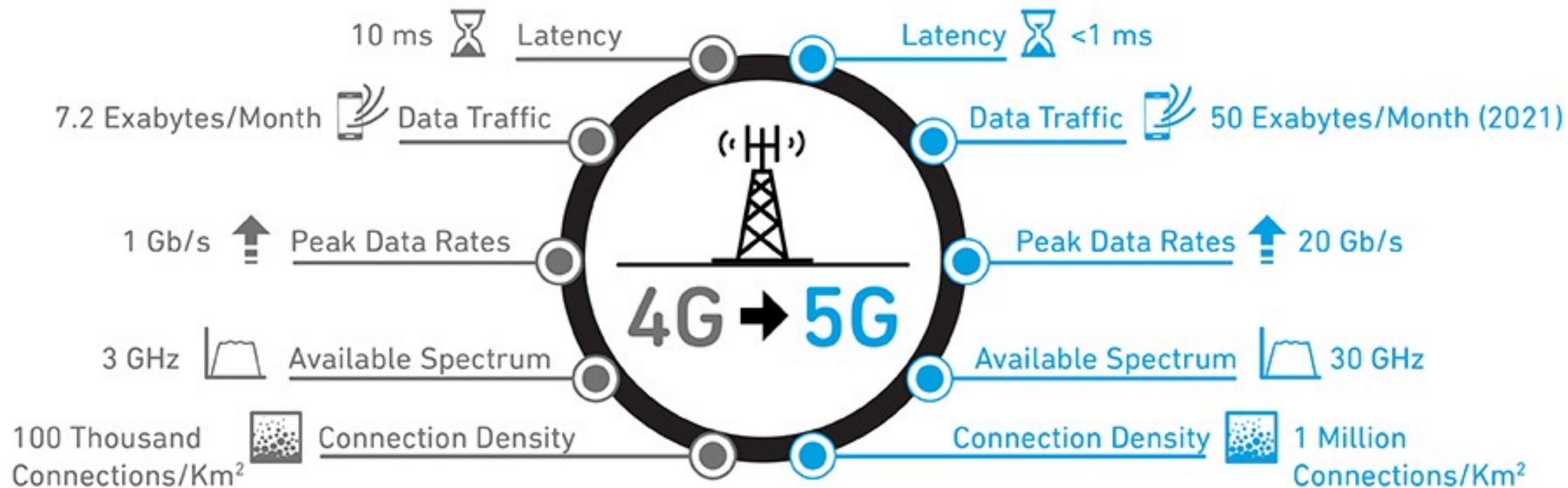


Brief History of Development [6][7]

The Evolution of 5G



Comparing 4G and 5G



Social Impacts [9]

“The Socio-Economic Impacts of 5G” by
TELUS (one of Canada's three major
national telecommunications carriers)



Increase economic growth across **all sectors**, delivering an estimated 16% of GDP growth by 2036 while supporting growth in high-paying digital economy jobs



Reduce **greenhouse gas emissions** up to 20% and deliver other environmental benefits such as more sustainable agricultural practices



Increase the productive capacity of **rural communities** through the deployment of 5G fixed wireless access (FWA) where last-mile fibre is not feasible



Improve **healthcare** system performance, including enabling the expansion of rural and virtual care models



Deliver new interactive capabilities built on augmented and virtual reality and artificial intelligence that enhance the **quality of life** for older Canadians and those living with disabilities



Increase crop yields and optimize water, pesticide, herbicide, and fertilizer use for the **agriculture** sector

Environmental impact of the digital sector: 5-year trends and 5G governance

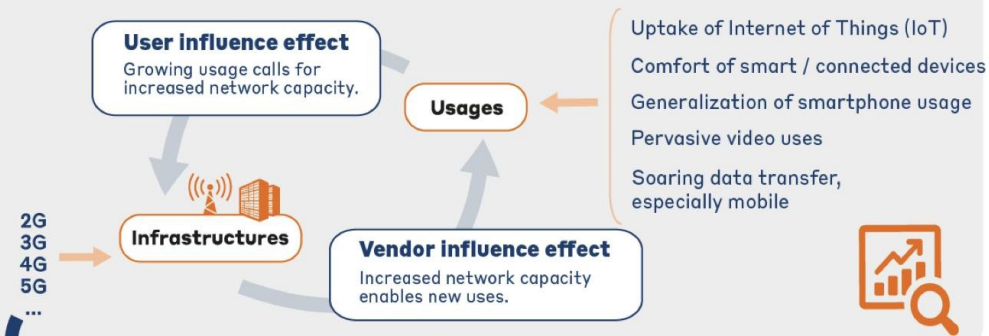
Today's digital sector...

Our digital system
+
is at the heart of our other systems
+
is a key asset to face future crises

... is incompatible with a 2°C pathway.

GHG emissions from the digital sector grow by **6%** per year, and already account for **3.5%** of global GHG emissions. This share could double by 2025.

The pace of technological progress in energy efficiency falls short of fast-increasing usage.



As such, making 5G deployments rational rather than compulsive...

... would pave the way towards a new, sustainable digital sector.

Mass 5G roll-out would increase the digital sector's environmental footprint*, from both utilization and production

Making 5G sustainable requires thoughtful deployment, and being able to answer two questions:

- 1 Where is it needed, and why?
- 2 To what uses do we limit ourselves, and how do we choose them?

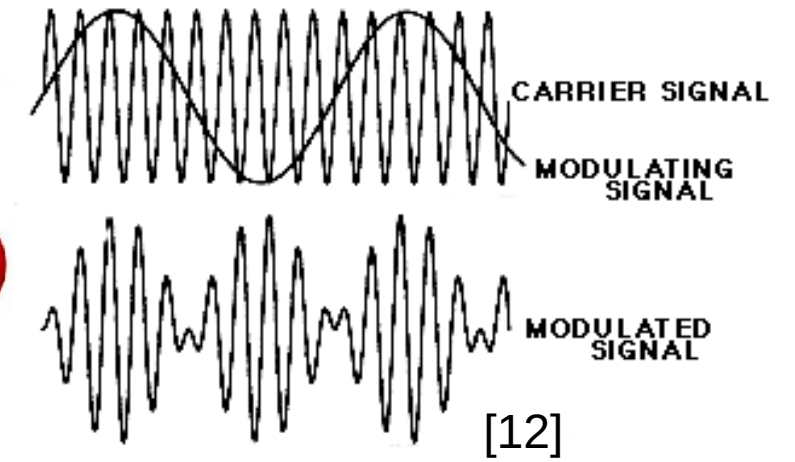
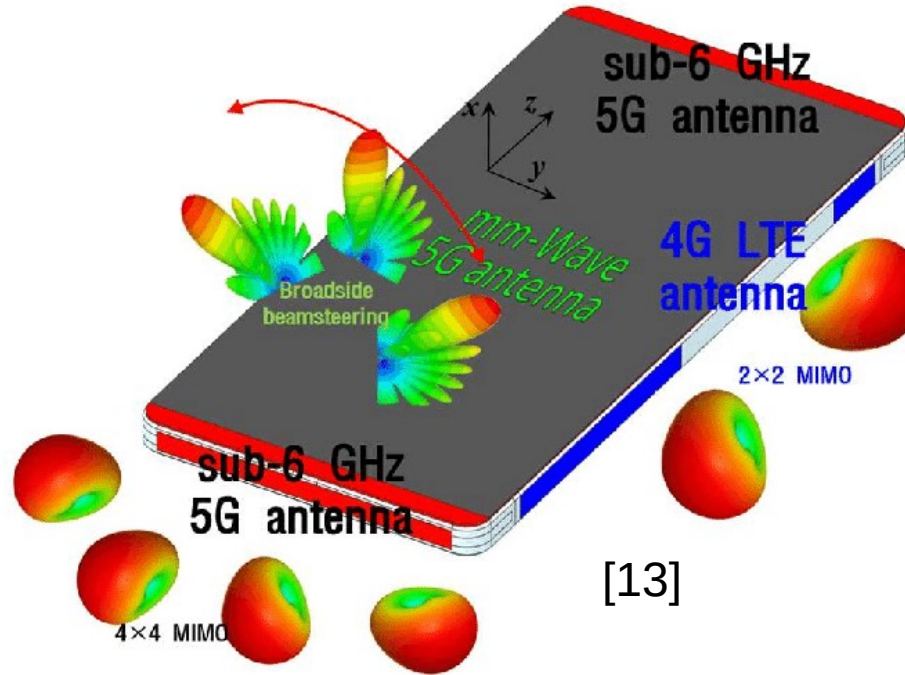
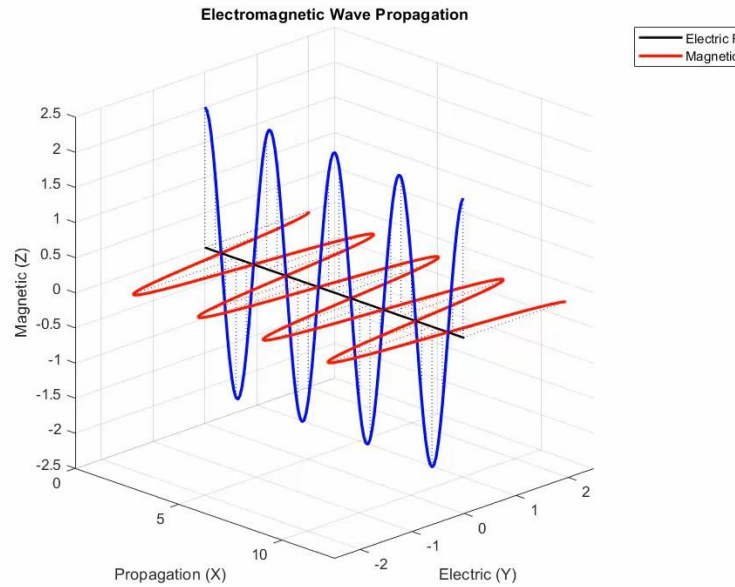
To that end, we need a plan:

- 1 **Building a new digital governance framework, involving all stakeholders**
(incl. regulatory bodies, consumers, national and international institutions)
- 2 **Inventing new economic models, compatible with reducing environmental impacts**
(operators, service providers, manufacturers)
- 3 **Developing sustainable management tools:**
 - Defining quantitative goals
 - Developing impact assessment tools

* Source : HCC, 2020a ; Huawei, 2020 ; GSMA, 2019a

Economic & Environmental Impacts

“Environmental impacts of digital technology: 5-year trends and 5G governance” by The Shift Project [10]

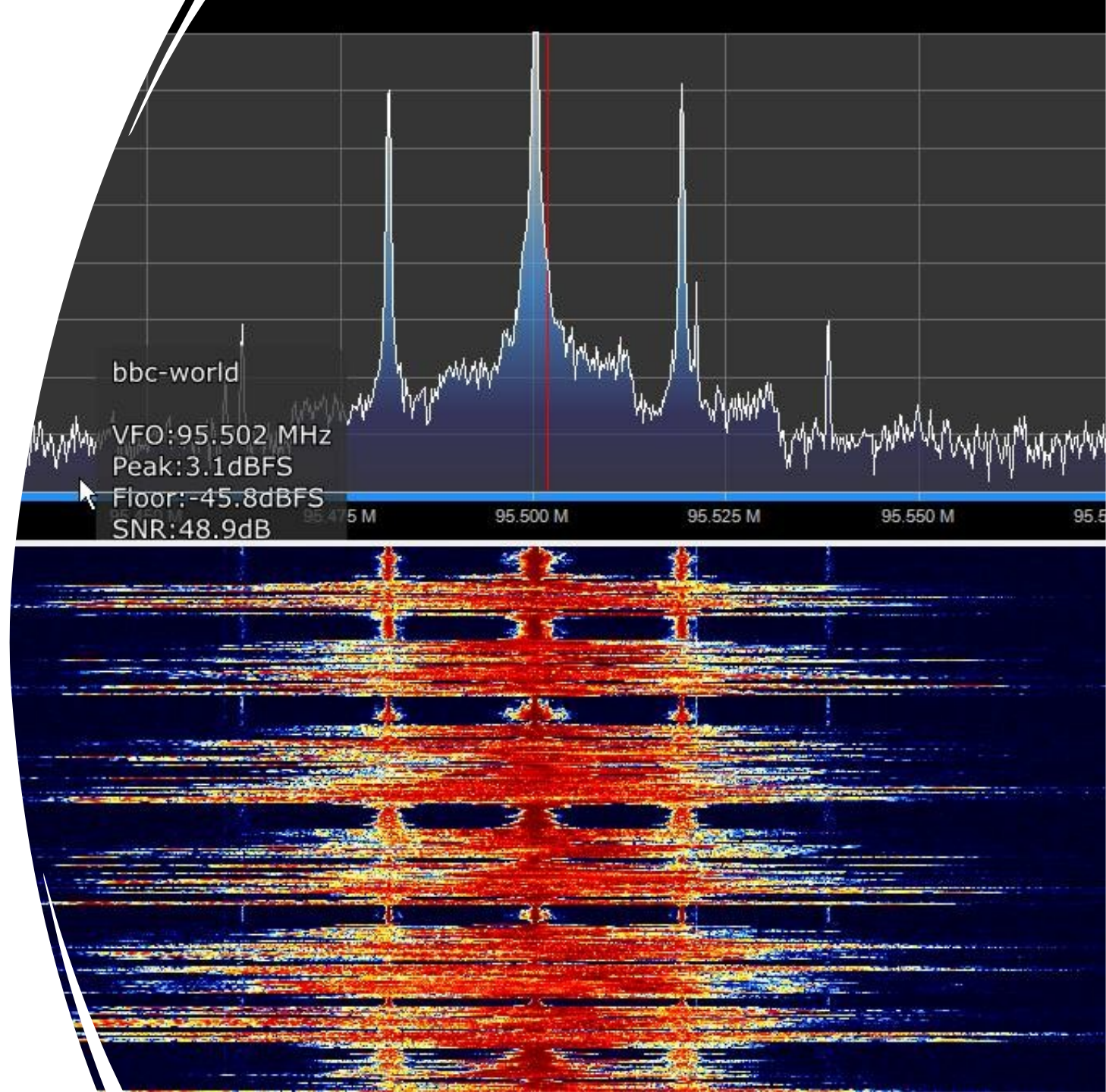


Main Physical Principles – Electromagnetic Waves [11]

- All radio signals send a modulated signal from a transmitter to a receiver
- Most 5G is very high frequency, which means very small wavelength
- $\frac{1}{2}$ and $\frac{1}{4}$ wavelength antennas range from several millimeters to several centimeters
- In MIMO, antennas are phased to cause intentional interference to direct the signal

Wave Propagation & Challenges [14]

- Multipath and Scattering
 - Multipath: signal takes multiple paths to get to same destination
 - Scattering: signal strikes obstacles and its energy is dispersed in multiple directions, decreasing the original signal strength
 - Found in urban environments
 - Signal is scattered and diffracted, multiple copies arrive with different phases and cause interference
 - Caused by rain and haze as well as buildings



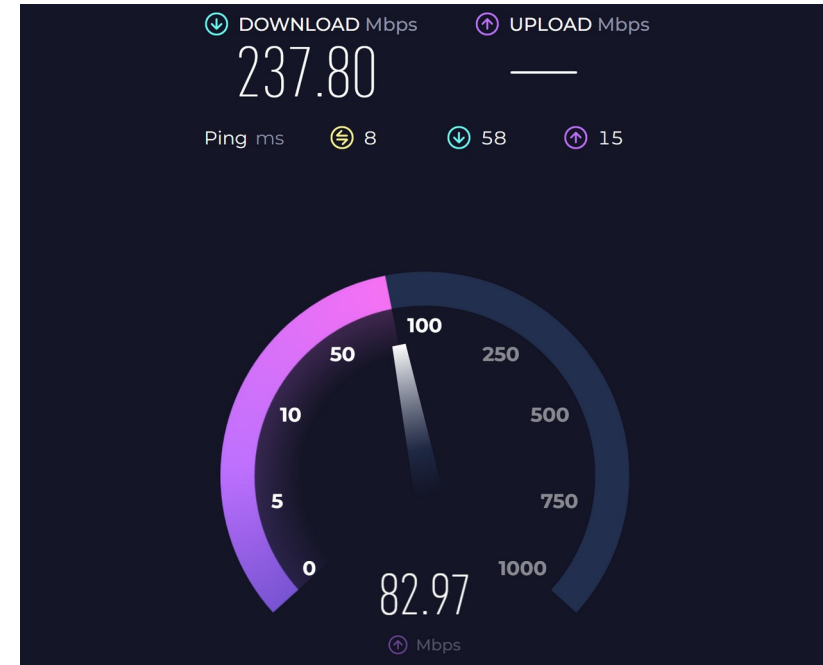
Alpha-Beta-Gamma Gamma(ABG) & Close-In (CI) [15]

- Alpha-Beta-Gamma (ABG)
 - complex

$$\text{PL}^{\text{ABG}}(f, d)[\text{dB}] = 10\alpha \log_{10} \left(\frac{d}{1 \text{ m}} \right) + \beta \\ + 10\gamma \log_{10} \left(\frac{f}{1 \text{ GHz}} \right) + \chi_{\sigma}^{\text{ABG}}$$

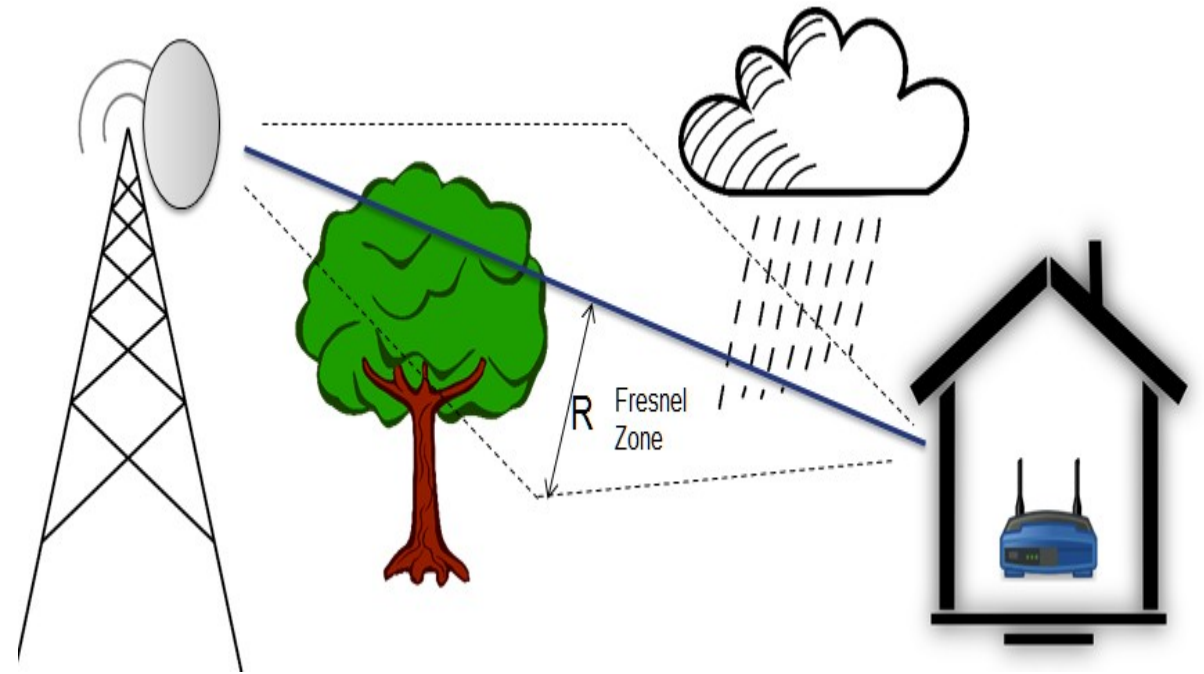
- Close-In
 - Simple
 - Both essentially equal in accuracy

$$\text{PL}^{\text{CI}}(f, d)[\text{dB}] = \text{FSPL}(f, 1 \text{ m})[\text{dB}] + 10n \log_{10}(d) + \chi_{\sigma}^{\text{CI}}$$



Poor Penetration and Loss [14]

- Signals above 60 GHz suffer severe path loss and shadowing
 - Path loss- loss as the signal travels from transmitter to receiver
 - Shadowing- loss as result of large objects blocking the path of the signal
- 5G mmWave loses 40-80 dB wall loss, while 4G only experiences 3-5 dB
- As carrier frequencies increase, so does the path loss



General System Diagram [1]

User Equipment

UE



MS+USIM

5G Wireless Link

NR-Uu



Radio Access

Network

NG-RAN

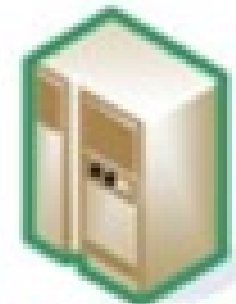


gNB

"g" stands for "5G"
"NB" for "Node B" which is inherited
from 3G and refers to the radio
transmitter

Core Network

5GC



AMF/UPF

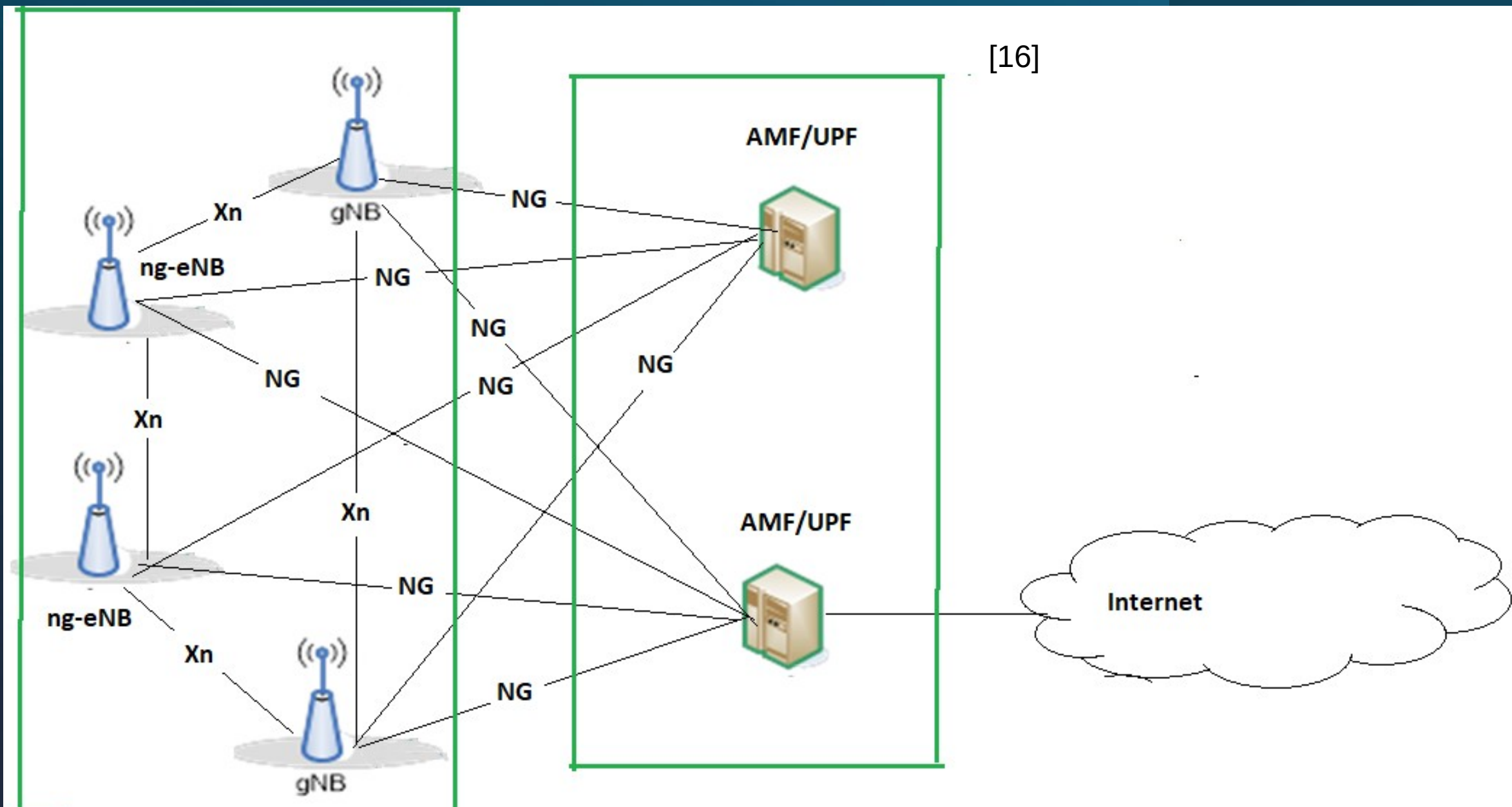
User Plane Function/Mobility
management Function

5G Wired
Link

NG



[16]



EM Components – Antennas & Arrays [17][18]

- 5G relies heavily on phased array antennas instead of traditional single antennas
- Enables directional signal transmission rather than broadcasting in all directions
- Supports Massive MIMO (Multiple Input Multiple Output)
 - Uses dozens to hundreds of antenna elements
- Benefits:
 - Increased capacity (more users at once)
 - Higher data rates
 - Improved reliability in dense environments



Why High Frequencies (mmWave)? [19]

5G uses frequencies up to
**millimeter wave (24–100
GHz)**

Advantages:

- Extremely high data rates
- More available bandwidth

Trade-offs:

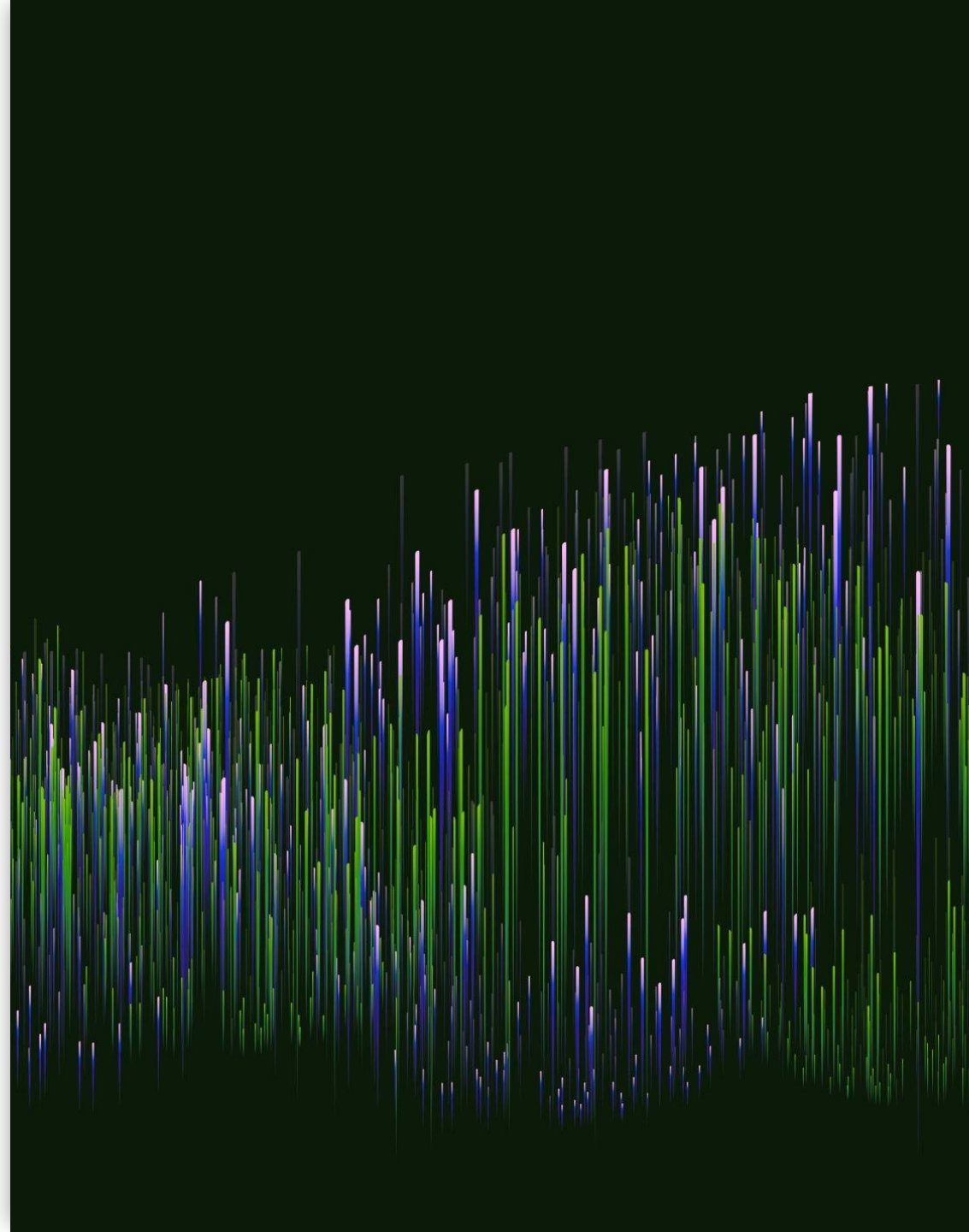
- Shorter range
- Poor wall penetration

Requires:

- Dense infrastructure (small cells)
- Advanced antenna systems

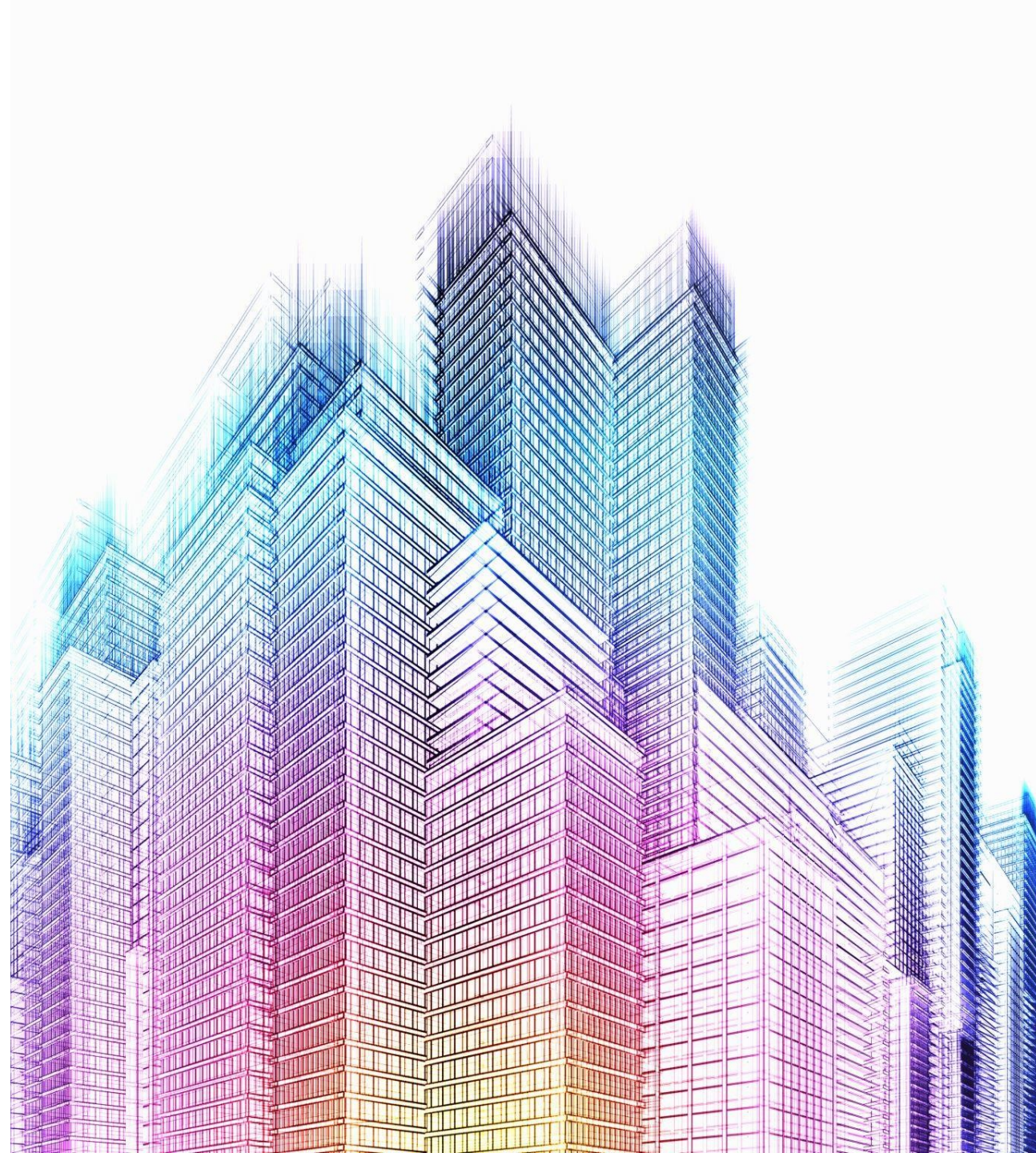
Beamforming & MIMO in Depth [18][19]

- Beamforming focuses signal energy toward a specific user instead of spreading it
- Achieved by adjusting phase and amplitude of signals across antenna elements
- Types:
 - Analog beamforming
 - Digital beamforming
 - Hybrid beamforming (most common in 5G)
- Massive MIMO:
 - Serves multiple users simultaneously using spatial separation
 - Increases spectral efficiency



Small Cells & Network Density [20] [21]

- 5G relies on small cells instead of large towers
- Deployed every few hundred meters in cities
- Benefits:
 - Higher capacity
 - Lower latency
- Challenges:
 - Infrastructure cost
 - Urban deployment complexity



+

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- Propagation & Channel Modeling
[15][22][23]

- 5G uses high-frequency bands (especially mmWave)
 - Shorter wavelength → more data, but weaker penetration
- Key challenges:
 - Path loss increases with frequency
 - Blockage from buildings, walls, even people
 - Weather effects (rain attenuation)
- Channel modeling predicts:
 - Signal strength over distance
 - Reflection, diffraction, and scattering
- Important models:
 - Free-space path loss
 - Urban microcell / macrocell models



Real-World Limitations of 5G [24]

- Signal blocked by:
 - Buildings
 - Trees
 - Human bodies
- Requires:
 - Line-of-sight (especially mmWave)
- Battery consumption increases due to:
 - Higher processing demands
- Coverage gaps still exist outside cities



Future Development s [25]

- 6G around 2030
- Symmetrical faster uploads for AI tasks
- Integrated sensing and communication (ISAC)
 - Let's the same radio signals used for data transfer also function like radar
- Stronger AI processing closer to devices for reduced delays
- Better efficiency

Our Suggestions for Improvement



- Improve low-band range
- Privacy
- Efficiency
- LEO Satellite Connectivity

Conclusion & References

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