5G

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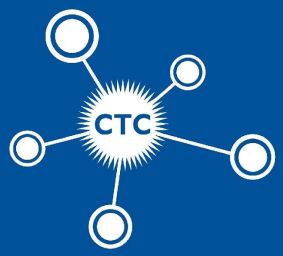


NATIONAL
CONVERGENCE
TECHNOLOGY CENTER

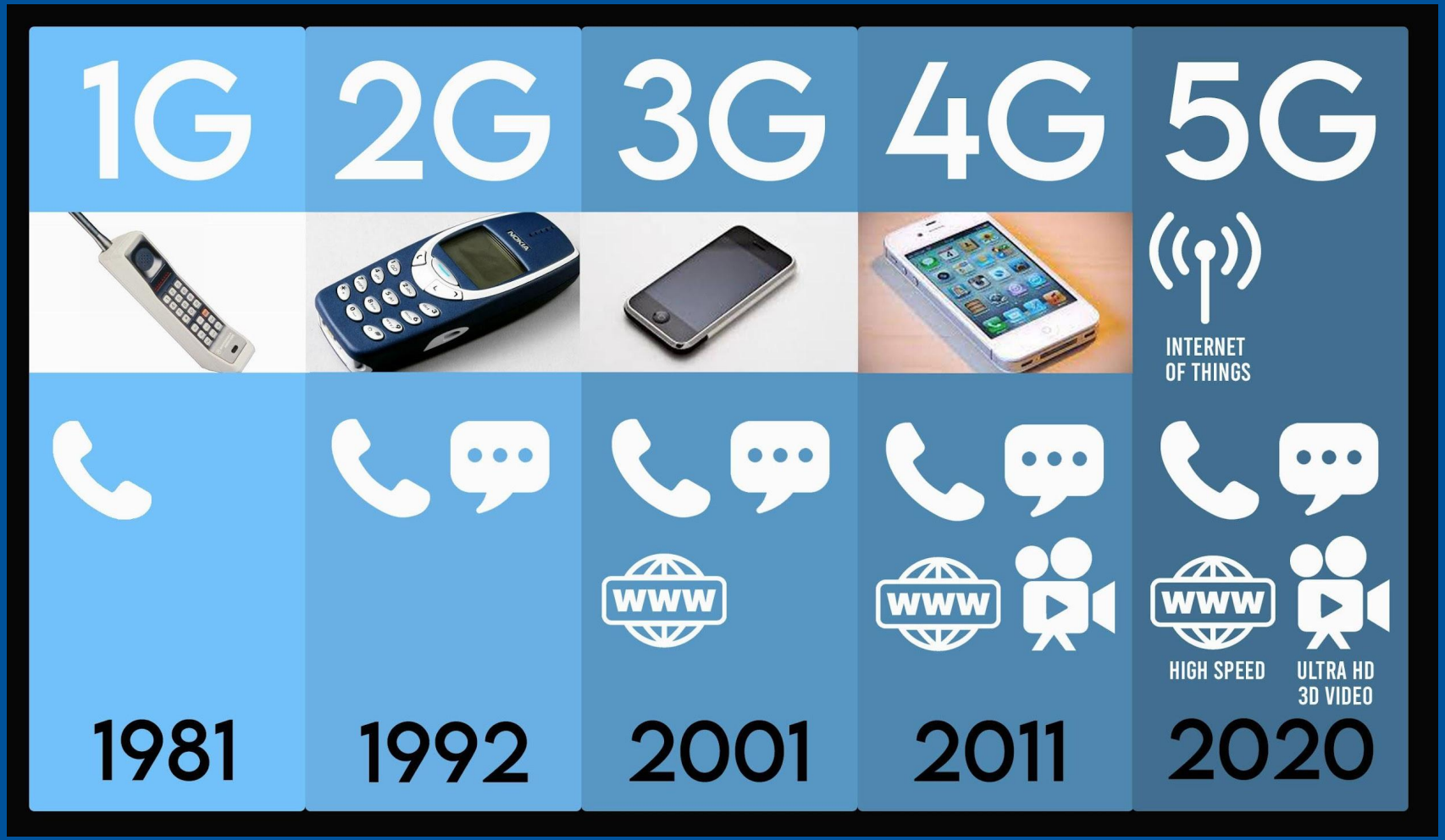
Class Discussion Items

5G will enable new applications along with increased vulnerabilities. Here's a short list of discussion items in no particular order:

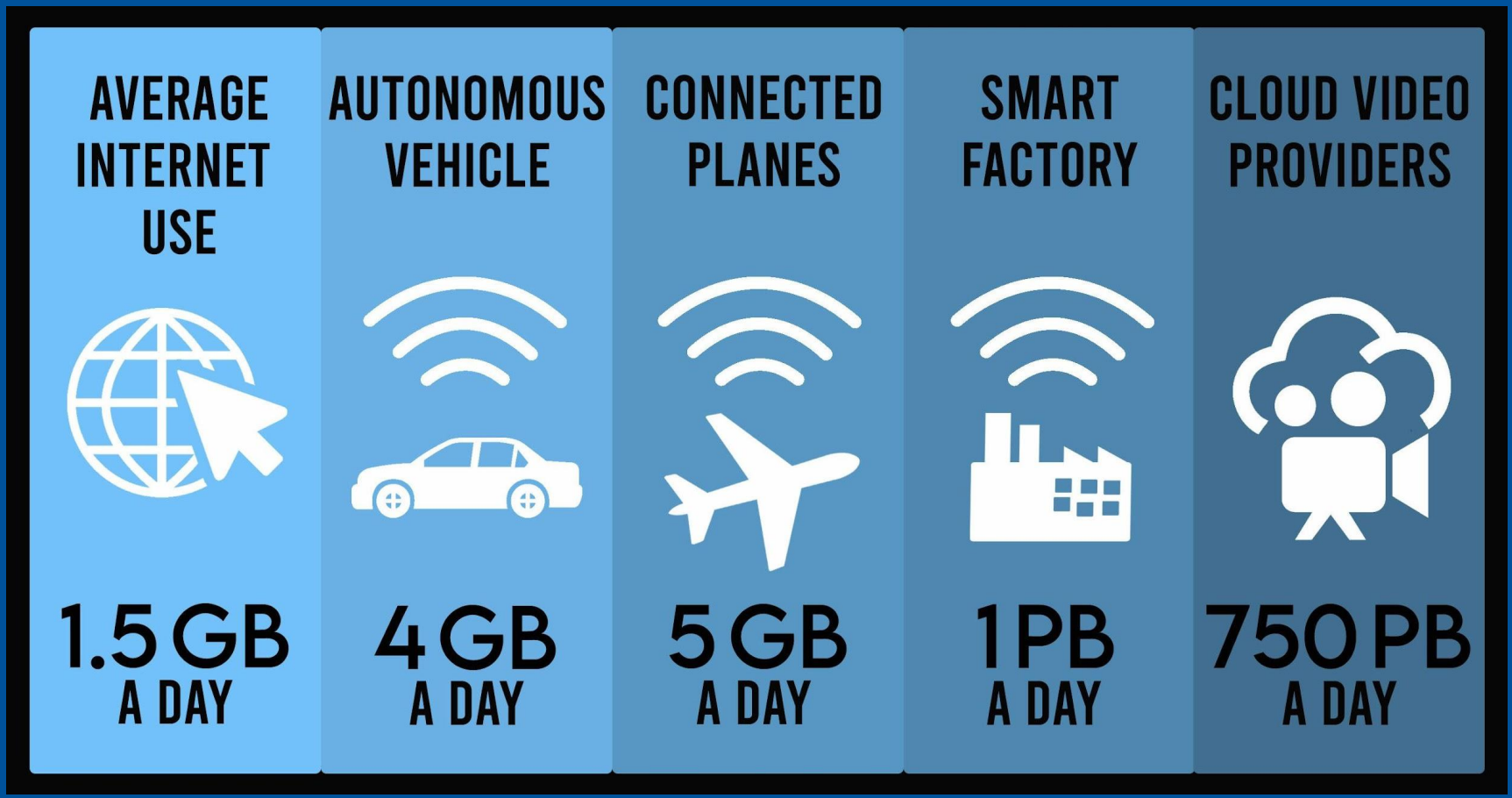
- Heavy reliance on fiber backhaul
- Capturing, integrating and curating data from every part of the network
- Geospatial tech including location-based services
- IoT
- AI
- Mobile Edge computing
- An integrated data approach
- Predictive analytics to predict sites most vulnerable to damage and degradation
- SDN
- How the *softwarization* of network components will increase 5G security vulnerabilities – including cloud security and system redundancy software

5G Overview

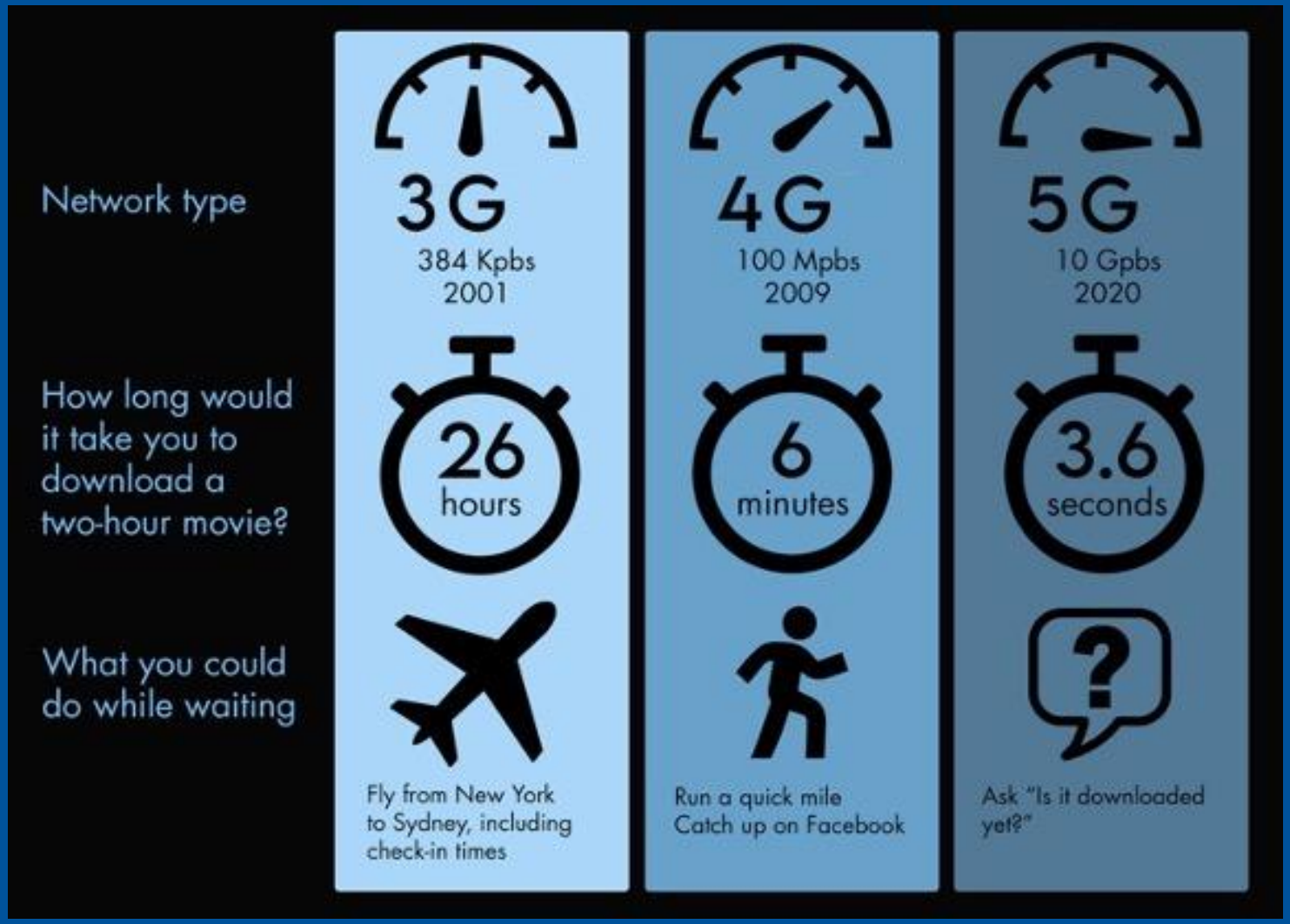
History: Evolution Mobile Communications



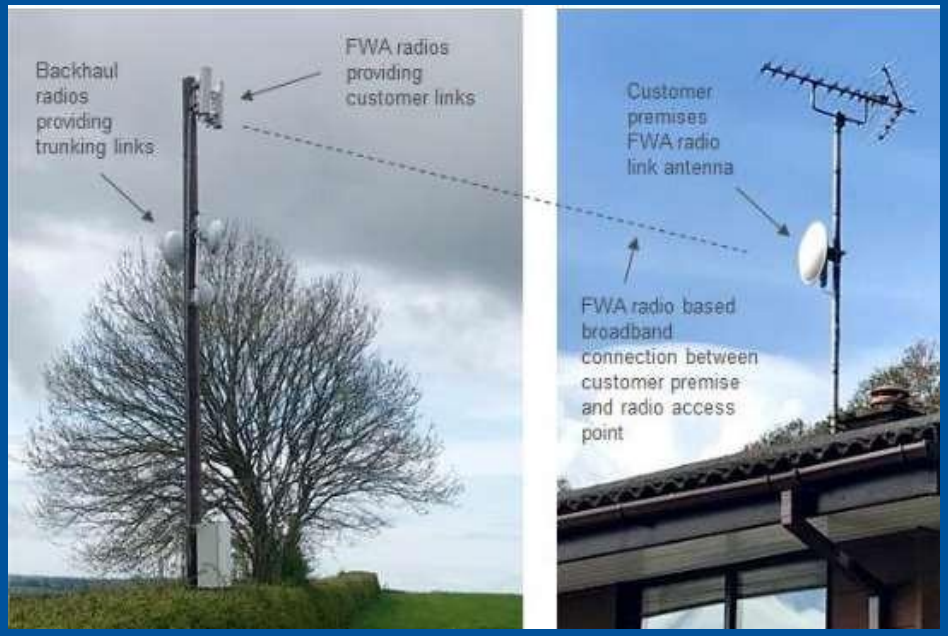
5G Mobile Network Data Traffic Projections

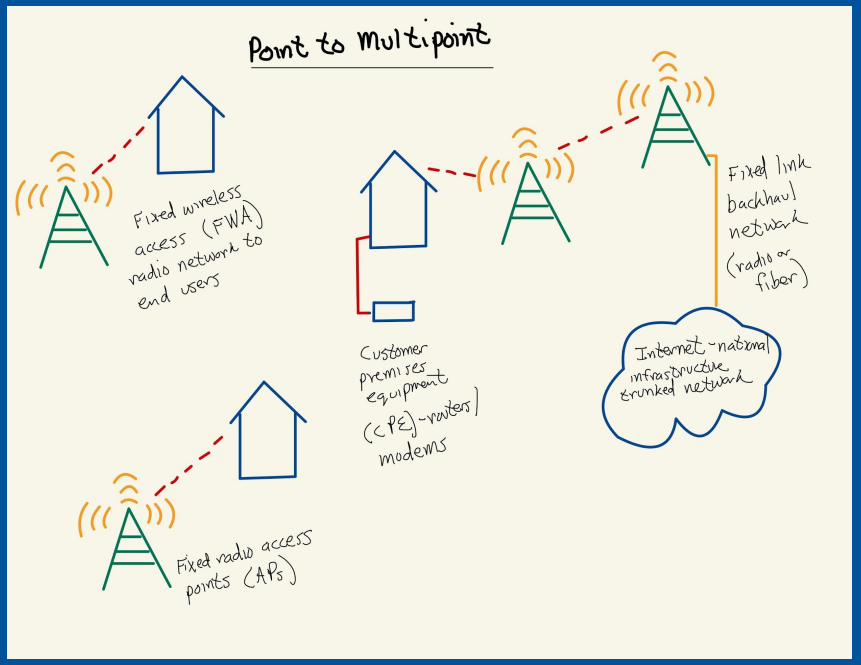


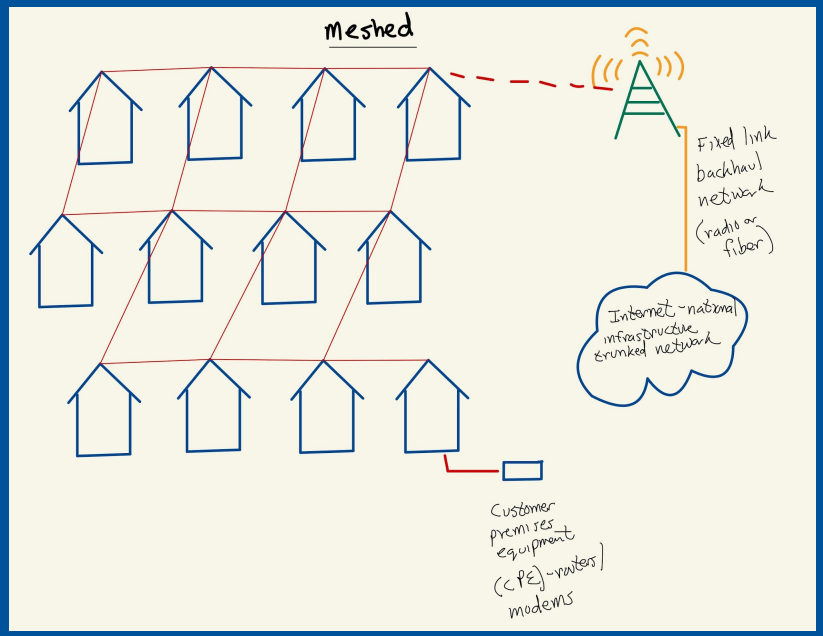
3G, 4G, 5G Comparison … much faster !



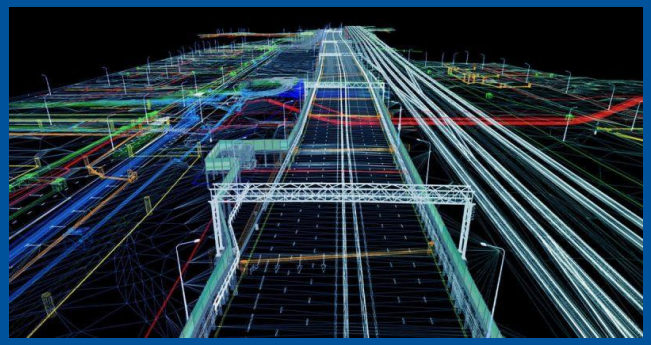
FWA – Fixed Wireless Access







Market and Use Cases



Massive IoT - mMTC

Smart City – Sensors – eHealth Smart Agriculture - Environment Smart Home - Smart Building Smart Industry – Oil - Mining

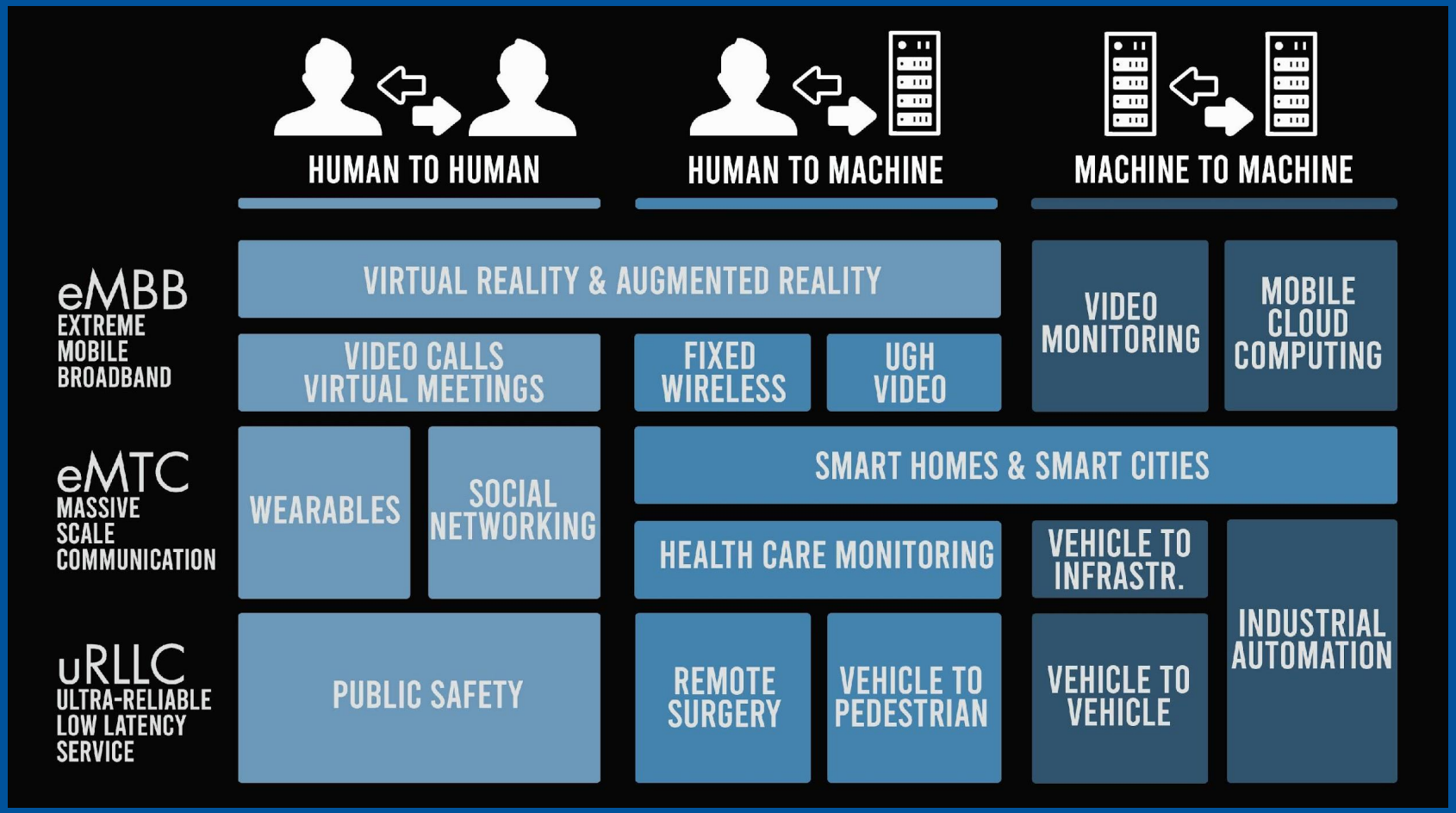
eMBB - Enhanced Mobile Broadband

Augmented Reality – AR Virtual Reality – VR Gaming – HD Video Holograms

Ultra Reliable Low Latency uRLLC

Remote Surgery w. haptic fbk Remote Driving – Self Driving Remote robotic, motion control Online Gaming, real time

5G Use Cases


HUMAN TO HUMAN
HUMAN TO MACHINE
MACHINE TO MACHINE
eMBB
EXTREME MOBILE BROADBAND
VIRTUAL REALITY & AUGMENTED REALITY
VIDEO CALLS VIRTUAL MEETINGS
FIXED WIRELESS
UGH VIDEO
VIDEO MONITORING
MOBILE CLOUD COMPUTING
eMTC
MASSIVE SCALE COMMUNICATION
WEARABLES
SOCIAL NETWORKING
SMART HOMES & SMART CITIES
HEALTH CARE MONITORING
VEHICLE TO INFRASTR.
INDUSTRIAL AUTOMATION
uRLLC
ULTRA-RELIABLE LOW LATENCY SERVICE
PUBLIC SAFETY
REMOTE SURGERY
VEHICLE TO PEDESTRIAN
VEHICLE TO VEHICLE

5G Tech

Some Definitions

Bandwidth is how much information you receive every second.

Throughput is how much information actually gets delivered in a certain amount of time.

Network Speed is how fast that information is received or downloaded.

Latency is sometimes referred to as delay or ping rate. It's the lag you experience while waiting for something to load. If bandwidth is the amount of information sent per second, latency is the amount of time it takes that information to get from its source to you.

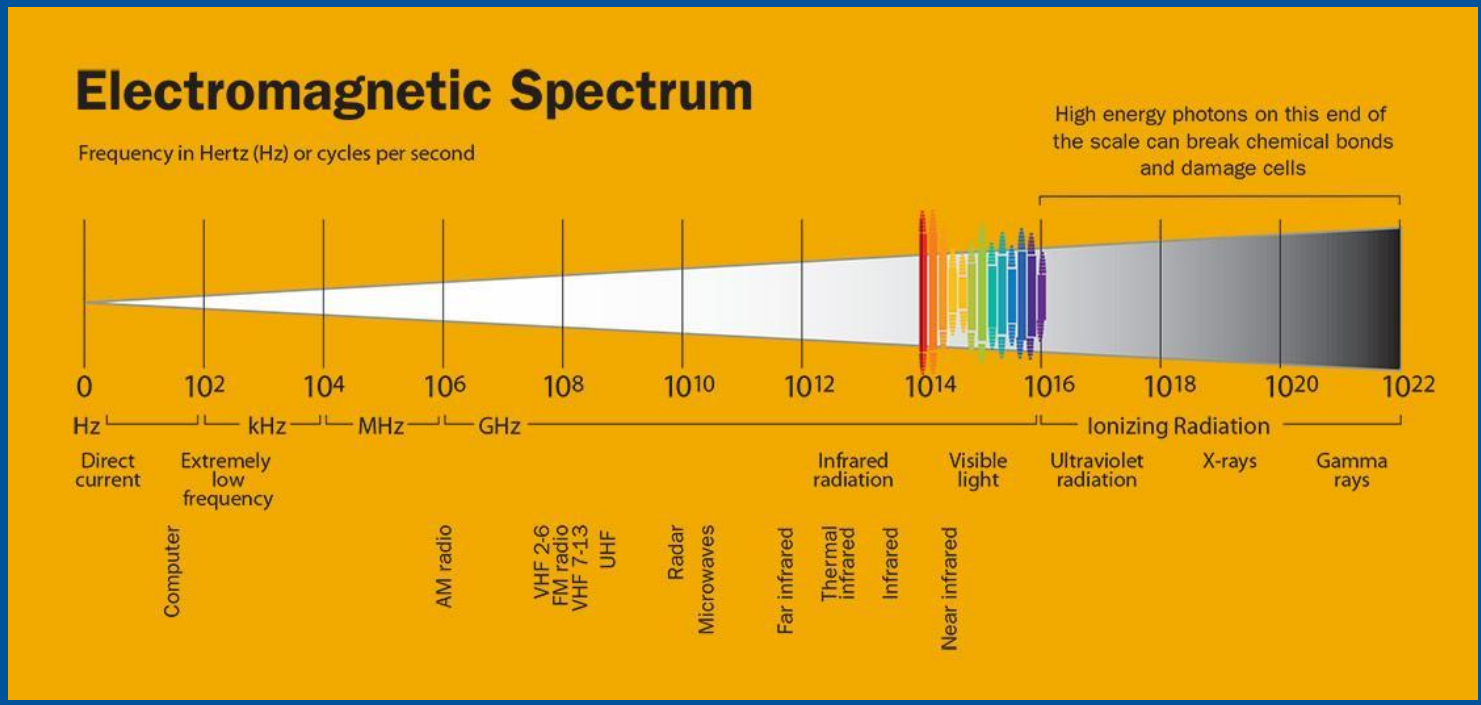
Packet loss occurs when one or more packets of data travelling across a computer network fail to reach their destination. Packet loss is either caused by errors in data transmission, typically across wireless networks, or network congestion. Packet loss is measured as a percentage of packets lost with respect to packets transmitted successfully.

So if bandwidth is the max amount of data, throughput is how much of that data makes it to its destination – taking latency, network speed, packet loss and other factors into account.

Wireless Spectrum

- Radio spectrum includes frequencies between 3 kilohertz (kHz) and 300 gigahertz (GHz).
- Early cellular networks, including 1G, operated at a frequency of 850 MHz and 1900 MHz.
- 2G and 3G networks operated at additional frequency bands and spectrum around 2100 MHz
- 4G LTE technology operated at additional frequency bands and spectrum around 600 MHz, 700 MHz, 1.7/2.1 GHz, 2.3 GHz, and 2.5 GHz.
- Verizon's 5G Ultra Wideband network uses 28 GHz and 39 GHz spectrum bands.

Spectrum



Radio Wave Spectrum: 3kHz – 300 GHz

0-5 GHz – Preamble Zone

2-5 GHz – Semi-Permeable Zone

5-50 GHz – Line-Of-Sight Zones

50-300 GHz – Military, Gov, Industry

Radio Wave Spectrum Breakdown

0-5 GHz – Preamble Zone

Frequencies in this range are considered more valuable because they can penetrate dense objects, such as buildings made out of concrete.

e.g.

- AM radio (535-1,700 kHz)
- Garage door openers
- Remote controlled toys
- Broadcast TV UHF channels (14-83)
- Non-5G Cell phones
- Wireless medical telemetry
- GPS

2-5 GHz – Semi-Permeable Zone

Difficult for signals to penetrate dense objects.

e.g.

- Satellite radio
- Weather radar
- Cable TV satellite transmissions
- 2.4 GHz band used by more than 300 consumer devices, including microwave ovens, cordless phones and wireless networks (Wi-Fi and Bluetooth)

5-50 GHz – Line-Of-Sight Zones

Signals in this zone can travel long distances but could be blocked by trees and other objects.

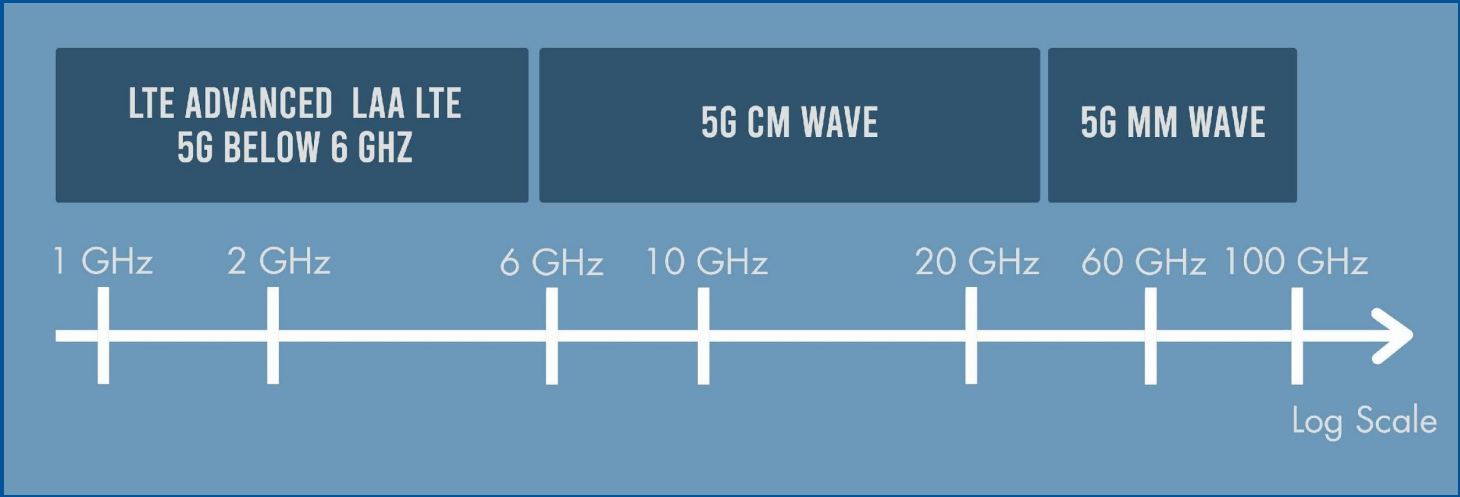
e.g.

- Wi-Fi networks
- Highway toll tags
- Satellite TV
- Security alarms
- Police radar

50-300 GHz

Military, federal government and industry use

5G Spectrum … New Spectrum



Band designation	Frequency range	Explanation of meaning of letters
HF	0.003 to 0.03 GHz	High Frequency[8]
VHF	0.03 to 0.3 GHz	Very High Frequency[8]
UHF	0.3 to 1 GHz	Ultra High Frequency[8]
L	1 to 2 GHz	Long wave
S	2 to 4 GHz	Short wave
C	4 to 8 GHz	Compromise between S and X
X	8 to 12 GHz	Used in WW II for fire control, X for cross (as in crosshair). Exotic.[9]
K_u	12 to 18 GHz	Kurz-under
K	18 to 27 GHz	Kurz (German for "short")
K_a	27 to 40 GHz	Kurz-above
V	40 to 75 GHz	
W	75 to 110 GHz	W follows V in the alphabet[citation needed]
mm or G	110 to 300 GHz[note 1]	Millimeter[7]

Radio Wave Spectrum: 3kHz – 300 GHz

0-5 GHz – Preamble Zone

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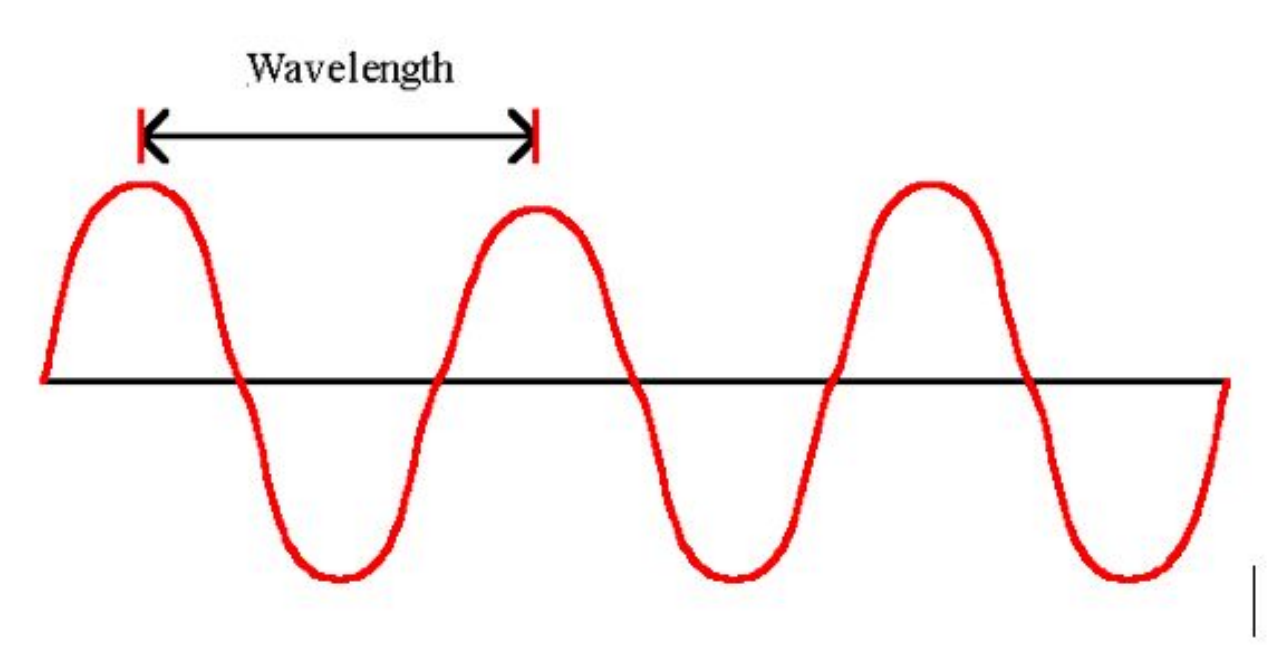
Wavelength

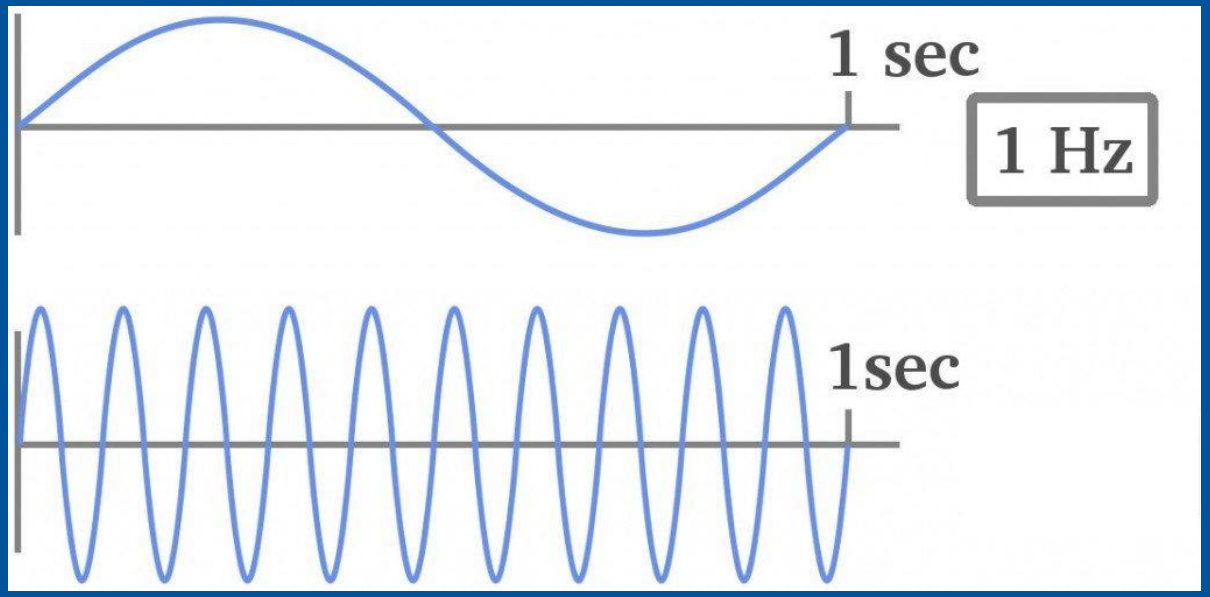
Cellular signals are electromagnetic radiation and sinusoidal in nature. Wavelength, represented by the Greek letter lambda (λ), is a distance measurement usually expressed in meters. Wavelength is defined as the distance in meters of one sinusoidal cycle as illustrated in the figure below.



Frequency

Frequency is the number of occurrences of a repeating event per unit of time.

Higher frequency signals have the capacity to transmit larger amounts of information when compared to lower frequencies.



In the first example 1 sine wave cycle is completed in 1 second – this is referred to as the period and abbreviated T. To calculate the frequency (f) in Hertz (Hz) calculate the reciprocal the period in seconds (s).
So for the first example T = 1 second and

$$f = 1/T = 1 / 1\ s = 1\ Hz$$

Class Exercise: Find the frequency of the second example in Hz.

Wavelength and Frequency Are Related

Consider a WiFi signal at 2.4 Giga Hertz (GHz) – what is the wavelength?

2.4 Giga Hertz (GHz) = 2.4 Billion cycles per second!

In the WiFi world, the 2.4 GHz WiFi signal range is divided into 11 channels and you probably know that channels can be selected when setting up a wireless network to avoid other devices transmitting in the same frequency range.

Ok – back to our question – what's the wavelength? To find it just divide the speed of light by the frequency.

1Hz = 1 cycle per second

All electromagnaetic radiation travels at the speed of light, abbreviated "c".

Speed of Light = c = 300,000,000 meters per second = 3×10^8 m/s

Our frequency (f) in this example is 2.4 GHz = 2.4×10^9 Hz

Calculating Wavelength in meters:

$\lambda = c/f = (3\times10^8 \text{ m/s})/(2.4\times10^9 \text{ Hz}) = .125\text{m} = 12.5\text{cm}$

12.5 cm is approximately 4.92 inches and..... that's your wavelength.

Class Exercises

1. Verizon's 5G Ultra Wideband network uses 28 GHz and 39 GHz mmWave spectrum bands. Calculate the wavelength for each of these frequencies.

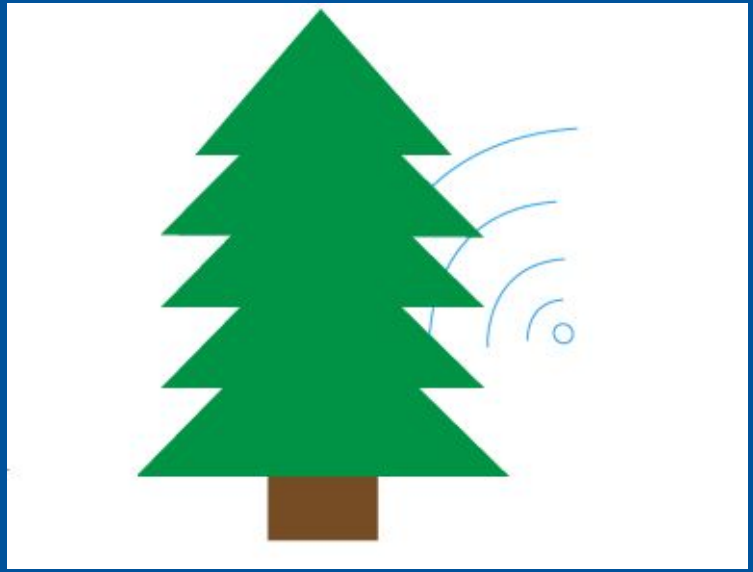
2. Verizon's 4G network uses about 700 MHz-2500 MHz frequency to transfer information. What is the wavelength for a 2500 MHz 4G signal?

3. Compare your answers from 1 and 2.
   - Which has the longer wavelength, 4G or 5G?
   - Which signal will travel farther? Why?

Is wavelength important in wireless communications?

•It turns out it is very important!

- Signal loss or attenuation is much worse at higher frequencies meaning the range of a transmitter/receiver becomes lesser.
- Lower frequencies will travel undamaged further than higher frequencies. This includes traveling through walls, trees, rain, etc.
- Higher frequencies are more attenuated with distance.
- However – higher frequencies transmit more information
-

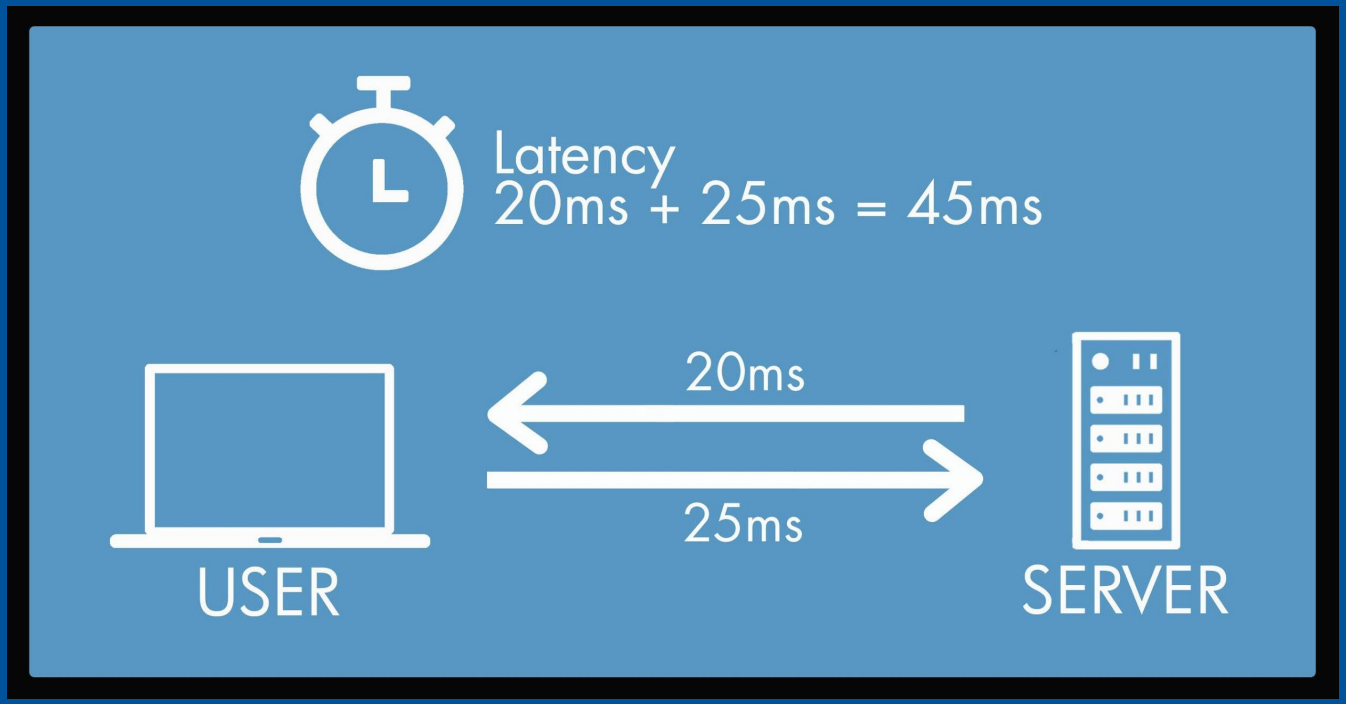


How about Latency?

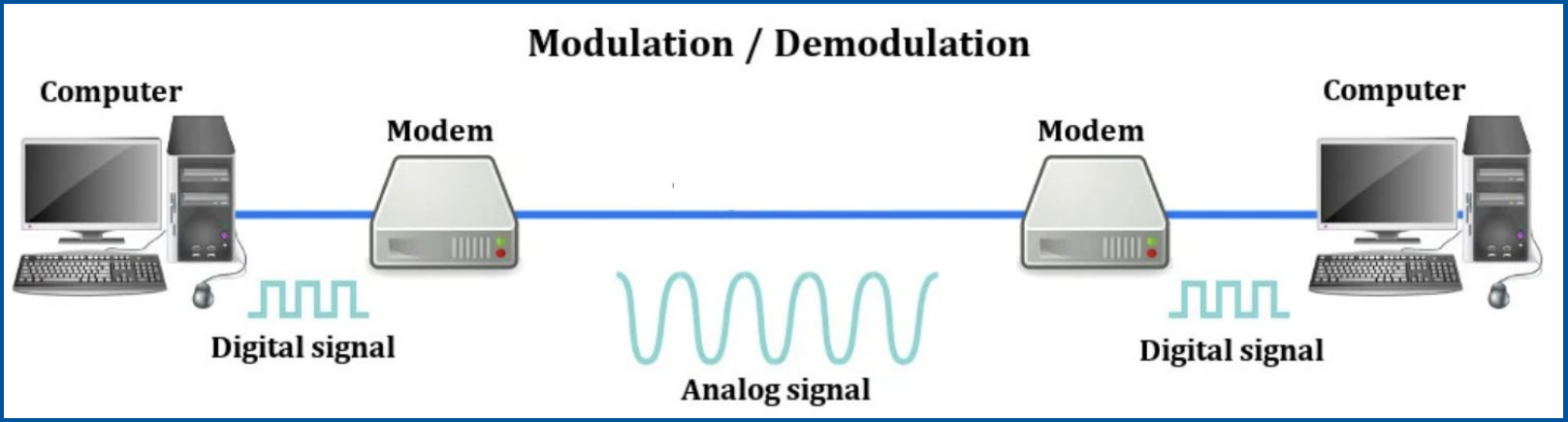
Latency in a communications system is defined as the amount of time for information to travel between origin and receiver.

Network latency is caused by a variety of factors, including the speed of the network as well as the available bandwidth and the size of the transmitted data.

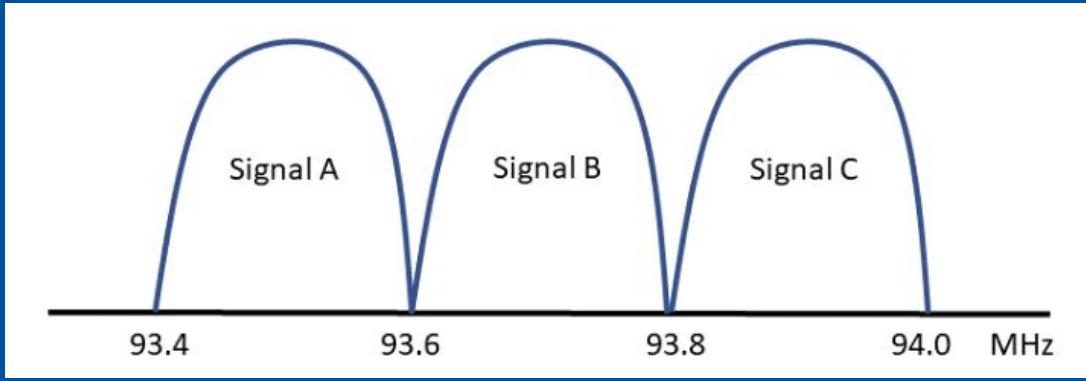
- 4G latency is around 20-30 milliseconds
- 5G latency averages 10 milliseconds.



MODEMS


Modulation / Demodulation
Computer
Modem
Modem
Computer
Digital signal
Analog signal
Digital signal

5G Modulation - Orthogonal Frequency Division Multiplexing (OFDM)

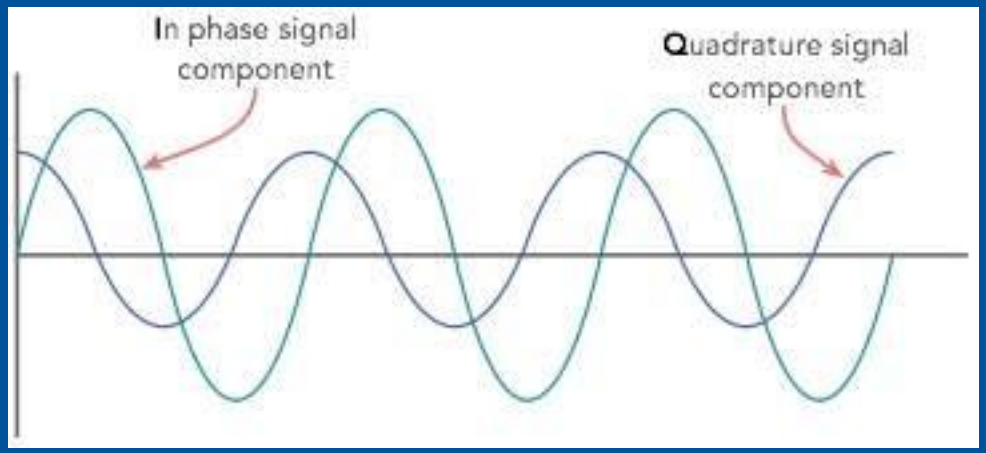


Multiple communication channels coexist by designating a slice of frequency spectrum for each channel. A common example of this is FM broadcast radio: the overall (US) frequency allocation is 87.8 MHz to 108 MHz, divided into channels that are 0.2 MHz wide. FDM frequency allocations must not overlap and often have guard bands between the channels to minimize adjacent channel interference.

OFDM combines the benefits of Quadrature Amplitude Modulation (QAM) and Frequency Division Multiplexing (FDM) to produce a high-data-rate communication system.

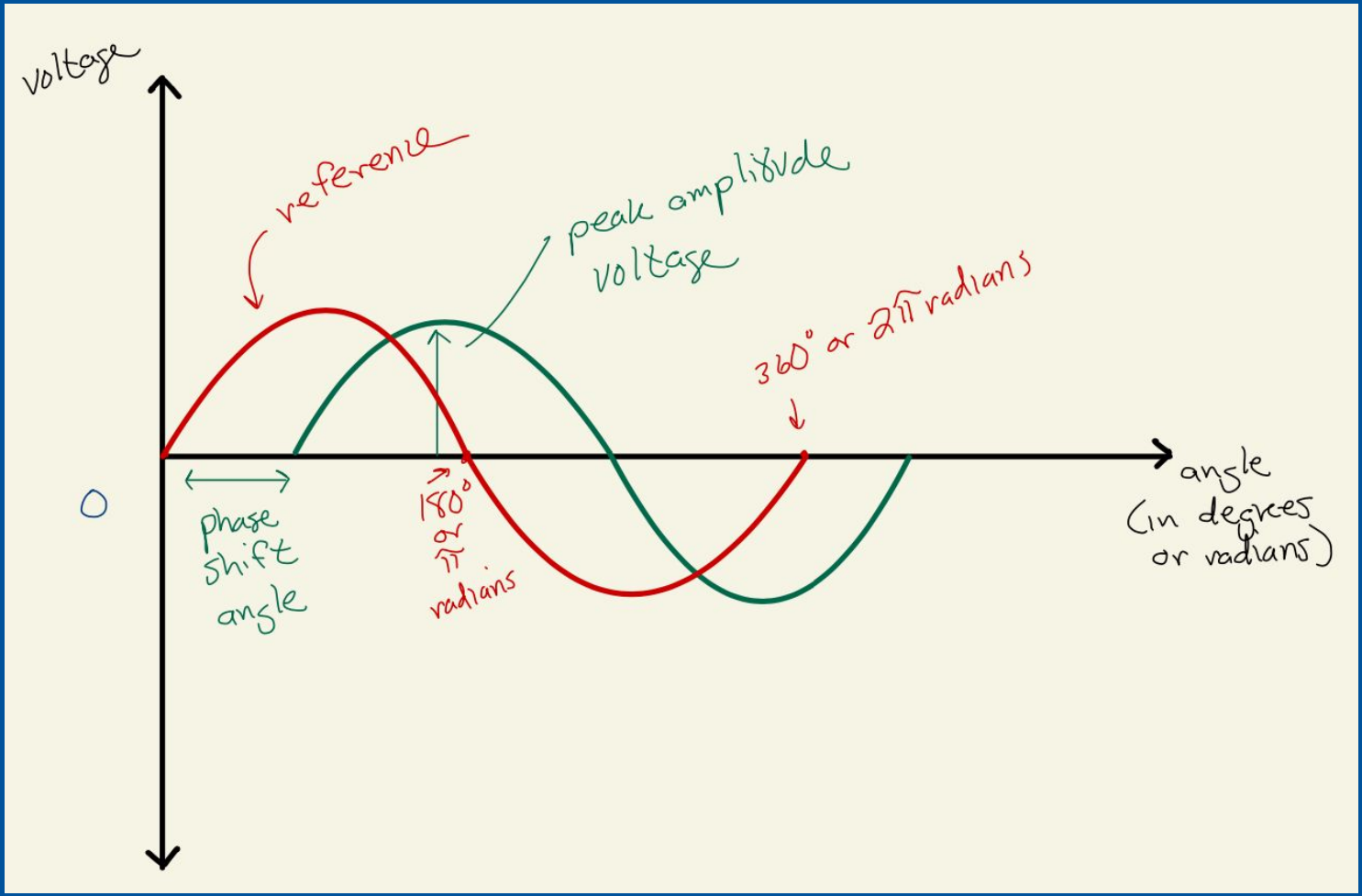
Modulation and Quadature Amplitude Modulation (QAM)

Analog modems have used a form of QAM for years to move information from device to device across the Public Switched Telephone Network (PSTN) or voice network. QAM is also used by cable modems, W-Fi and cellular networks modulate (convert digital signals to analog) and demodulate (convert analog signals back to digital) communications signals.



QAM combines amplitude modulation (think height of a sine wave) and phase shift (think of a sine wave moving along the x-axis relative to a zero degree reference) and allows multiple bits (combinations of binary 1's and 0's) to be transmitted for each cycle of a sine wave. Think *multiple bits per cycle* to describe QAM.

QAM is broadband



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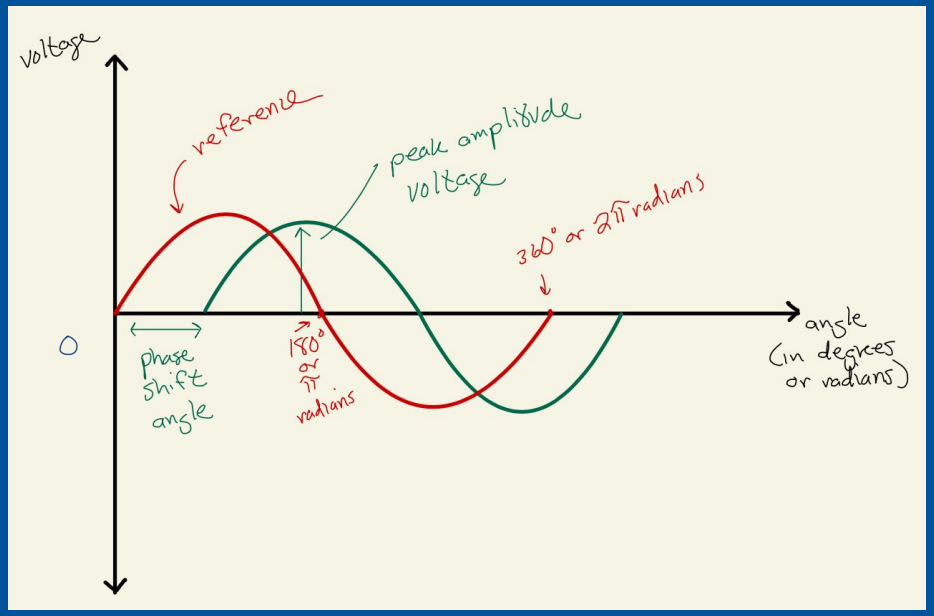
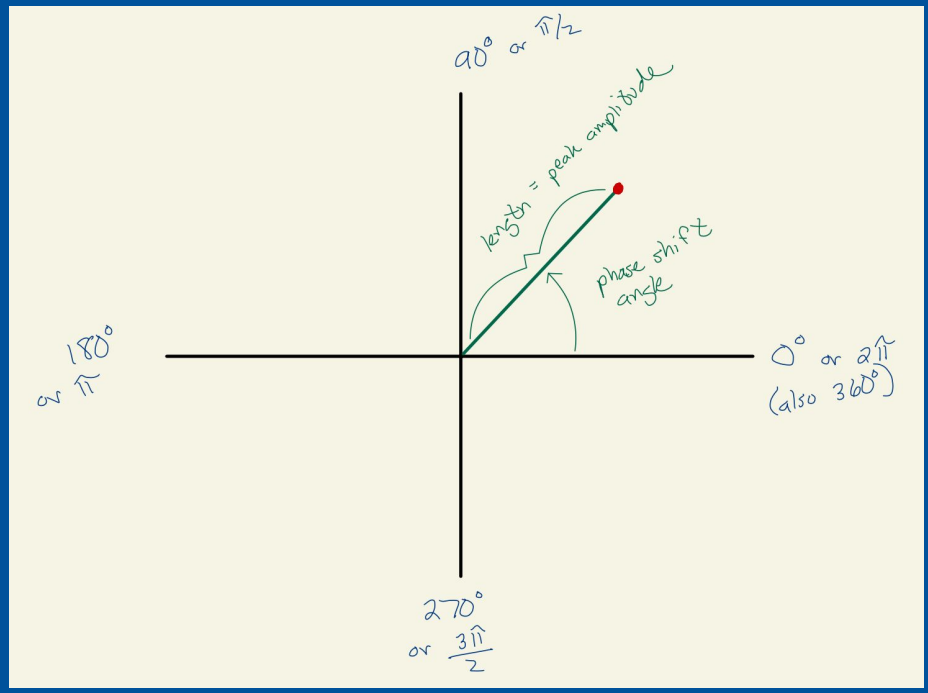
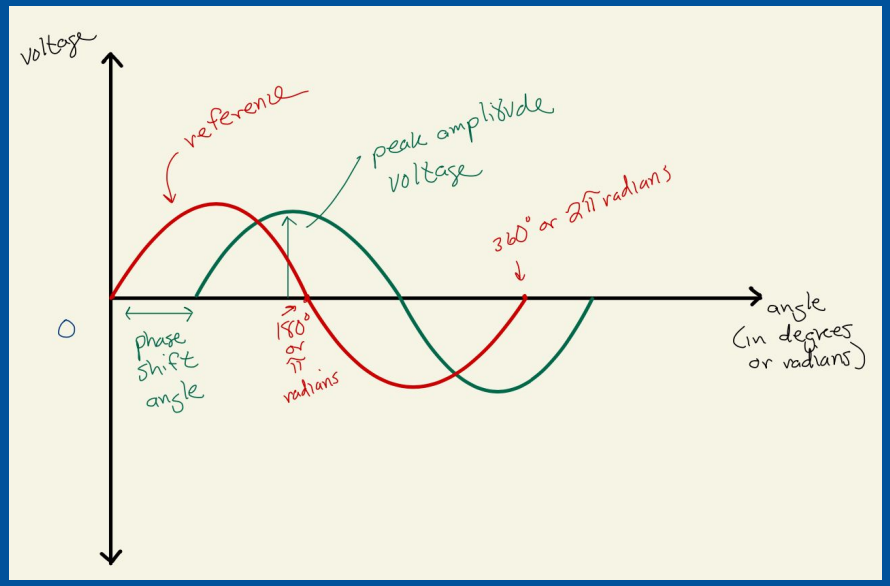
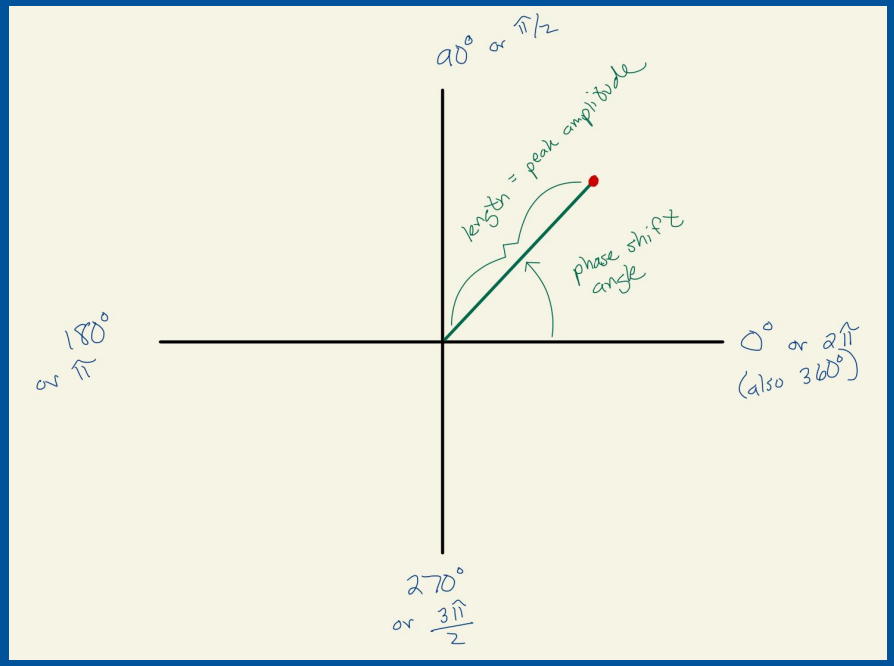
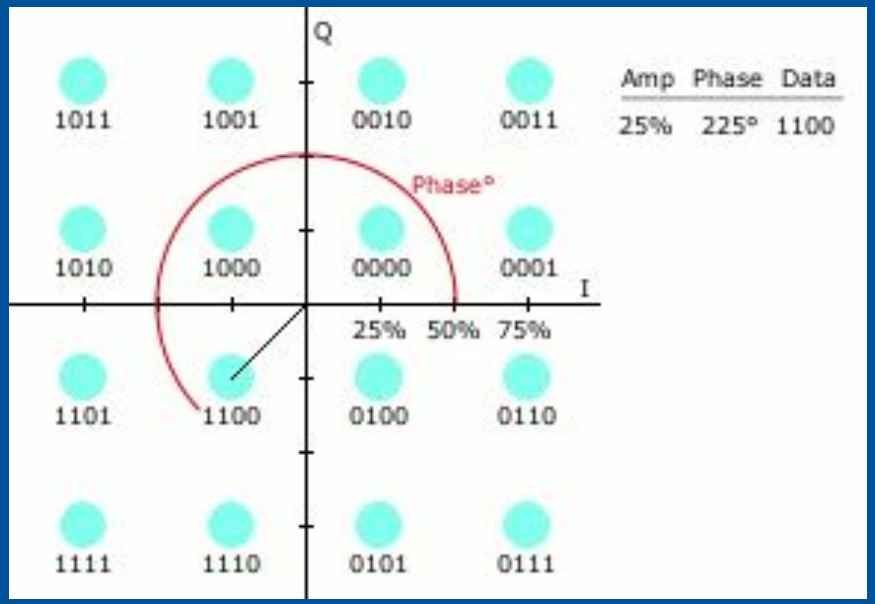




QAM is broadband

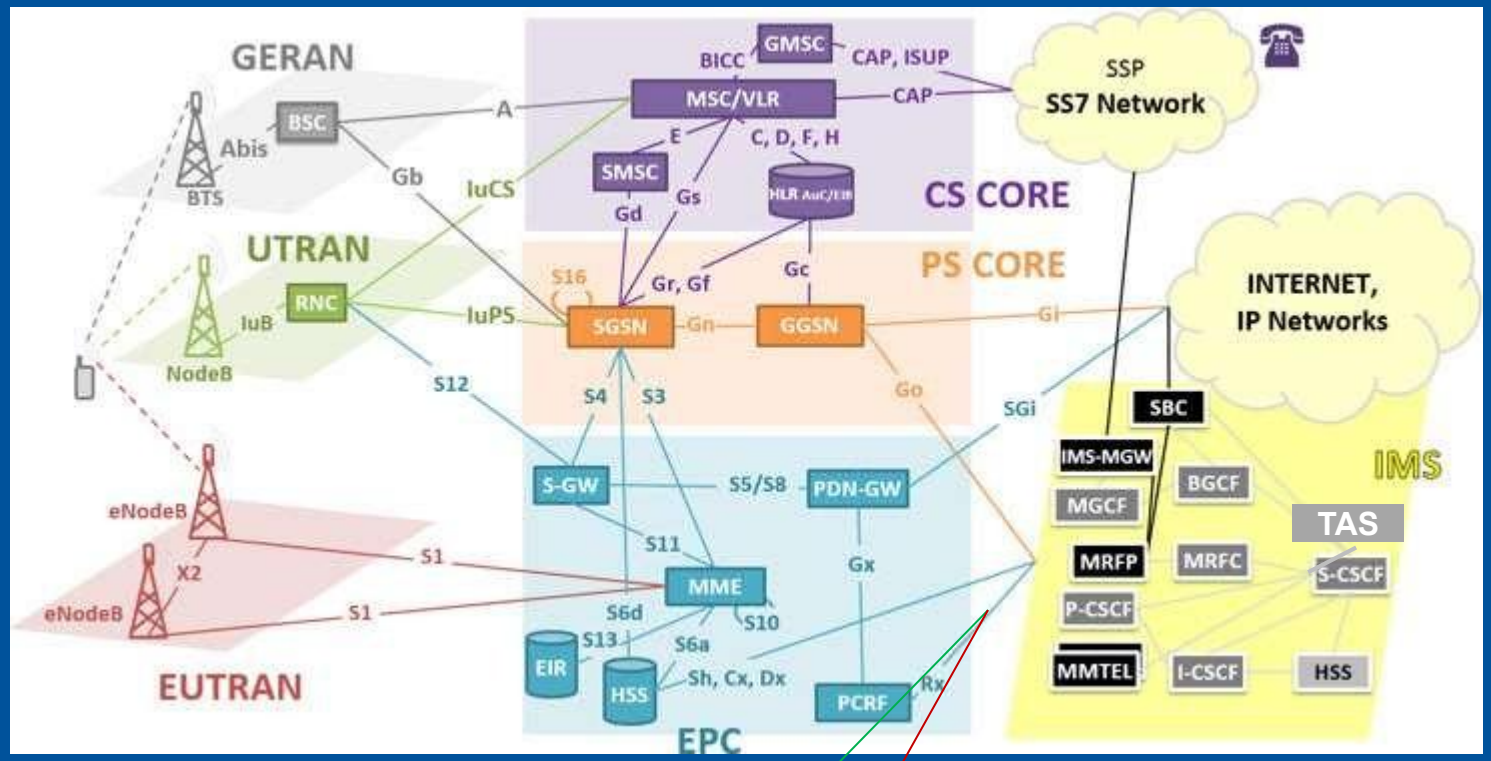






gif source:
https://upload.wikimedia.org/wikipedia/commons/9/90/QAM16_Demonstration

Current - Multiple Silo networks



5G: new Antennas, new network Architecture

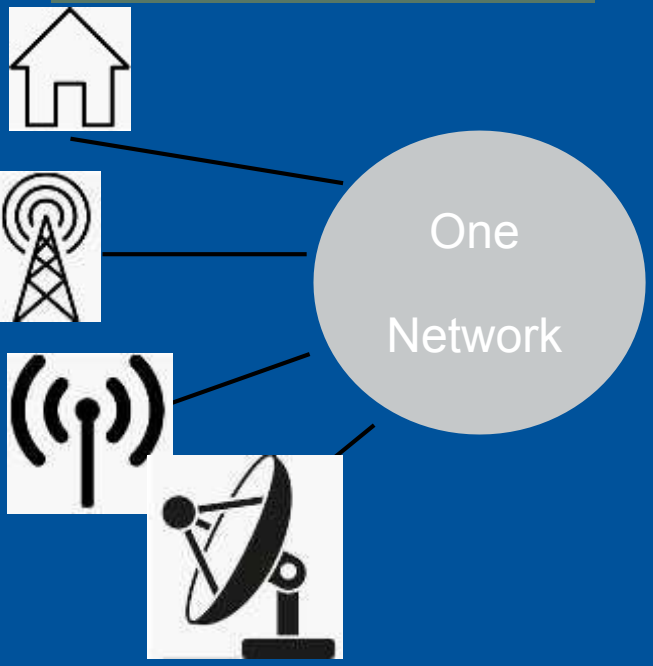
(silos)

broadband

mobile

wifi

IoT



Cloud-native 5G Core that connects everyone and everything

What 5G will bring … a more Efficient Network

Enhanced Mobile Broadband

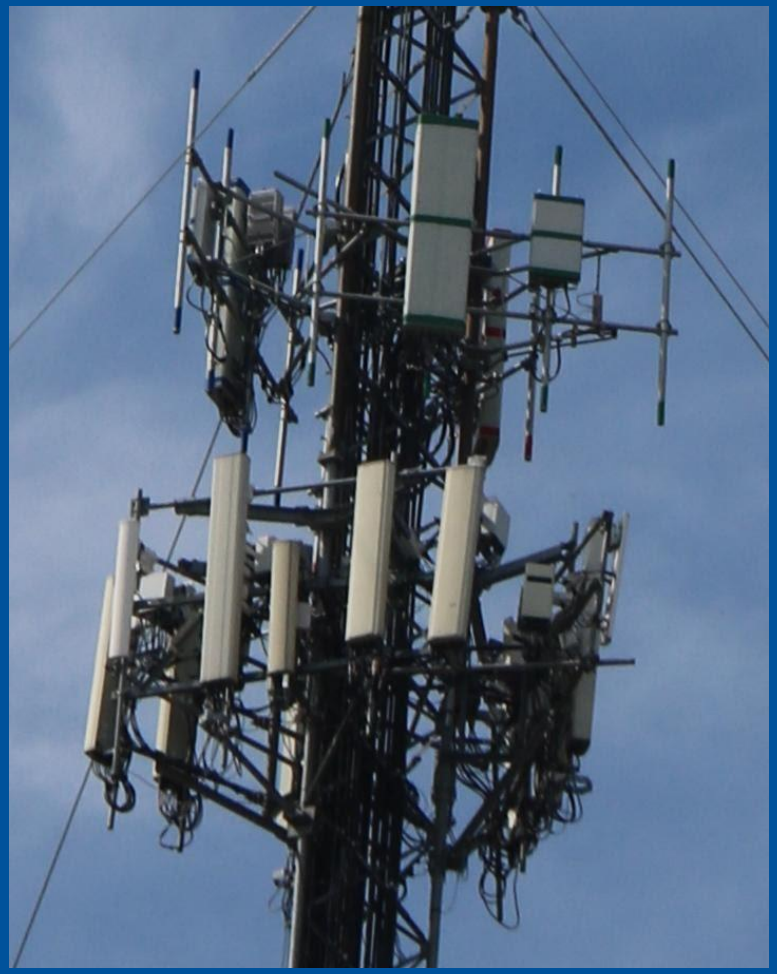
- 20 Gbps = Peak Data Rate
- 100 Mbps = User Experienced Data Rate
- 10Mbps/m^2 = Area Traffic Capacity
- 100X = Network Energy Efficiency
- 3X = Spectrum Efficiency

Massive IoT

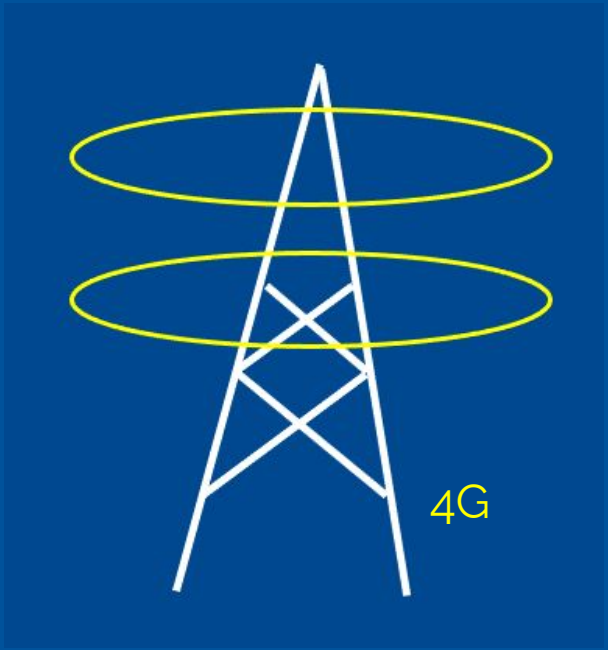
- 10^6 per km^2 = Connection Density

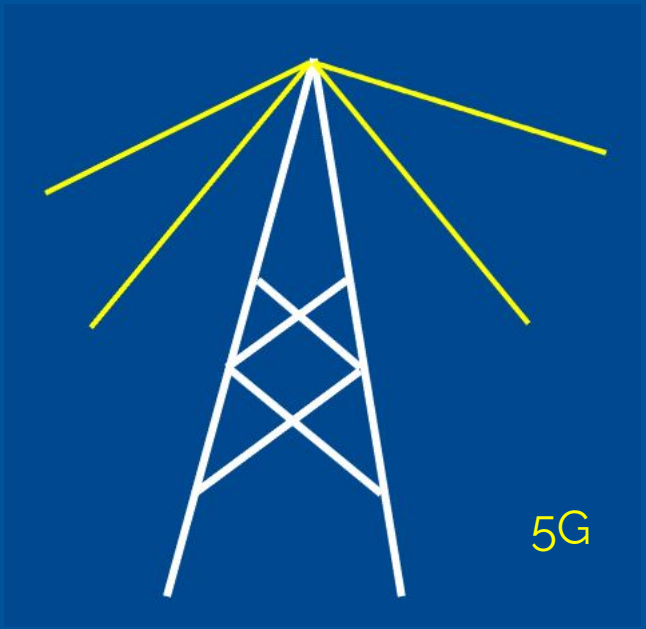
Ultra Reliable and Low Latency

- 1 msec = Latency
- 500 km/h = Mobility

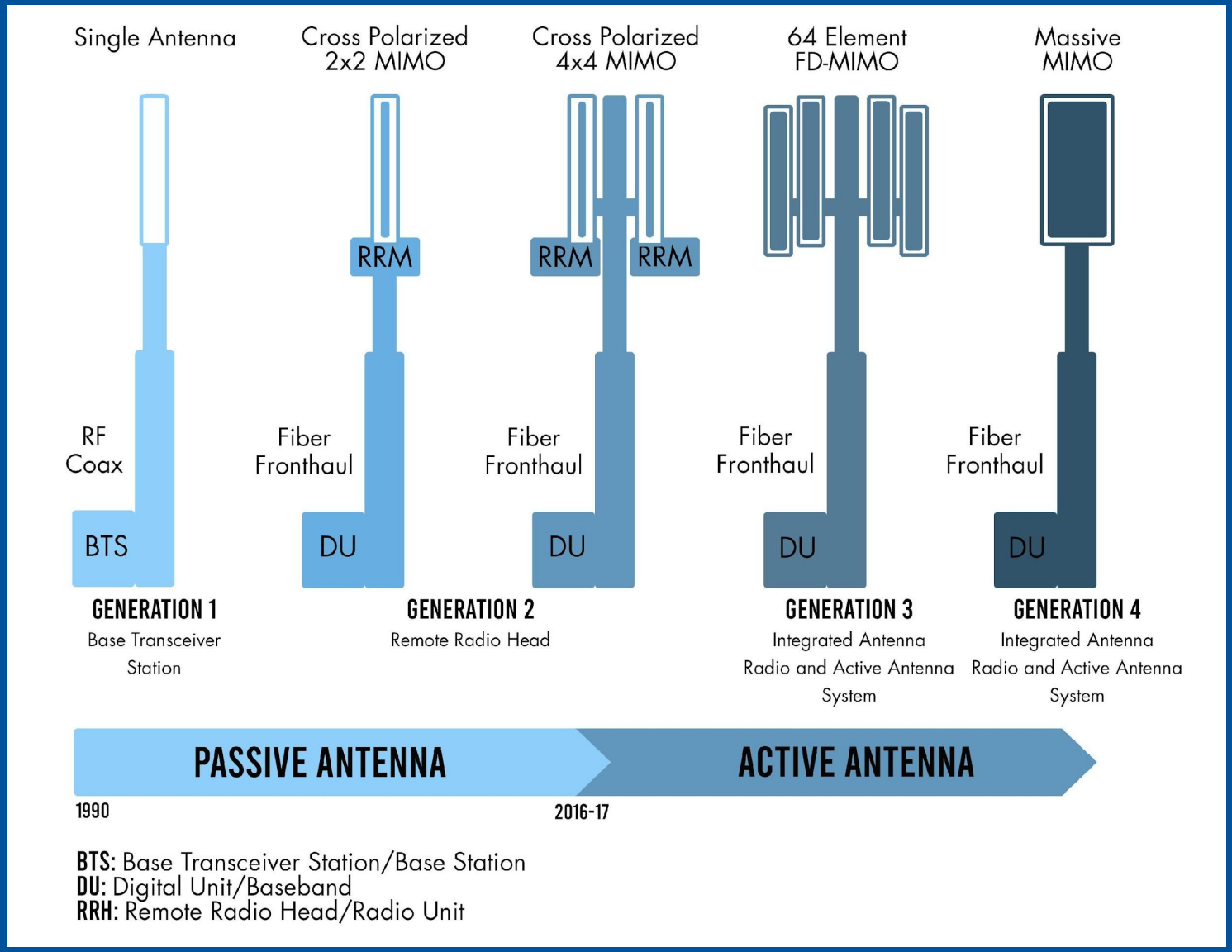


Antennas … directional, more efficient

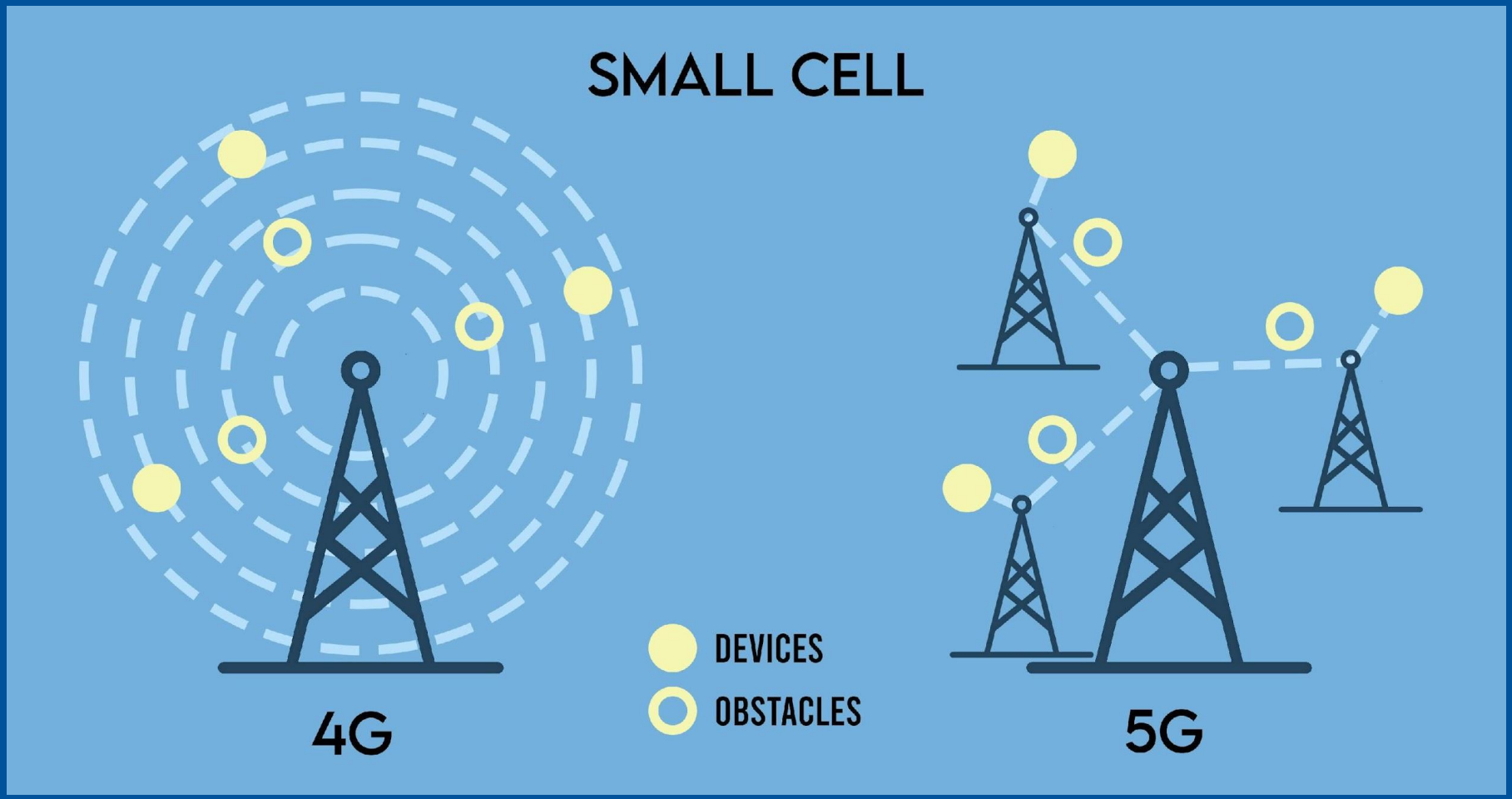




Antenna evolution

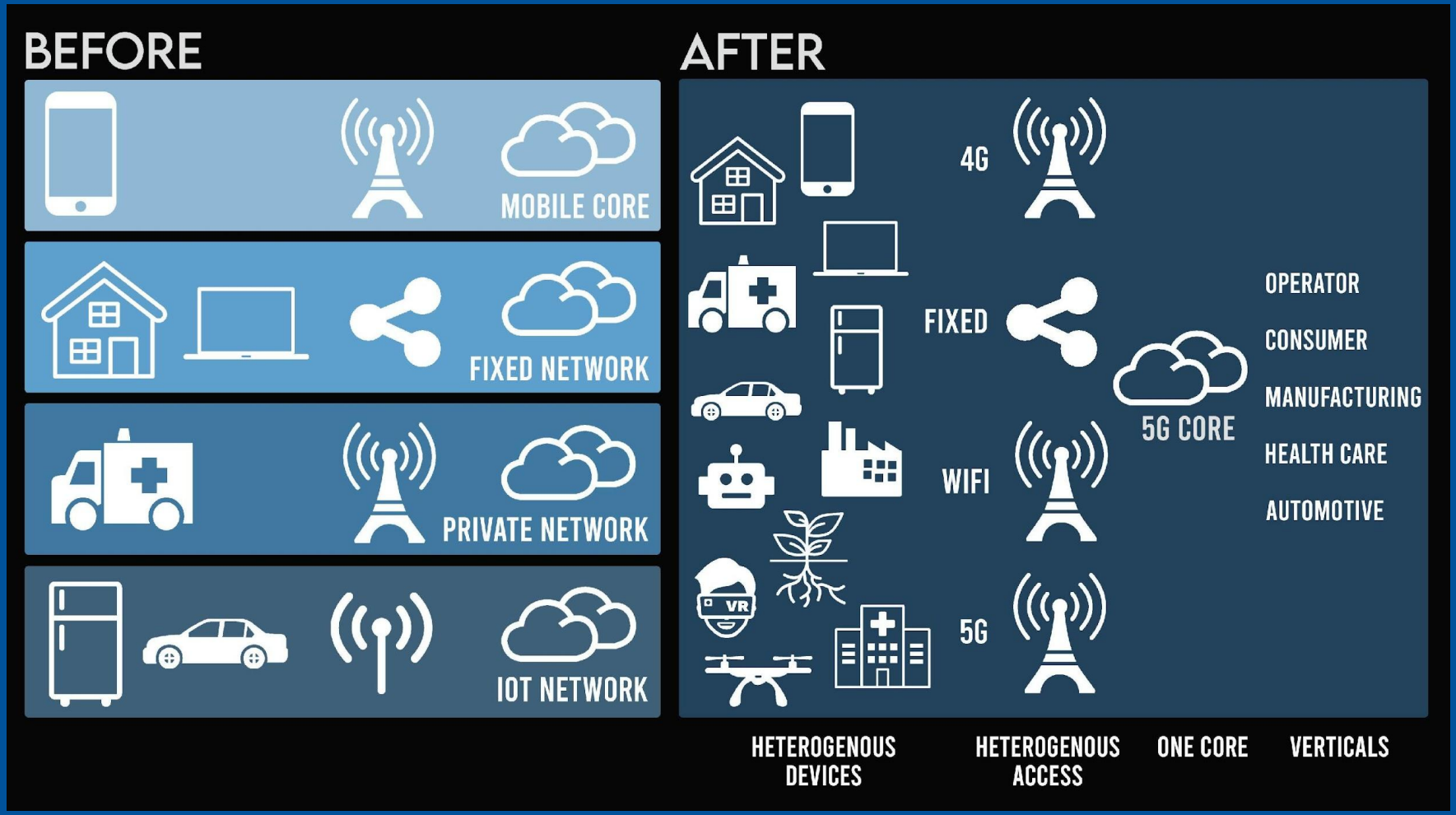


Small Cell

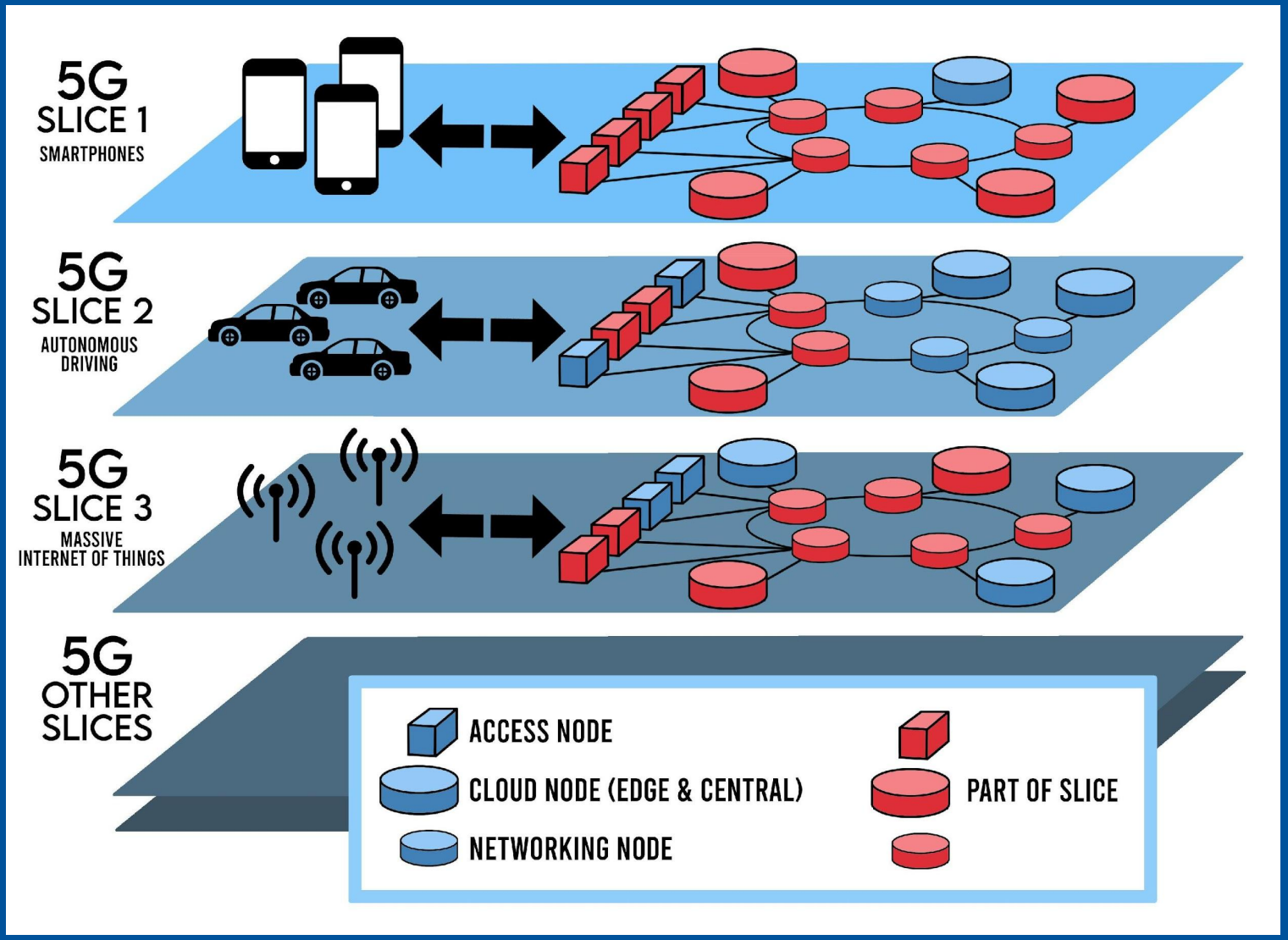


Source: Infinion

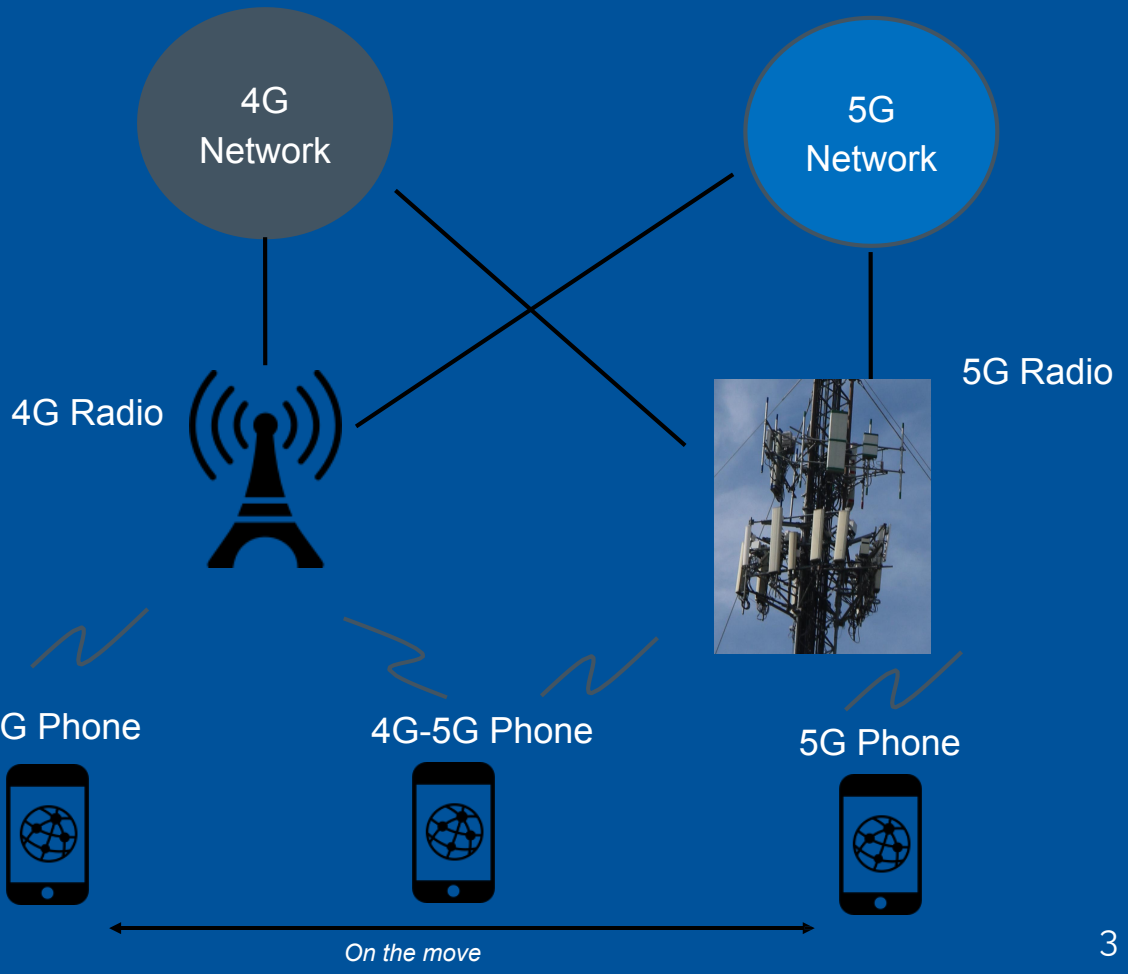
From Silos to a Common Core for All



5G Network Slicing

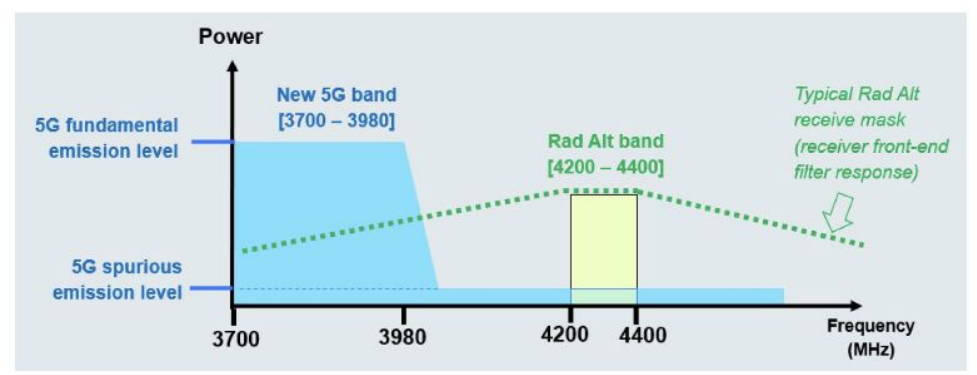


Deployment


4G
Network
5G
Network
4G Radio
5G Radio
4G Phone
4G-5G Phone
5G Phone
On the move

What about airports and 5G?

Fundamental 5G emissions may lead to blocking interference in the radar altimeter receiver, wherein a strong signal outside of the normal receive bandwidth cannot be sufficiently filtered in the receiver to prevent front-end overload or other effects. Source: https://www.rtca.org/wp-content/uploads/2020/10/SC-239-5G-Interference-Assessment-Report_274-20-PMC-2073_accepted_changes.pdf



What's going on? Altimeters have poor filters and spurious noise can enter band of receiver. That noise can come from both 5G base stations and 5G handsets. Poor filtering at the receivers raises the potential problem, so the altimeters need to be replaced or better filters added.

Updates:
https://www.reuters.com/business/aerospace-defense/faa-wants-us-airlines-retrofit-replace-radio-altimeters-2022-05-03/

https://www.cnet.com/news/buttigieg-5gfaa-interference-issue-wont-be-resolved-by-summer/

Class Exercises

1. Most carriers are now offering 5G services using sub-6GHz bands that cover wider areas. They are also planning to launch or have already launched mmWave service in select urban locations. Do some research on the web to determine:

a. Which carriers are currently offering sub-6GHz band service in your region?
b. Which carriers are currently offering mmWave service in your region?

2. Research current 5G phones currently being sold that will work with your current carrier 5G service offerings. Describe the phone you would select and why.

3. List and describe three advantages and three disadvantages of fixed 5G service for your home.

4. Research Low Earth Orbit (LEO) satellite internet service offerings and list and describe three advantages and three disadvantages of LEO satellite service for your home.

Class Discussion Items

5G will enable new applications along with increased vulnerabilities. Here's a short list of discussion items in no particular order:

- Heavy reliance on fiber backhaul
- Capturing, integrating and curating data from every part of the network
- Geospatial tech including location-based services
- IoT
- AI
- Mobile Edge computing
- An integrated data approach
- Predictive analytics to predict sites most vulnerable to damage and degradation
- SDN
- How the *softwarization* of network components will increase 5G security vulnerabilities – including cloud security and system redundancy software

Resouces:

GSMA: https://www.gsma.com/futurenetworks/ip_services/understanding-5g/

LightReading: https://www.lightreading.com/5g.asp

Integrated access and backhaul – a new type of wireless backhaul in 5G: https://www.ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/introducing-integrated-access-and-backhaul?gclid=EAIaIQobChMIlK-0vIKJ6wIVilTICh1arweuEAAYAiAAEgIOXfD_BwE&gclsrc=aw.ds

5G bandwidth and wavelength: https://www.verizon.com/about/news/5g-bandwidth-wavelength

What is edge computing? The benefits of mobile edge computing and 5G: https://www.verizon.com/about/news/what-is-edge-computing

5G Telecommunications Science Safety: https://mdsafetech.org/5g-telecommunications-science/

5G Spectrum and Frequencies: Everything You Need to Know: https://www.lifewire.com/5g-spectrum-frequencies-4579825

Cellular Frequencies in the U.S. https://en.wikipedia.org/wiki/Cellular_frequencies_in_th

Holographic Beam Forming and Phased Arrays https://pivotalcommware.com/wp-content/uploads/2019/10/HBF-vs-APA-White-Paper-2019.pdf