

Wireless!

The forces and strategies that shaped a
revolution

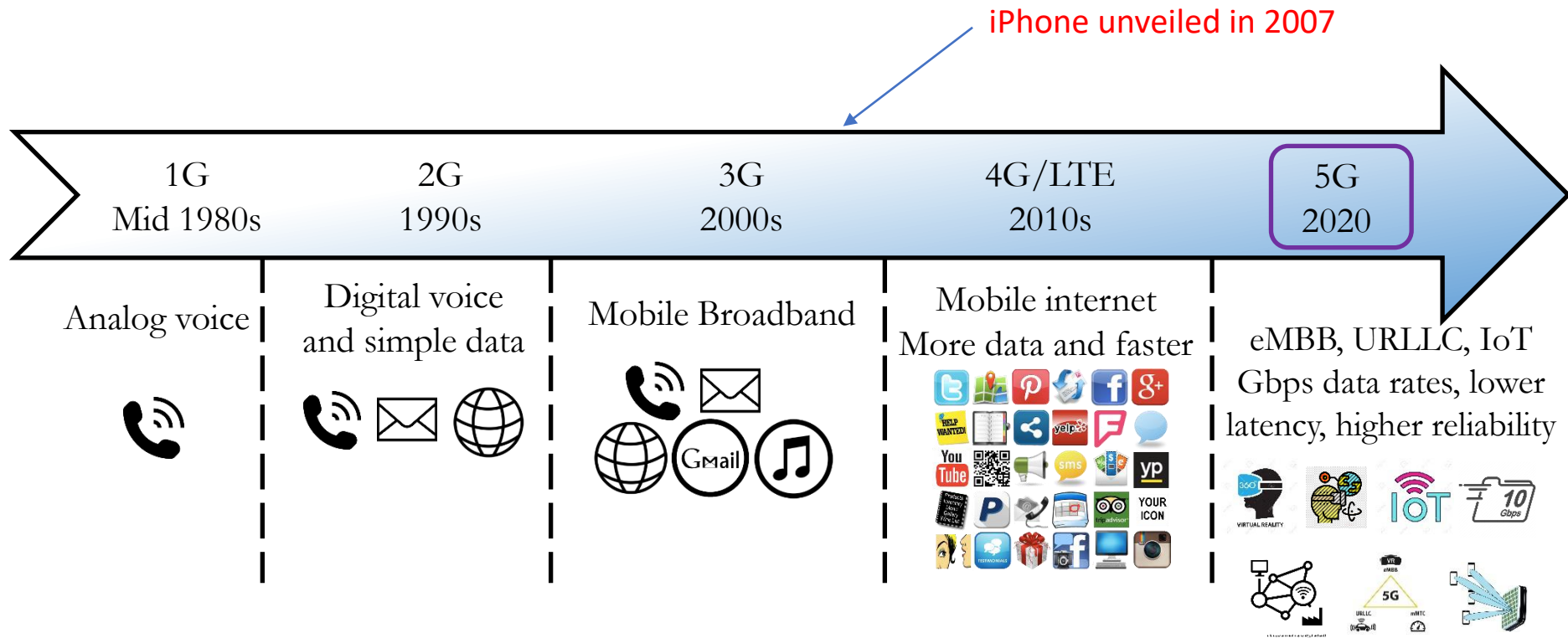


Lecture 17- The Technology of Gs (2G, 3G, 4G, 5G)

Lecture 17- Classwork

1. Please summarize in 3-4 sentences the Pre-Lecture reading for Lecture 17 including some important takeaways from your reading.
2. What was the fundamental technology transition from 1G to 2G?
3. What were the fundamental technology transformations from 2G to 3G?
4. What were the major technological advances that were used in 4G/LTE systems?
5. What are the major technological advances used in 5G systems?

Roadmap of Cellular Networks

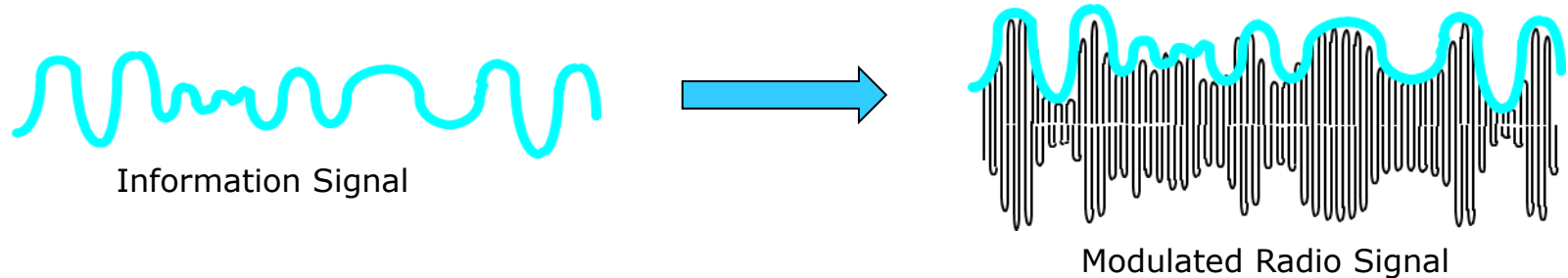


Q2

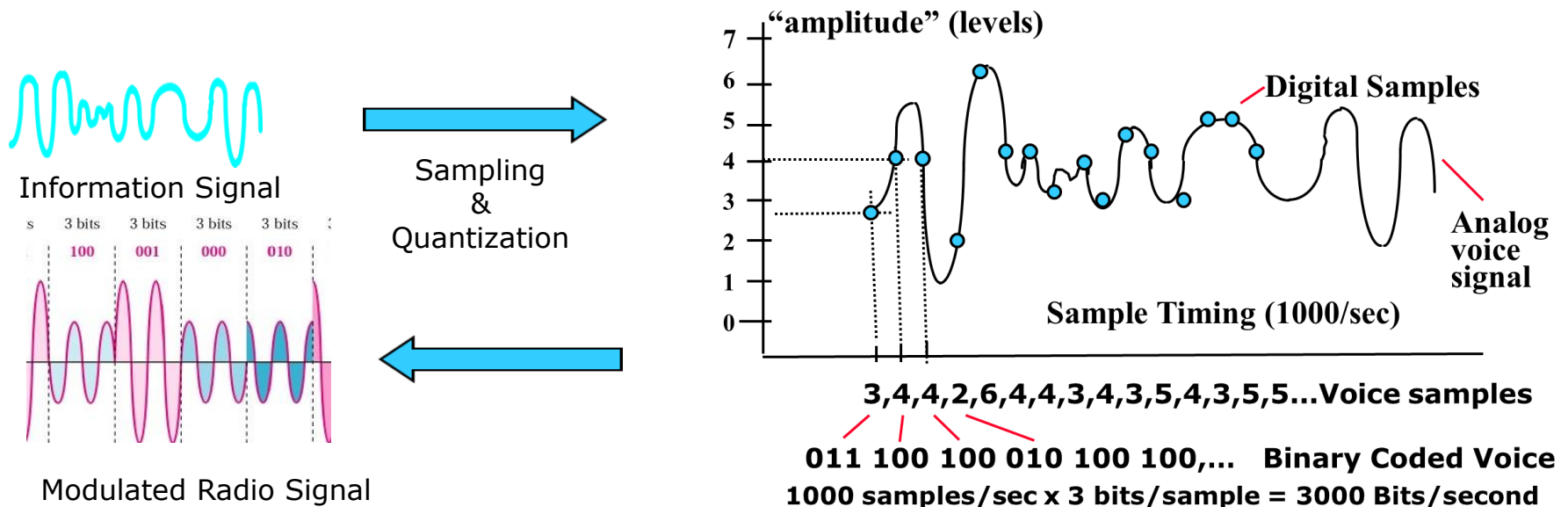
eMBB: enhanced Mobile Broadband
URLLC: ultra reliable low latency communications
IoT: Internet of Things

Analog vs. Digital Radio Communications

Analog: Information Carried Directly over Radio Waves



Digital: Information Converted to Bits and Carried over Radio Waves



Key Features of Cellular Generations (1G and 2G)

- 1G:
 - Analog voice communications with frequency reuse
 - Carrier frequency: 900MHz
 - Channel Bandwidth: 30 kHz channel
- 2G: GSM (2.5: GPRS), CDMA (IS-95)
 - Digital communications
 - Access technology: USA- TDMA & CDMA, Europe- TDMA
 - Data rates: 64 Kbps
 - Supported Apps: Voice, SMS, Data(in GPRS)
 - Carrier frequency: 800/850/900 MHz, 1,800/1,900 MHz
 - Channel Bandwidth: CDMA (1.25 MHz), TDMA (200 kHz)



❑ What was the fundamental technology transformation between 1G and 2G?

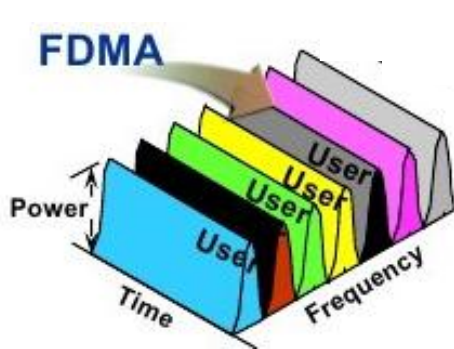
Analog to Digital

“Politics” of 1G and 2G

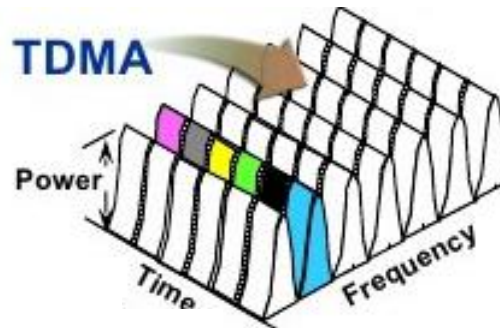
- ❑ 1G Cellular Systems Deployments were delayed in the US
 - ❑ FCC delays (courtesy AT&T and Motorola)
 - ❑ Search for “Single Best Technical Solution”
- ❑ 2G Cellular Systems Deployments were also delayed in the US
 - FCC encouraged “Multiple Best Solutions”
 - ❑ TDMA vs CDMA Controversy
 - ❑ TDMA Technology (GSM) developed by Ericsson
 - ❑ CDMA Technology (IS-95) developed by Qualcomm
- ❑ Europe by contrast opted for a “single” universal solution
 - Roaming, Portability across EU
 - TDMA (GSM)

TDMA vs CDMA

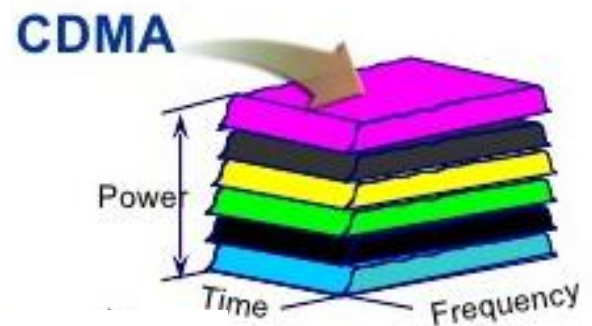
❑ Time Division Multiple Access vs Code Division Multiple Access



Users use different frequency slots



Users use different time slots



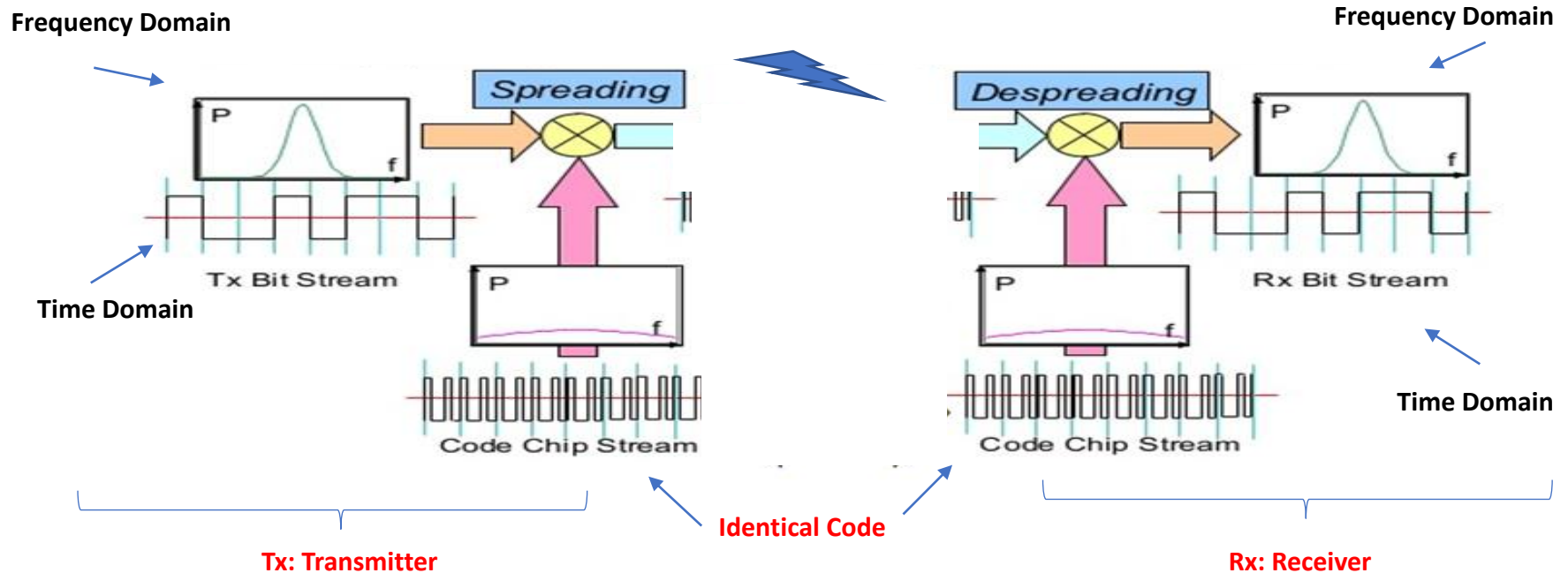
Users use different spreading codes

❑ Cocktail Party Analogy of Multiple Access

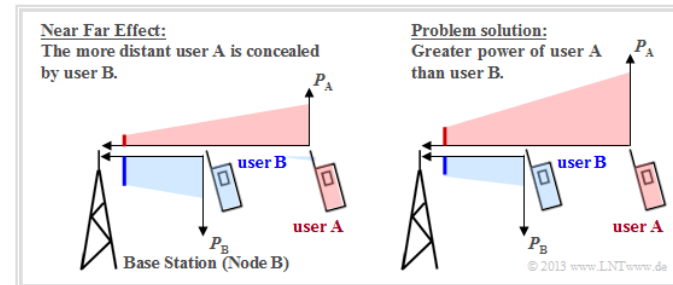
- ❑ Multiple simultaneous conversations
- ❑ Raising amplitude or decibel level of conversations hurts all
- ❑ TDMA and FDMA are equivalent
- ❑ CDMA codes can be analogous to “different languages”

CDMA (Code Division Multiple Access)

CDMA Codes: “Spreading” and “Despreading”



- ❑ Users use different spreading codes
- ❑ No need for channelization (frequency separation)
- ❑ Power Control Critical (Near-Far Problem)



Qualcomm's Claims of CDMA Advantages

- ❑ **No Channel Reuse Necessary**- All available frequencies used all the time and everywhere (**Universal Frequency Resuse**)
- ❑ **Soft Handoffs**- Complicated handoff of channels from one base station to another is not necessary as mobiles roam
- ❑ **Capacity Gains over TDMA in Multiple Cells**- Design of “near” orthogonal codes can handle interference gracefully from neighboring cells
- ❑ **Reality was that CDMA and TDMA were more or less similar**
 - But Qualcomm won the “battle” for 3G
 - A truly universal worldwide standard emerged for 3G
 - 3GPP (**3rd Generation Partnership Project**)- International Standards Body for all future cellular systems

Key Features of Cellular Generations (3G)

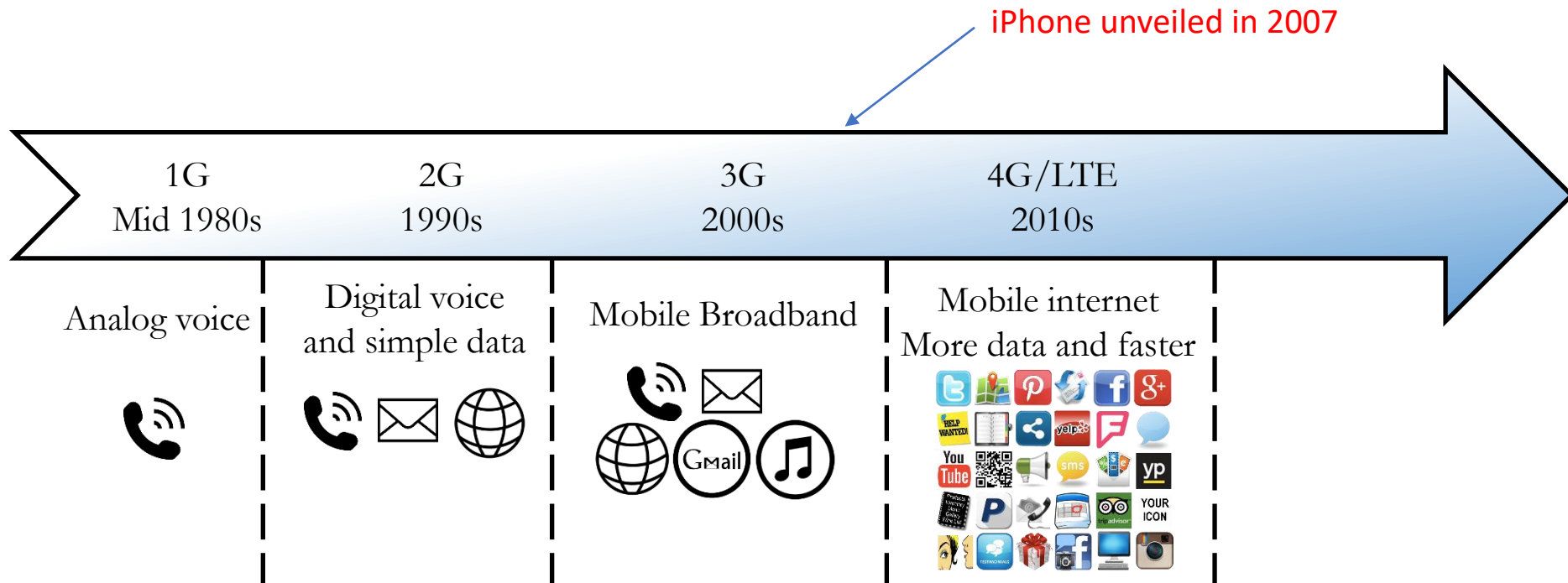
3G



- ❑ 3G: Wideband-CDMA (W-CDMA) (UMTS)
 - ❑ Access Technology: CDMA
 - ❑ Data Rate: 3-10 Mbps
 - ❑ Channel Bandwidth: 5 MHz (compared to 1.25 MHz in 2G)
 - ❑ Supported Apps: Voice, SMS, Data, Multimedia
 - ❑ Frequencies: Uplink: 1885–2025 MHz, Downlink: 2110–2200 MHz
- ❑ What was the fundamental technology transformation between 2G and 3G?
 - ❑ Still CDMA (a 2G technology) but over a wider band
 - ❑ Early multiple antenna (MIMO) technology
 - ❑ Preliminary network architecture evolution toward handling internet traffic

Something happened along the way of 3G

❑ What was the game changer?



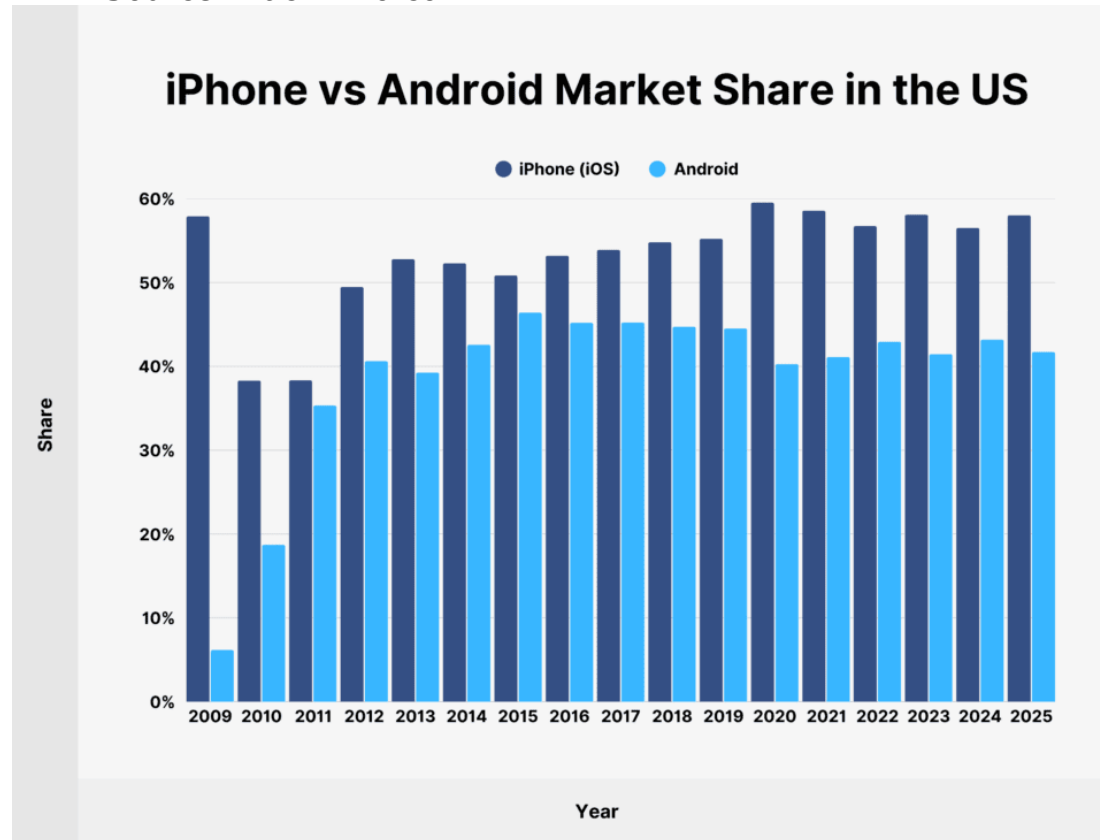
Enabler of the The Gig Economy

What did it mean for 4G?

- ❑ Cell Phone truly became an extension of the Internet
- ❑ Cellular System Architecture needed to be made compatible for Internet Traffic
- ❑ Wireless data became richer in content and demands grew exponentially
- ❑ Challenges:
 - ❑ Need more spectrum
 - ❑ Need more advances in multiple antenna (MIMO) technology
 - ❑ CDMA inefficient for high individual data rates of smart phone traffic
 - ❑ CDMA ineffective at combating multipath propagation effects
 - ❑ Redesign of cellular system architecture to make it internet compatible

iPhone vs Android (US)

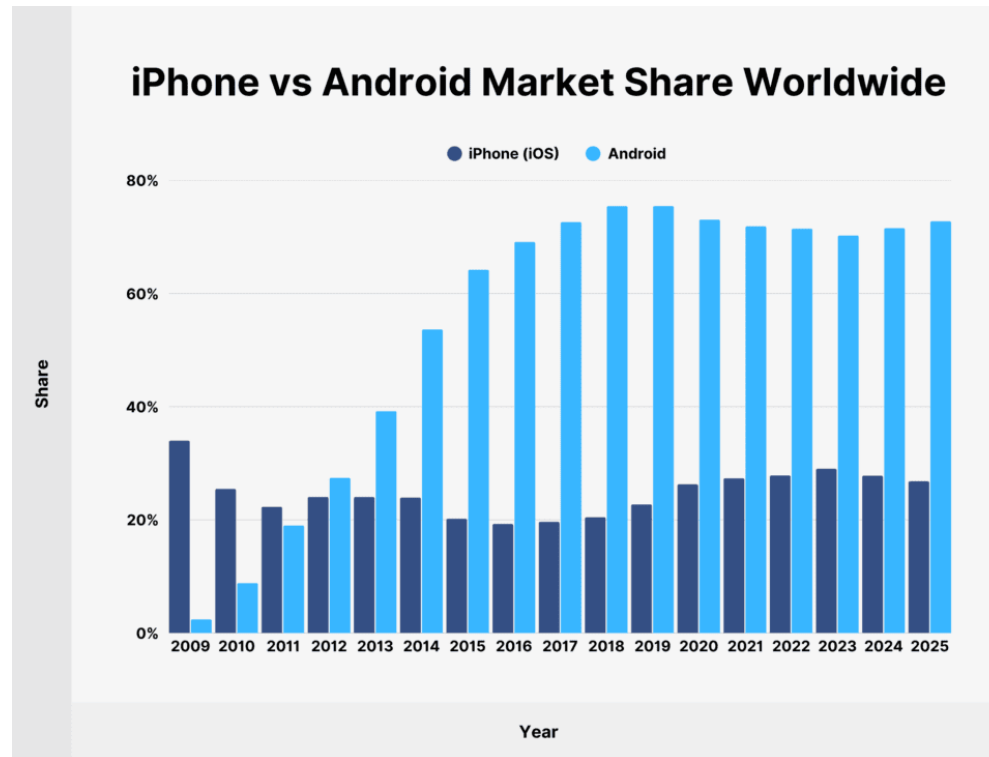
Source: Backlinko.com



iPhone has a 58.81% market share in US

iPhone vs Android (Worldwide)

Source: Backlinko.com



Android has a 70.93% global market share

“Fun Fact”: iPhone users have a 43.7% higher average salary than Android users 😊

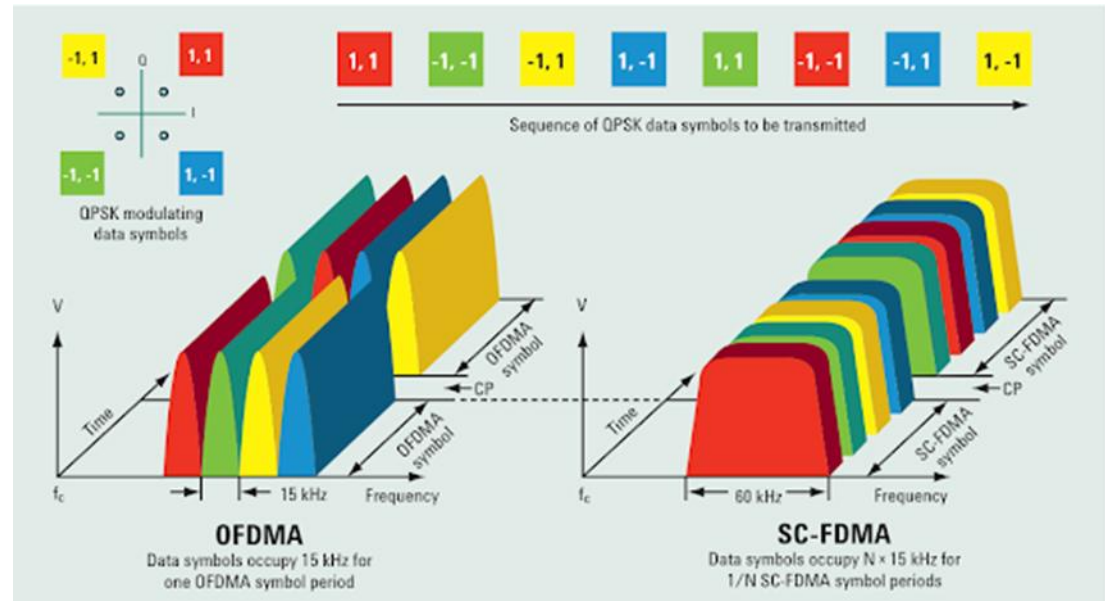
Key Features of Cellular Generations (4G/LTE)

❑ 4G/LTE

- ❑ Access Technology: OFDMA/SC-FDMA
- ❑ Data Rate: 1-3Gbps
- ❑ Channel Bandwidth: Increments of 180KHz, PRBs in 20MHz: 100
- ❑ Supported Applications: Voice, SMS, Data, Wireless Broadband Services



- ❑ Orthogonal Frequency Division Multiple Access (OFDMA)
- ❑ Single Carrier Frequency Division Multiple Access (SC-FDMA)
- ❑ Integrated with MIMO
- ❑ Software Defined Radios
- ❑ Software Defined Networking
- ❑ Cloud Radio Access Networks



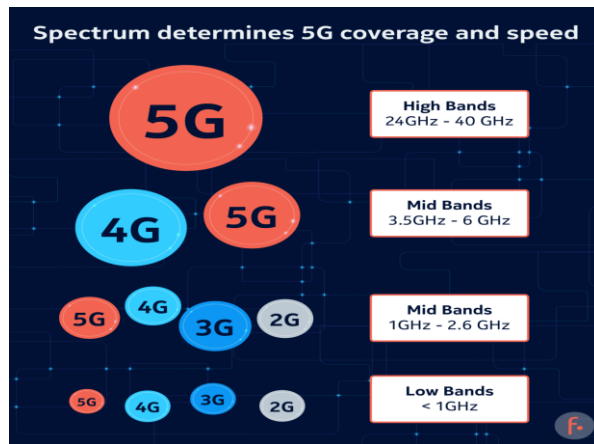
Key Features of Cellular Generations (5G)

❑ 5G NR: New Radio

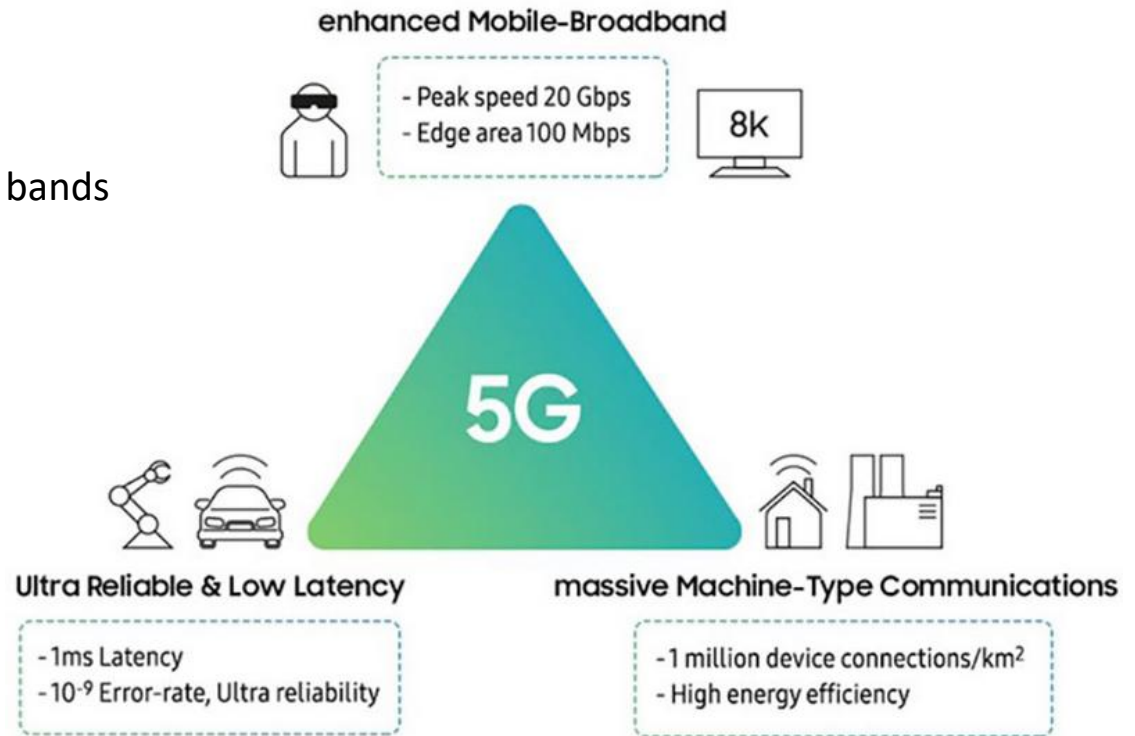
❑ Enables New Apps

❑ AR/VR, URLLC, IoT

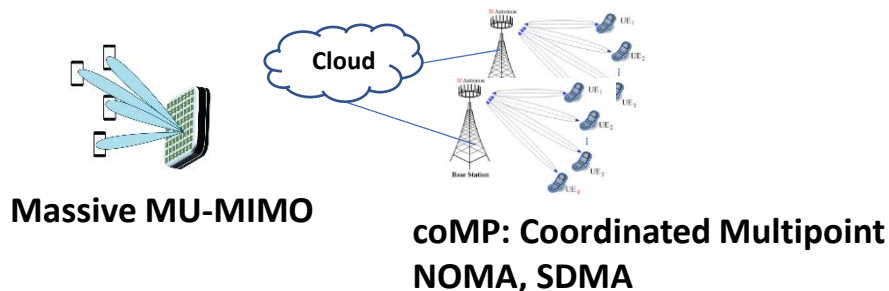
❑ **Spectrum:** Sub-6 GHz, mmWave bands



Three Category of Apps of 5G



❑ New Enabling Technologies



Potential Applications of 5G



AR/VR



Factory Automation



Self-driving, Safety



Commerce



Smart Cities, IoT

☐ ~~“Million Dollar” Question?~~

☐ “Billions of Dollars” Question?

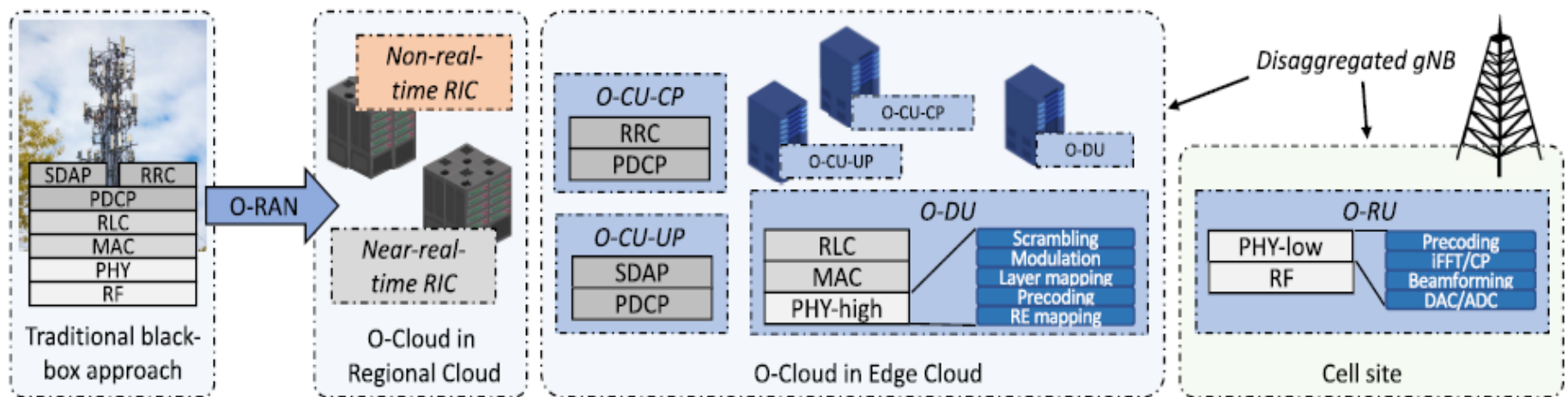
☐ How to monetize these applications?

☐ TBD

Beyond 5G and Next G: O-RAN

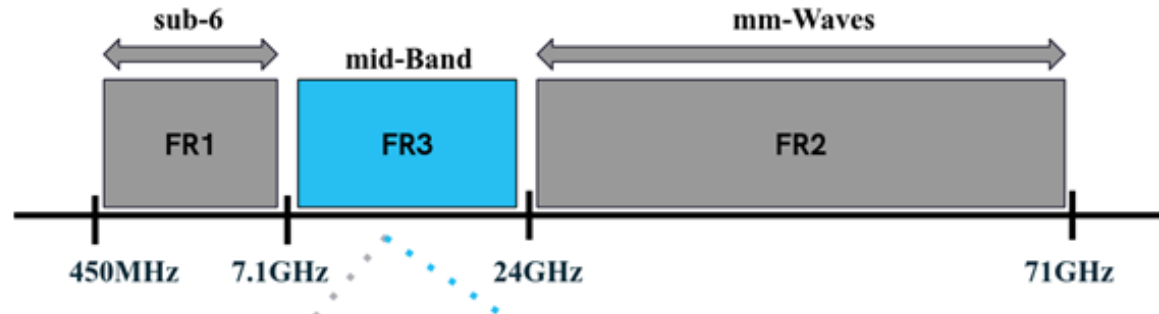
❑ O-RAN: Open Radio Access Networks

- From Traditional Base Station Architecture to Virtualized Cloud-based Architecture
- Virtualized RANs where disaggregated components are connected via open interfaces and optimized by intelligent controllers



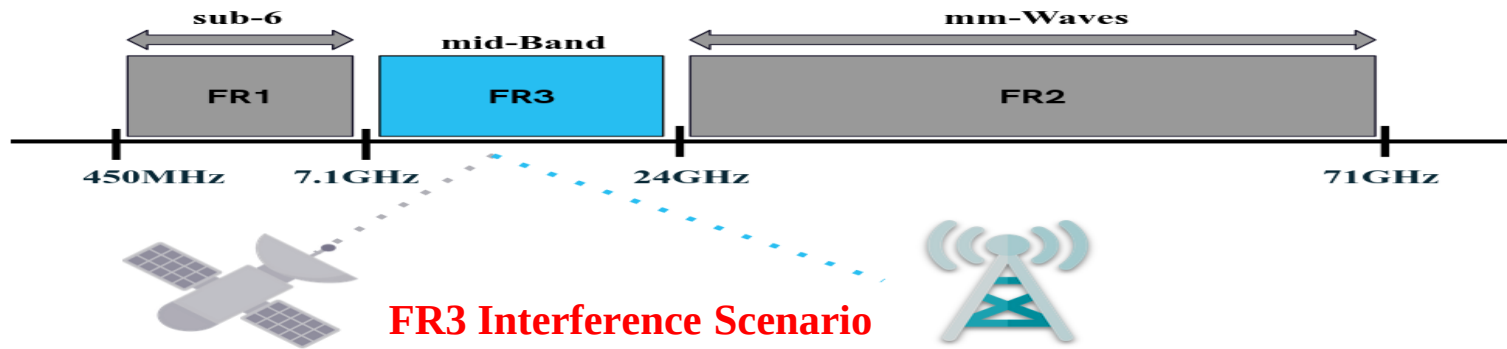
5G and Beyond: Newer and Higher Spectrum

- ❑ Push for newer and higher frequencies due to explosive demand in data and emerging applications
- ❑ Moving to FR3 (Frequency Range 3) Spectrum for Beyond 5G and 6G systems



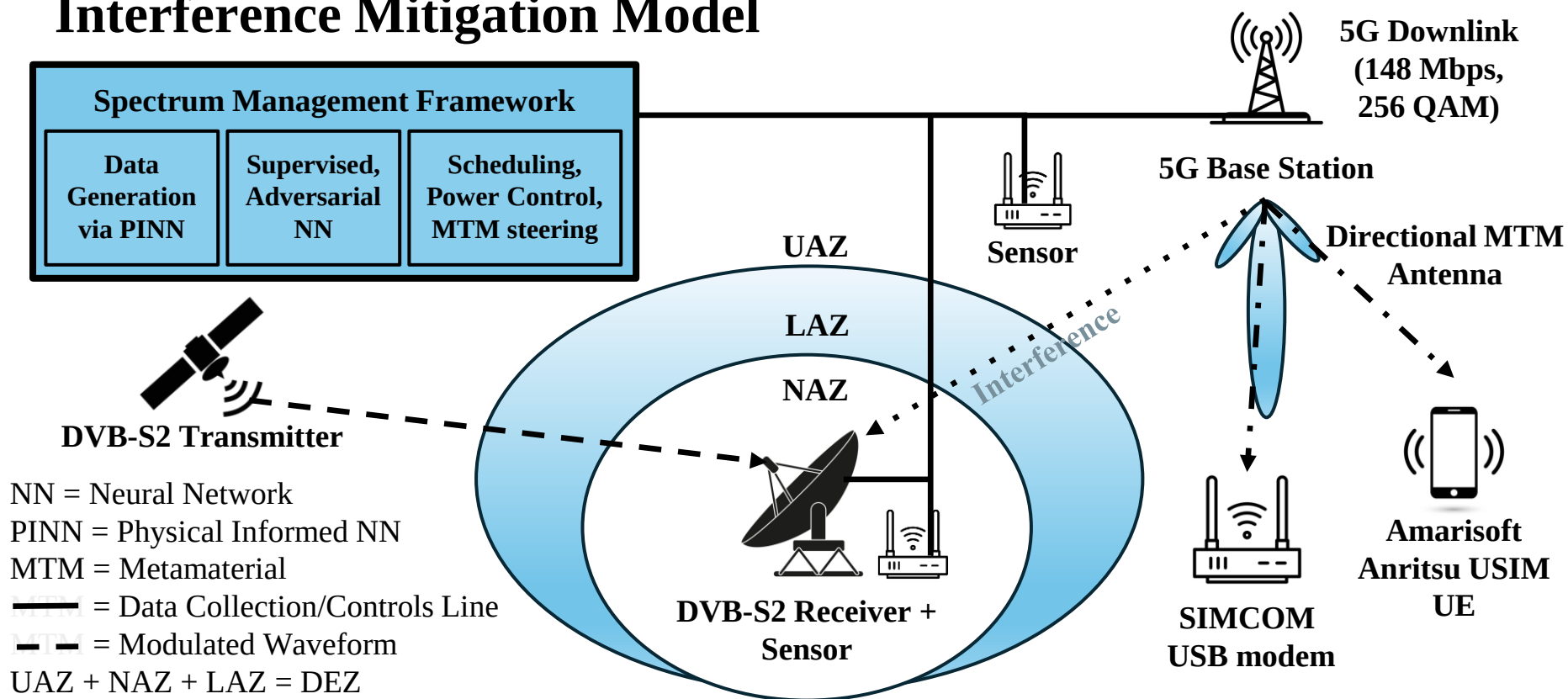
FR1: 450 MHz – 6 GHz (known as sub-6 GHz band)
FR2: 24 GHz – 52.6 GHz, 60 GHz (known as mmWave)
FR3: 6 GHz – 24 GHz

Challenges in FR3 Spectrum: Coexistence with SAT COM



- FR3 utility and feasibility in 12.2-12.7 GHz
 - Digital Video Broadcasting (DVB)
 - B5G channel occupancy of 100 MHz
- Improve on spectrum sharing and sensing:
 - Dynamic exclusion zones (DEZ)
 - Data-driven modeling (AI/Machine Learning)
 - Formulate efficient interference mitigation and spectrum coexistence.
- Build understanding of FR3 environment and potential FCC regulations.

Interference Mitigation Model



COSMOS Software Defined Radio Setup & Emulation of Model

5G and Beyond: Newer and Higher Spectrum

- ❑ The “other side” of the push for newer and higher frequencies due to explosive demand in data and emerging applications
- ❑ Unintended consequences for existing systems and applications not related to “communications”