Mobile Computing Architecture

UW Bothell, WA

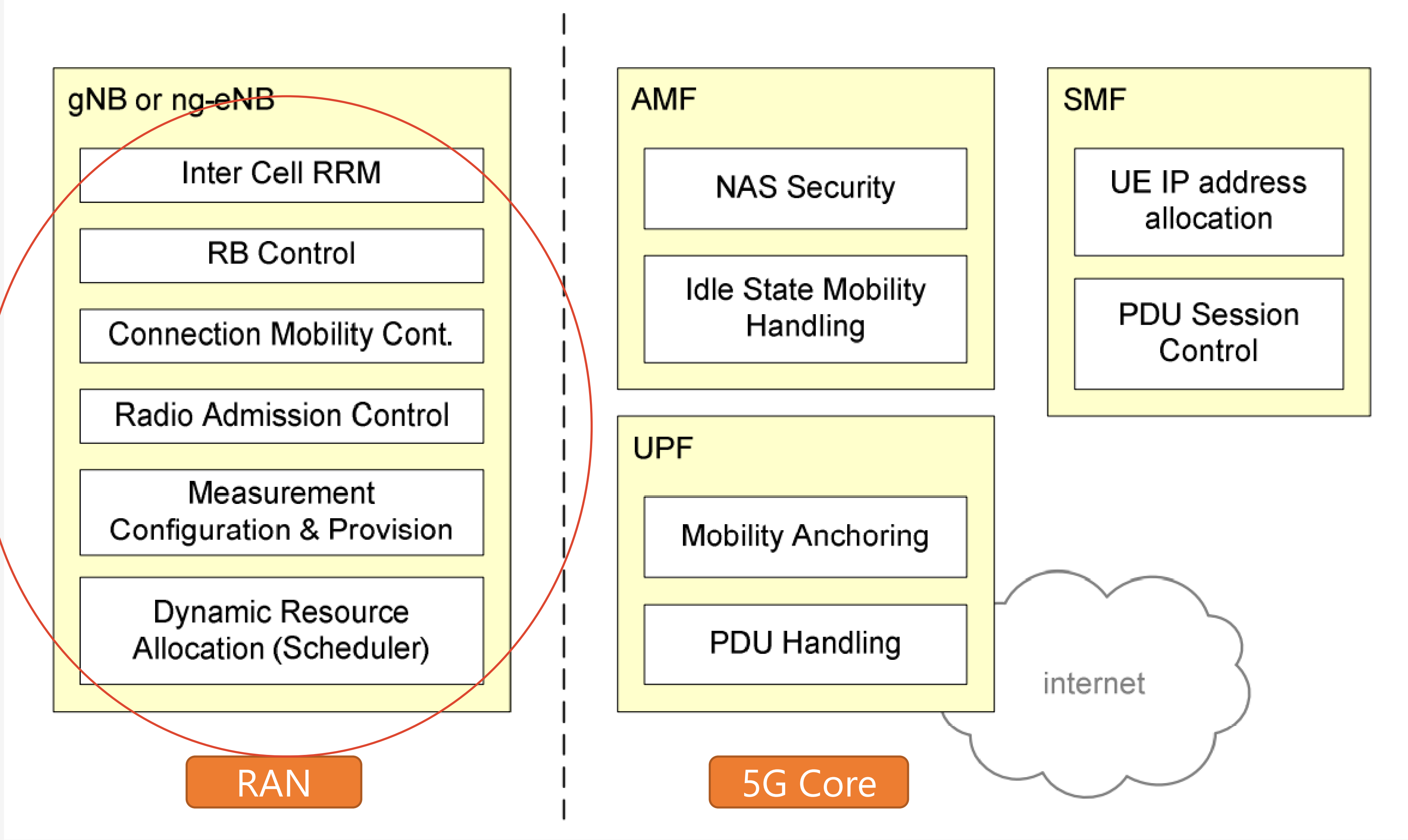
Radio Spectrum and Cellular Architecture

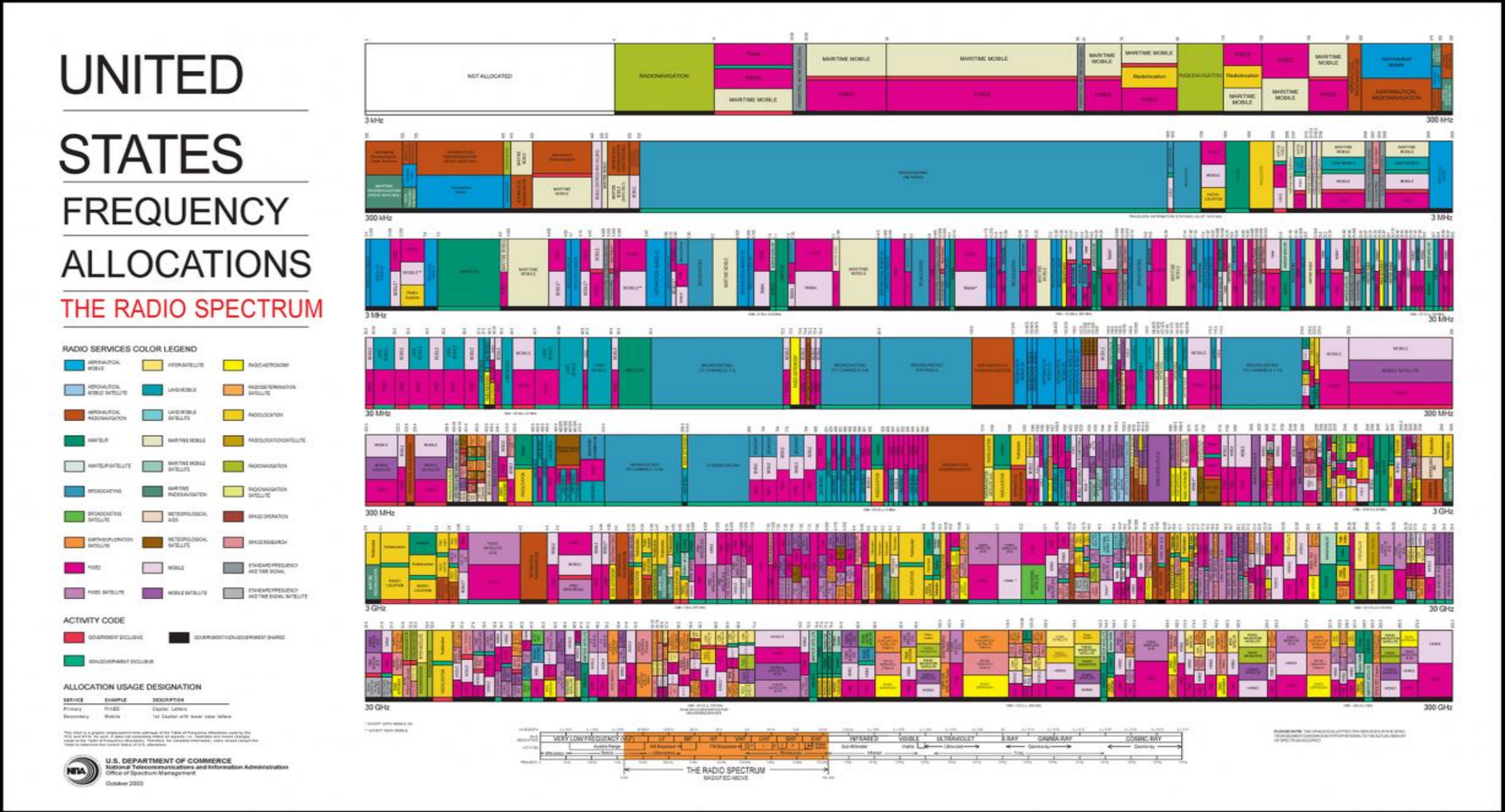
Frequency, Wavelength and Hz

Let’s see if you can explain in 5 minutes what Frequency and Wavelength are? And how they are related?

3GPP 5G Mobile Network Architecture

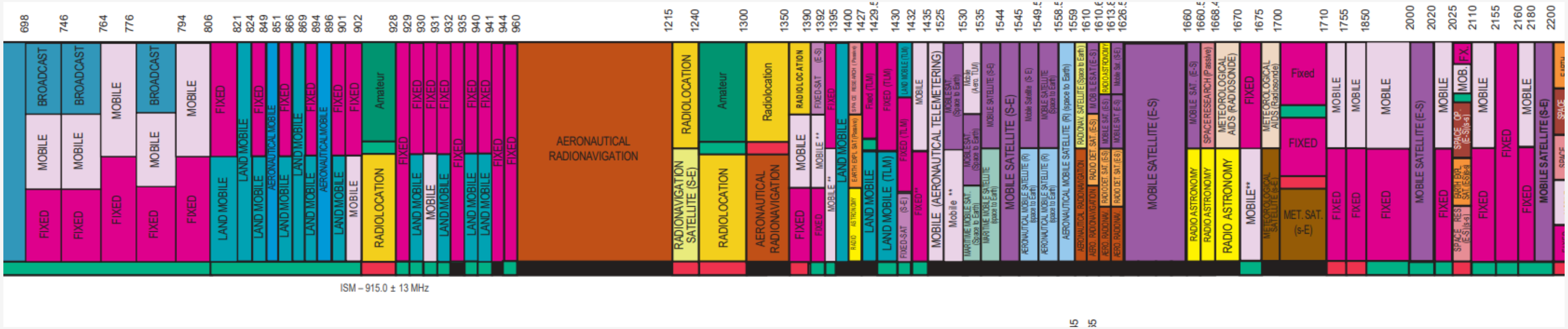
Functional Split: RAN and 5G Core (5GC)





https://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf

4G/5G Example: 700MHz



LTE Deployments

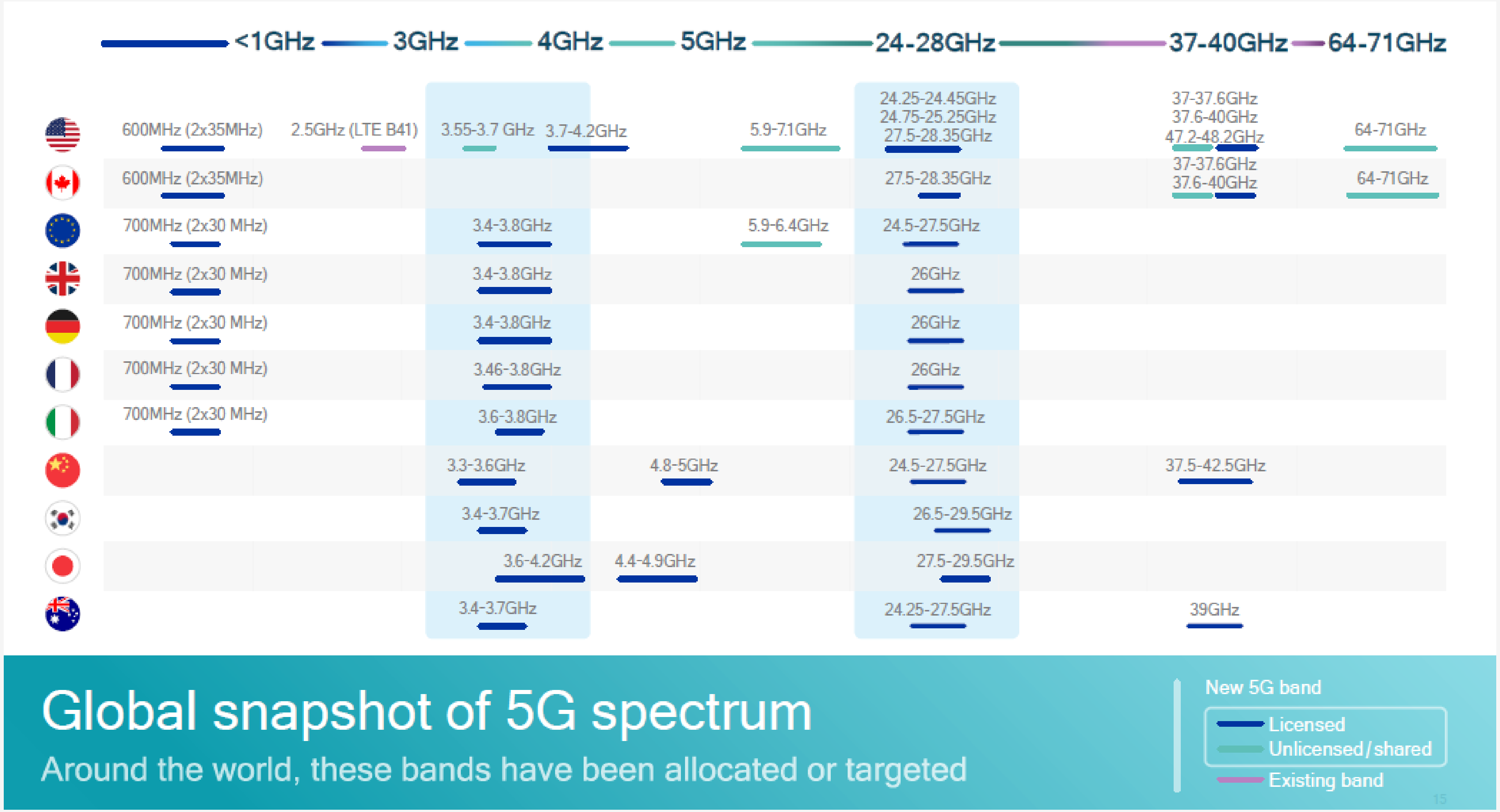
Band	Uplink (MHz)	Downlink (MHz)	Carrier Bandwidth (MHz)	Comments
700 MHz	746-763	776-793	1.25 5 10 15 20	Digital Dividend. U.S. commercial spectrum auctioned Q108. "D" block to be re-auctioned. Potential future alignment with Europe
AWS	1710-1755	2110-2155	1.25 5 10 15 20	U.S. Auctions completed September 2006
IMT Extension (Paired)	2500-2570	2620-2690	1.25 5 10 15 20	Initially Western Europe. Offers a unique opportunity for the deployment of LTE in channels of up to 20 MHz.
IMT Extension (Unpaired)	2570-2620		1.25 5 10 15 20	Potential for LTE –TDD in Europe and Asia Pac.
GSM 900	880-915	925-960	1.25 5 10 15 20	Reallocate this spectrum to advanced networks, such as LTE, from 2009 onwards
UMTS Core	1920-1980	2110-2170	1.25 5 10 15 20	Europe and Asia Pac. Potential for unused WCDMA carriers
GSM 1800	1710-1785	1805-1880	1.25 5 10 15 20	Europe and Asia Pac. Refarm underutilized band along with GSM 900
PCS 1900	1850-1910	1930-1990	1.25 5 10 15 20	U.S. Refarm after new 700 MHz and AWS spectrum is consumed.
Cellular 850	824-849	869-894	1.25 5 10 15 20	U.S. Refarm after new 700 MHz and AWS spectrum is consumed.
Digital Dividend	470-854		1.25 5 10 15 20	Identified at WRC-07.

Major Service Providers 4G Spectrum

Spectrum and LTE bands used by US carriers

	Spectrum frequency	LTE Bands	Year deployed
AT&T	700 MHz blocks b, c	17	2011
	1700 MHz blocks, a,b,c;d;e	4	2011
	1900 Hz	2	2013
Sprint	800 MHz	26	2013
	1900 MHz block g	25	2013
	2500 MHz	41	2013
T-Mobile	700 MHz blocks a	12	2013
	1700 MHz blocks d;e;f	4	2013
	1900 MHz	2	2014
Verizon Wireless	700 MHz block c	13	2010
	1700 MHz block f	4	2013

5G Spectrum



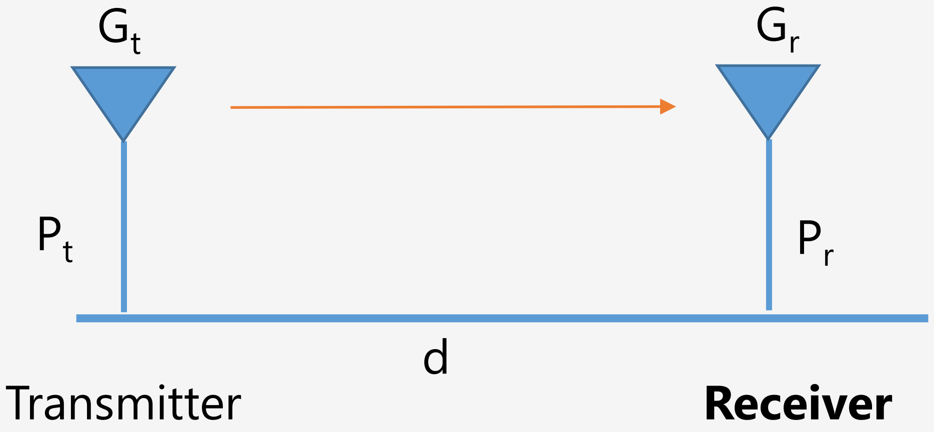
<1GHz
3GHz
4GHz
5GHz
24-28GHz
37-40GHz
64-71GHz
600MHz (2x35MHz)
2.5GHz (LTE B41)
3.55-3.7 GHz
3.7-4.2GHz
5.9-7.1GHz
24.25-24.45GHz
24.75-25.25GHz
27.5-28.35GHz
37-37.6GHz
37.6-40GHz
47.2-48.2GHz
64-71GHz
600MHz (2x35MHz)
27.5-28.35GHz
37-37.6GHz
37.6-40GHz
64-71GHz
700MHz (2x30 MHz)
3.4-3.8GHz
5.9-6.4GHz
24.5-27.5GHz
700MHz (2x30 MHz)
3.4-3.8GHz
26GHz
700MHz (2x30 MHz)
3.4-3.8GHz
26GHz
700MHz (2x30 MHz)
3.46-3.8GHz
26GHz
700MHz (2x30 MHz)
3.6-3.8GHz
26.5-27.5GHz
3.3-3.6GHz
4.8-5GHz
24.5-27.5GHz
37.5-42.5GHz
3.4-3.7GHz
26.5-29.5GHz
3.6-4.2GHz
4.4-4.9GHz
27.5-29.5GHz
3.4-3.7GHz
24.25-27.5GHz
39GHz
Global snapshot of 5G spectrum
Around the world, these bands have been allocated or targeted
New 5G band
Licensed
Unlicensed/shared
Existing band

Radio Propagation

- Radio (physical layer) is complex and extremely random
- Software and mathematical models are increasingly improving the engineering of radio systems [$$$$$Billions Industry: Qualcomm, Samsung, Sony, Ericsson, Nokia, etc.]
- The wireless radio channel puts fundamental limitations to the performance of wireless communications systems
- Modeling the radio channel is typically done in statistics and applied probability. From simple to very complex models
- This lecture will get you enough insights to tackle mobile devices architecture, design and modeling of the physical layer

Friis Model

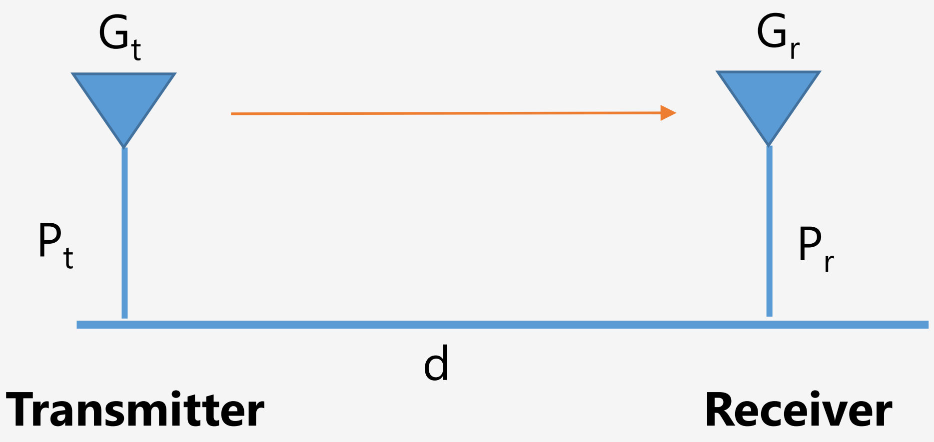
$$P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi d)^2}$$



- *λ is the wavelength =* ***(1/frequency)***
- *d is the distance between Transmitter and Receiver*
- *Pt is the transmitted power. Pr is the received power Pt and Pr are in same units*
- *Gt and Gr are the transmit and receive antenna gains. Gt and Gr are dimensionless quantities.*

Friis Model - Insights

$$P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi d)^2}$$



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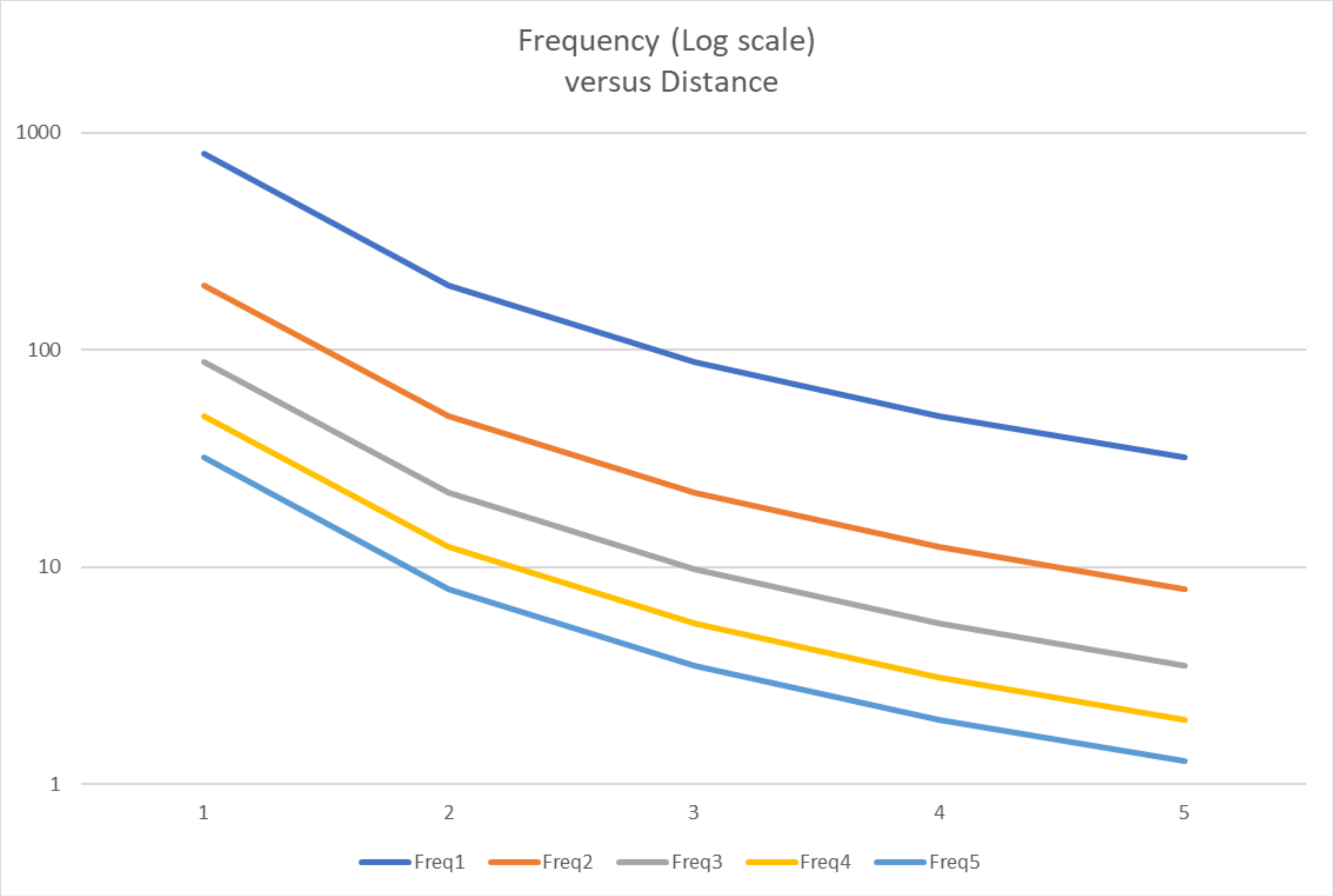
- Received power is inversely proportional to the square of distance
- Received power is inversely proportional to the square of Frequency
- More powerful (higher gain) antennae the more the power received

Received Power = f(distance, Frequency)

Pt	10
Gr	10
Gt	10

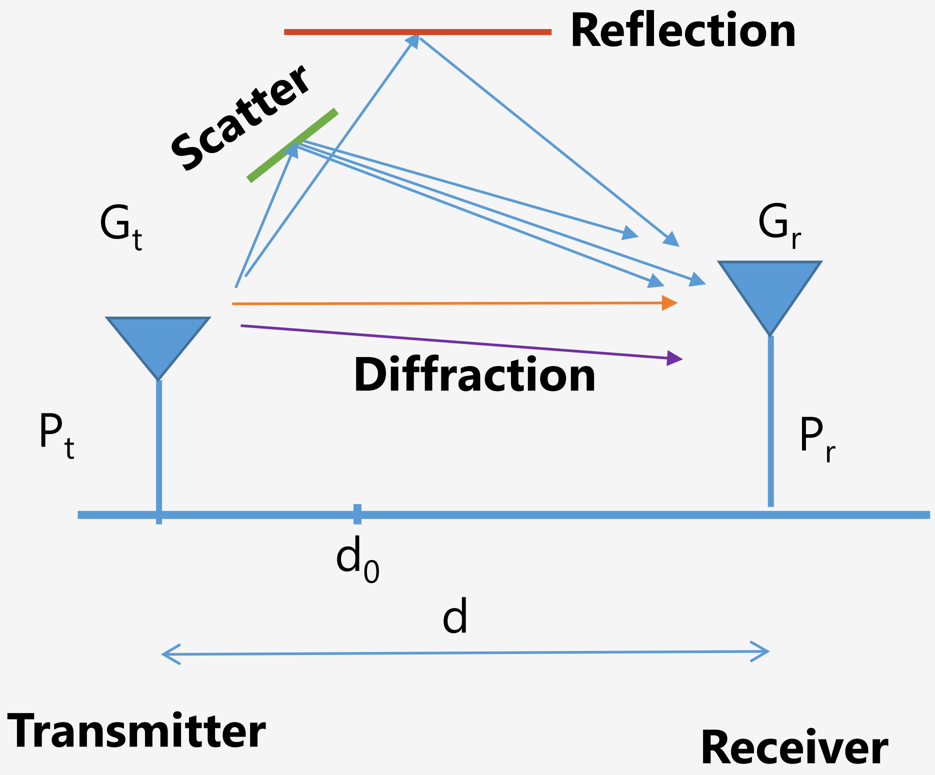
	Hz
Freq1	10
Freq2	20
Freq3	30
Freq4	40
Freq5	50



Free Space Propagation

Free Space Propagation expressed in relation to a reference point, d_0

$$P_r(d) = P_t K \left(\frac{d_0}{d}\right)^2 \qquad d \geq d_0$$



K is a unitless constant that depends on the antenna characteristics and free space path loss up to distance d_0

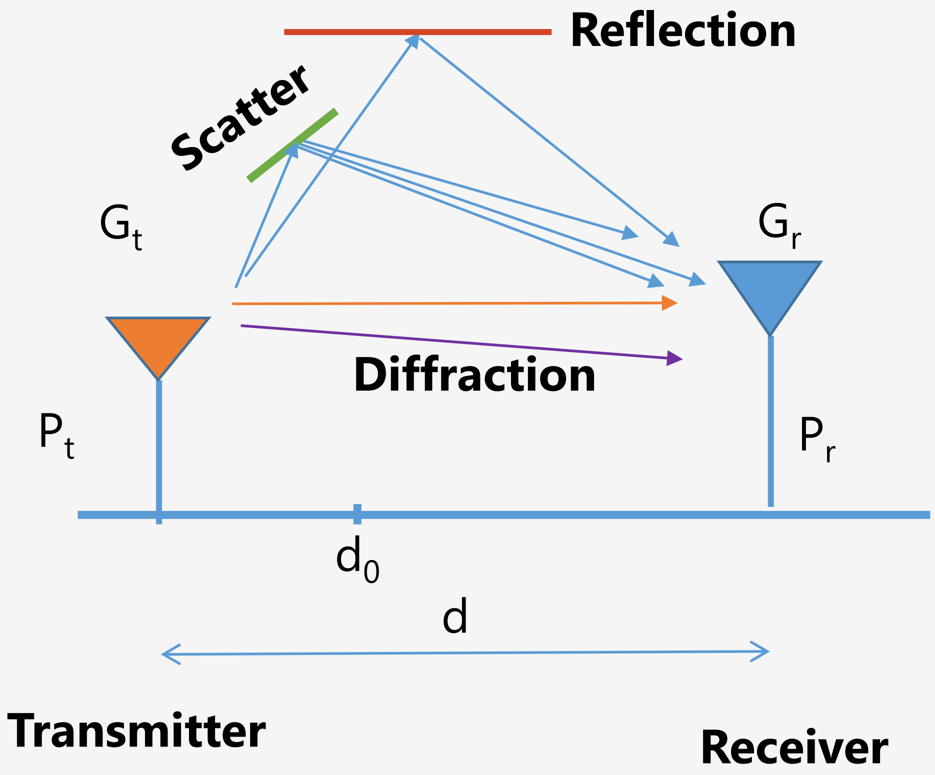
Typical value for , d_0:
- Indoor:1m
- Outdoor: 100m to 1 km

Free Space Propagation - Simplified

Free Space Propagation expressed with attenuation factors, in relation to a reference point, d_0

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma}$$

Environment	Path Loss exponent, γ
Free Space	2
Urban Area	2.7 to 3.5
Suburban Area	3 to 5
Indoor (line-of-sight)	1.6 to 1.8



K is a unitless constant that depends on the antenna characteristics and free space path loss up to distance d_0

Typical value for , d_0:

- Indoor:1m
- Outdoor: 100m to 1 km

$$P_r \text{ dBm} = P_t \text{ dBm} + K \text{ dB} - 10\gamma \log_{10}\left[\frac{d}{d_0}\right]$$

Cellular Networks

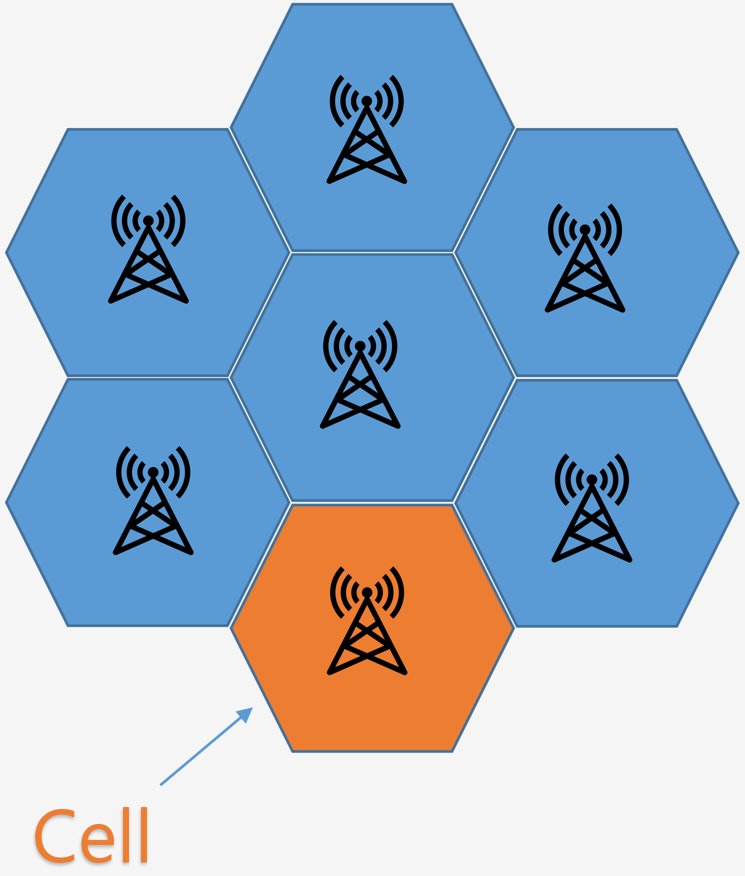
- Traditional mobile service was similar to television broadcasting. A transmitter located would broadcast in a radius of up to 35 miles. It was impossible to reuse the frequencies throughout the system because of *interference*.

- Instead of using one powerful transmitter, many **low-power transmitters** were placed throughout a coverage area to increase the capacity

- Each base station is allocated a portion of the total number of channels available to the entire system To minimize interference, neighboring base stations are assigned different groups of channels

- No frequency is re-used within a cell cluster

Cellular Cluster (n=7)

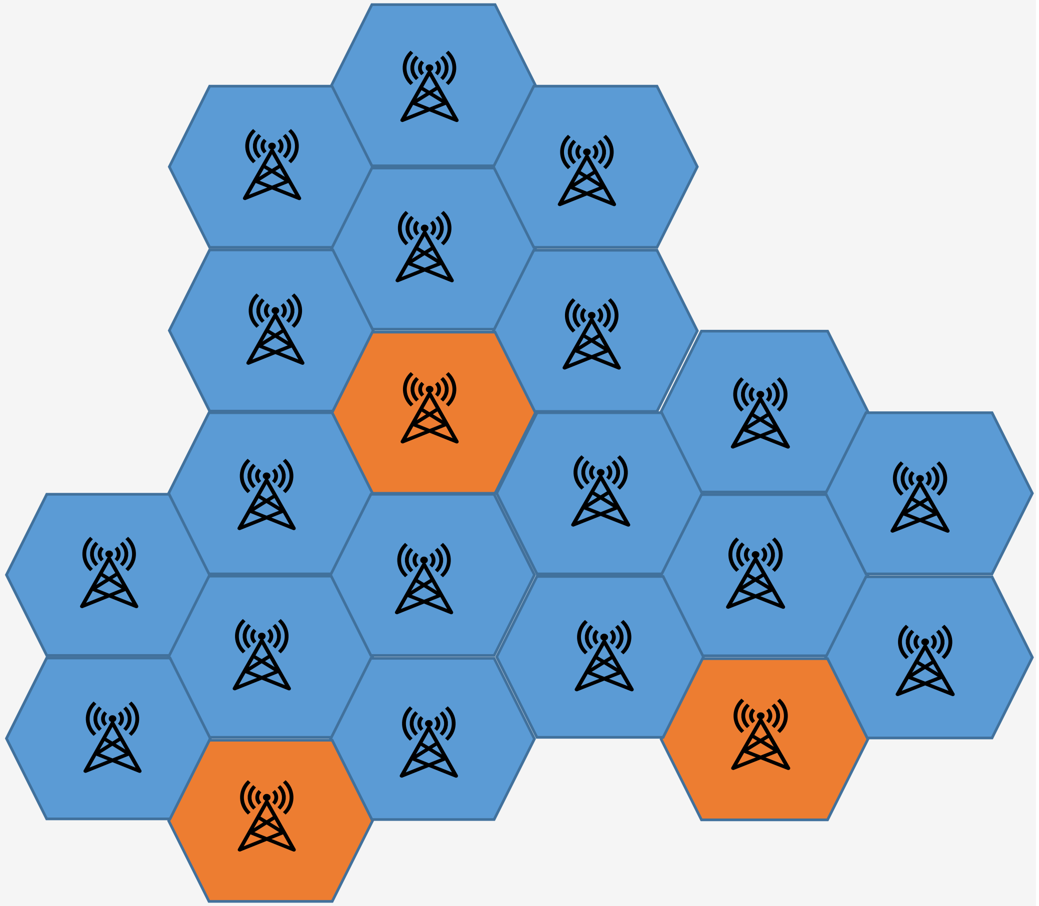


Cellular Networks – Frequency Reuse

- Cells with the same number have the same set of frequencies, Three clusters are shown in the figure

- In cluster size N = 7 each cell uses 1/N of available cellular channels (frequency reuse factor)

Cellular Cluster (n=7)



Cellular Networks – Interference

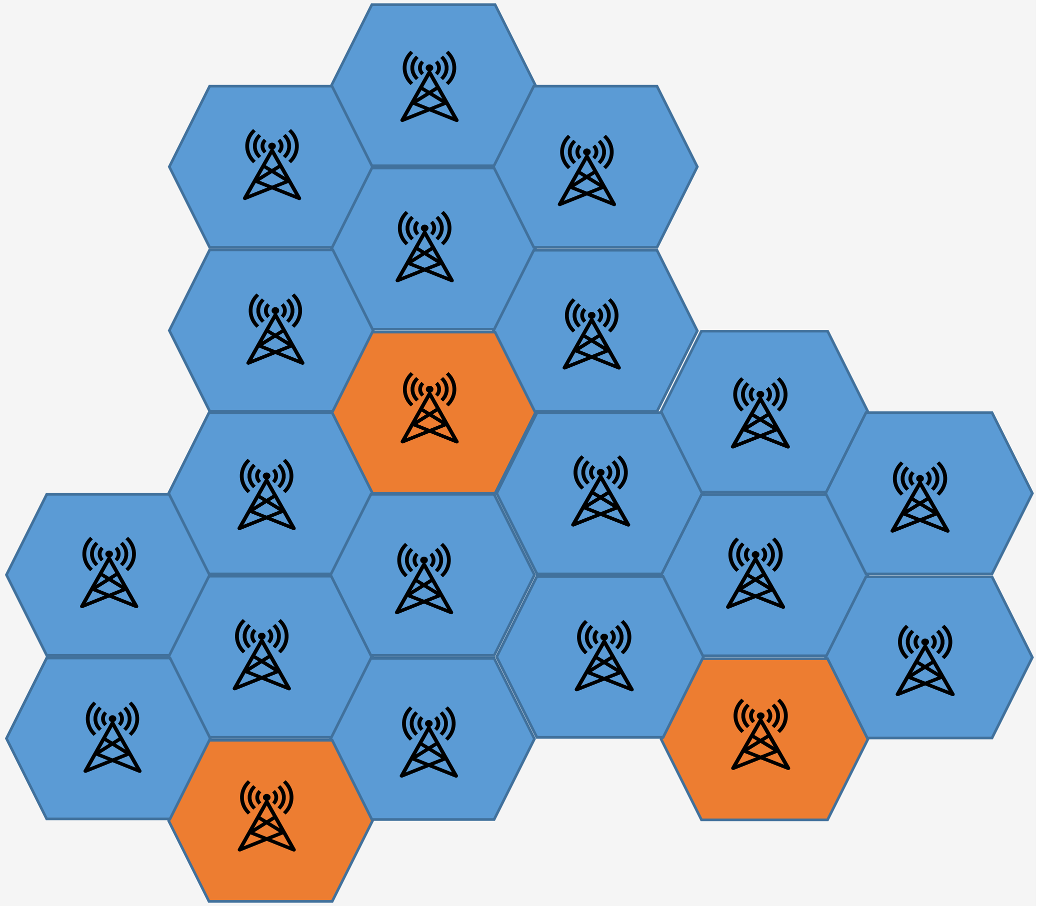
- There are several cells that use the same set of frequencies in a given coverage area these cells are called **co-channel cells**

- Interference between signals from these cells is cochannel interference

- Co-channel interference cannot be combated by simply increasing the carrier power of a transmitter. An increase in carrier transmit power increases the interference to neighboring co-channel cells

- To reduce co-channel interference co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation

Cellular Cluster (n=7)



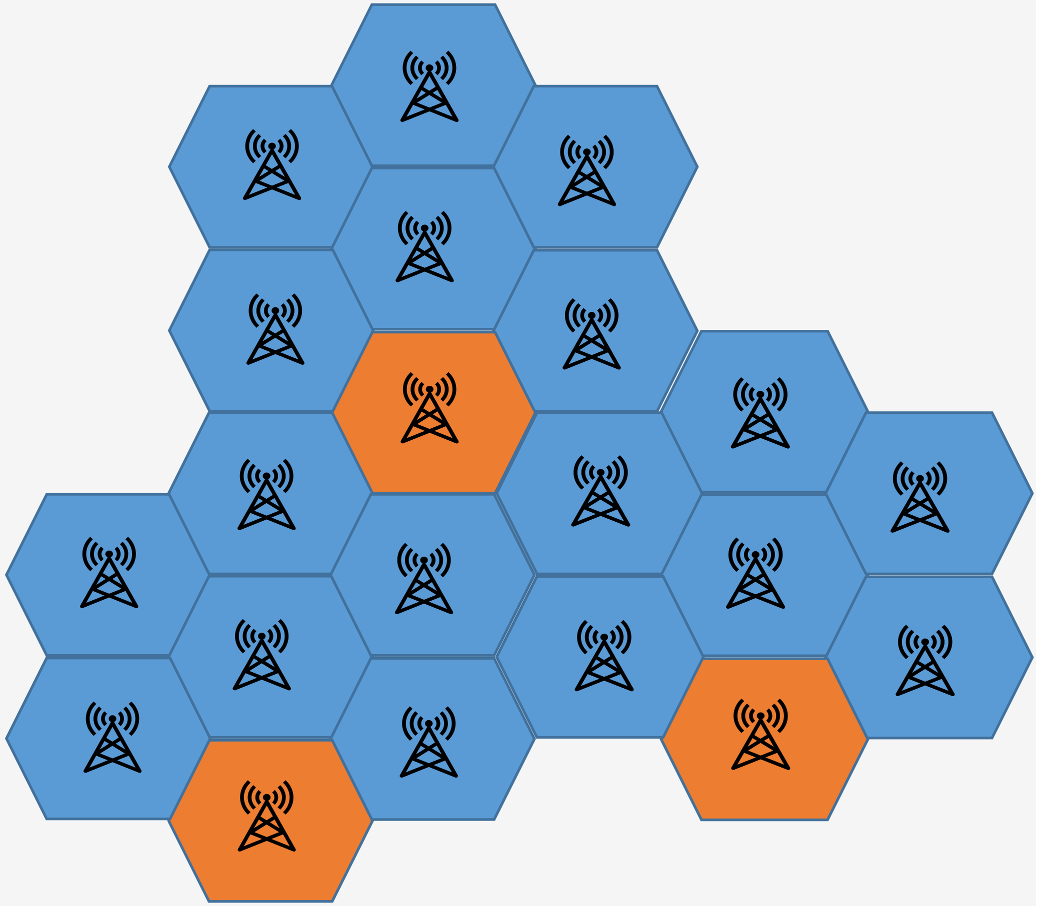
Cellular Networks – Signal to Interference Ratio (SIR)

- Let N_I be the number of co-channel interfering cells
- P_r is the desired signal power from the desired base station
- P_i is the interference power caused by the i^{th} interfering cochannel cell base station The SIR (S/I) at the desired mobile receiver is

$$\frac{S}{I} = \frac{P_r}{\sum_{i=1}^{N_I} P_i}$$

$$P_r = P_t K \left[\frac{d_0}{d}\right]^{\gamma}$$

Cellular Cluster (n=7)



Sireen Malik. Mobile Computing Architecture, 2020

Physics: Loss, Distance and Frequency [New Models]

Eq 1
$$PL^{\mathrm{FI}}(f_c, d) = 10\alpha \log_{10}\left(\frac{d}{1\mathrm{m}}\right) + \beta + 10\gamma \log_{10}\left(\frac{f_c}{1\mathrm{GHz}}\right) + \mathrm{N}(0, \sigma^{\mathrm{FI}})$$

Eq 2
$$PL^{\mathrm{CI}}(f_c, d) = \mathrm{FSPL}(f_c, 1\mathrm{m}) + 10n \log_{10}\left(\frac{d}{1\mathrm{m}}\right) + \mathrm{N}(0, \sigma^{\mathrm{CI}})$$

d = distance (meters)
f_c = carrier frequency (Ghz)

Table 1

Model scenario and frequency range		Model type	n or α	β	γ	σ
UMi Street Canyon in [7] Frequency range: 2-73.5 GHz	LOS	FI	2	31.4	2.1	2.9
		CI	2	–	–	2.9
	NLOS	FI	3.5	21.4	1.9	8.0
		CI	3.1	–	–	8.1
UMi Street Canyon in [5] Frequency range: 2-86 GHz	LOS	FI	1.92	32.9	2.08	2.0
	NLOS	FI	4.5	31	2.0	7.82
UMa in [5] Frequency range: 2-73.5 GHz	LOS	FI	2.8	11.4	2.3	4.1
	NLOS	CI	2.7	–	–	10

Table 2

Model scenario and frequency range		Model type	n or α	β	γ	σ
Indoor in [5][2] Frequency range: 2-86 GHz	LOS	FI	1.38	33.6	2.03	1.18
	NLOS	FI	3.69	15.2	2.68	8.03
InH Indoor Office in [6] Frequency range: 2-73 GHz	LOS	CI	1.73	–	–	3.02
InH Shopping Mall in [6] Frequency range: 2-73 GHz	LOS	CI	1.73	–	–	2.01

where σ^{FI} and σ^{CI} are the standard deviation of path loss (i.e., shadowing fading term) in FI and CI models, respectively. The parameters α, β and γ in Eq 1 are the path loss decay component, FI path loss at $d = 1\,\mathrm{m}$, and the frequency dependency coefficient, respectively. The term γ is dismissed in Eq 1 when a single frequency is modeled. In Eq 2 FSPL(f_c, 1m) is the free-space path loss at $d = 1\,\mathrm{m}$, and n is the path loss exponent. Table 1 and Table 2 present the curve-fitting omnidirectional path loss model parameters using FI and CI models. These are obtained from numerous measurements and ray-tracing simulations in outdoor and indoor

The End to End Mobile Network