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Spectrum Fundamentals:

Knowledge Sharing with South Africa

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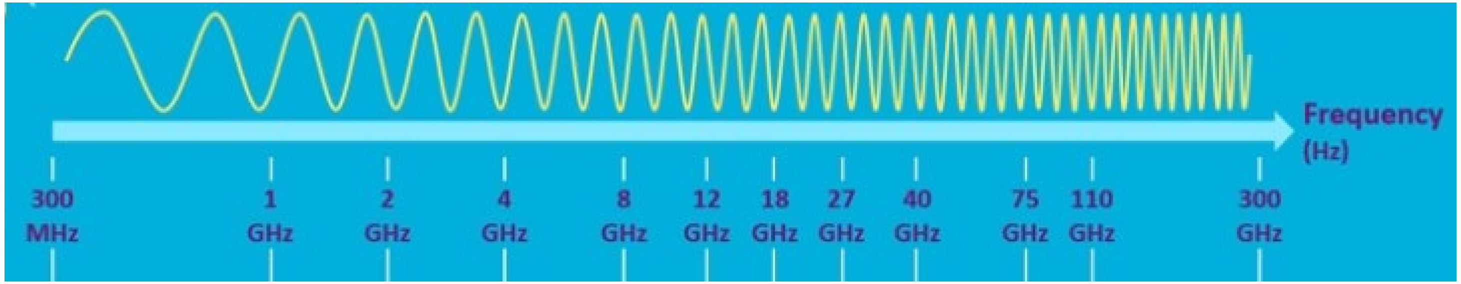
Introduction

- Spectrum is the core component of wireless communications.
- It is a <u>finite quantity</u> and needs to be utilized more effectively.
  - "Spectrum Scarcity" is a known issue and yet it is often misunderstood.
- The demand for mobile data—past, present, and projected—continues to grow, and licensed, exclusive use spectrum will be critical to meeting that demand.



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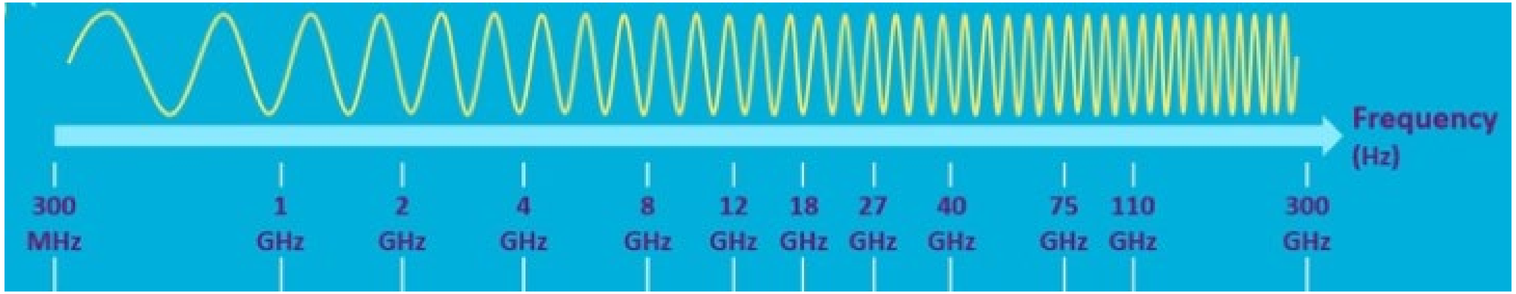
Introduction

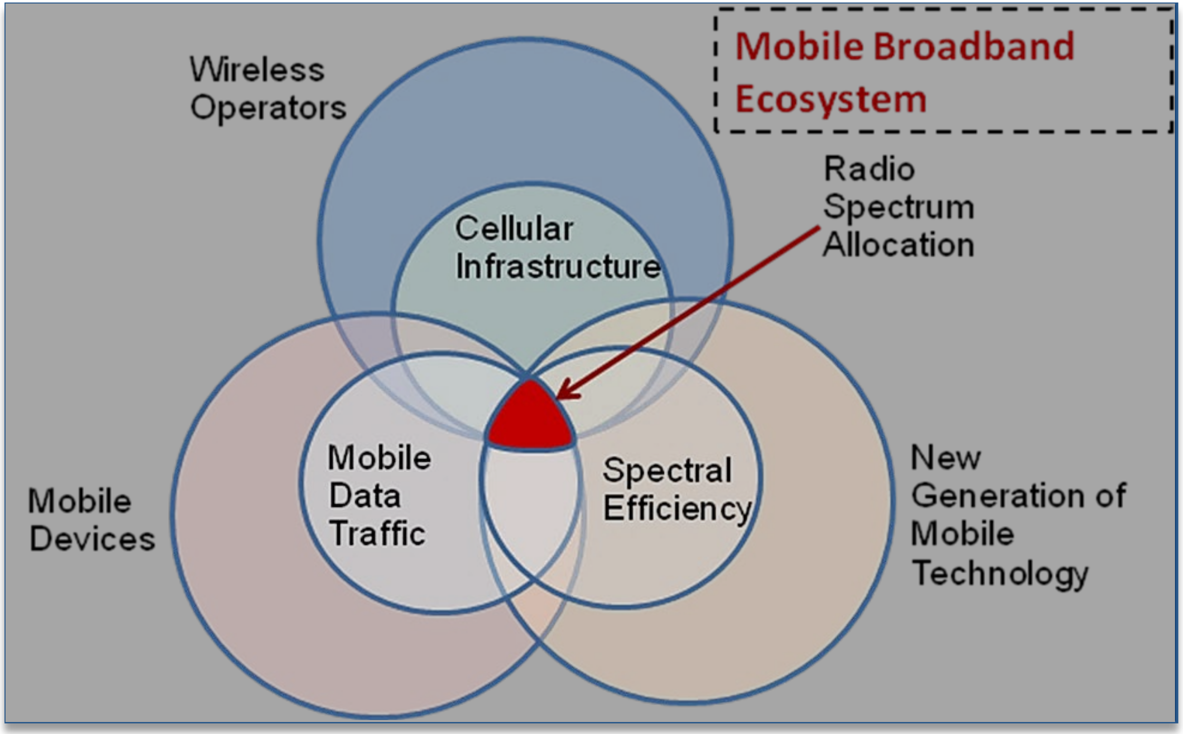
- All the benefits of 5G such as smart cities, telemedicine, Internet of Things, agricultural advancements, etc. depend on the availability of spectrum.

- This talk will provide an overview of key aspects of spectrum bands –
  - Properties, Coverage vs Capacity, Propagation issues
  - Knowledge sharing of US auctions and allocation
  - future-readiness.

- Different types of spectrum bands (low-band, mid-band, and mmWave) are also summarized.



Mobile Broadband Eco-system



Spectrum is essential for Mobile Broadband Eco-system.

Three key elements that rely on spectrum:

1. Wireless Operators
2. Mobile Devices
3. New Generation of Mobile Technology

Source: Thakker, R., Eveleigh, T., Holzer, T., & Sarkani, S. (2013).

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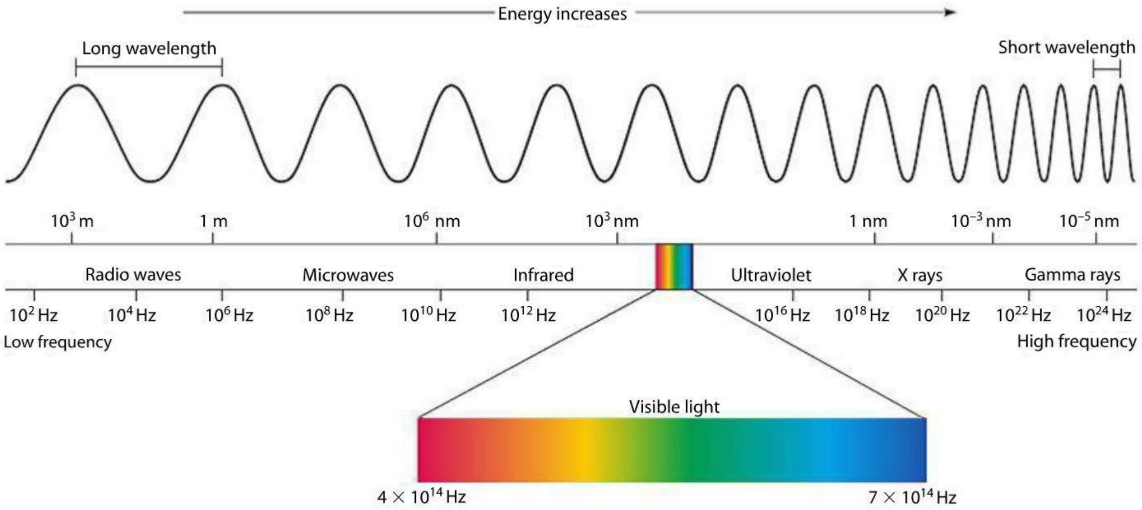
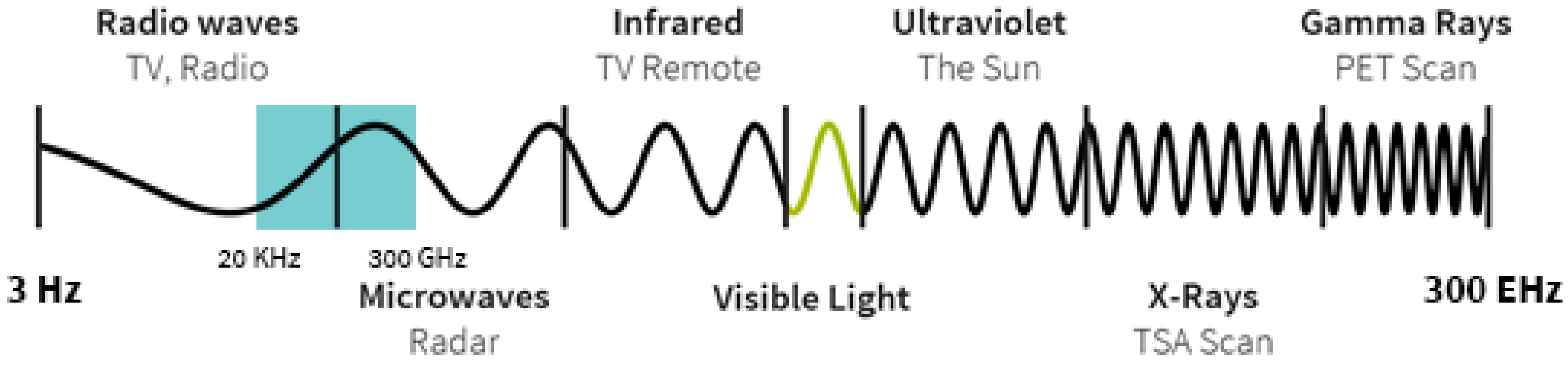
What is "Spectrum"?

- Remember – ROYGBIV? That's the acronym for the colors that make up the visible part of spectrum—the spectrum we see.
- For wireless comms, it is the radio frequencies that wireless signals travel over.
- Spectrum is the "lifeblood of wireless networks".
- The frequencies we use for wireless are only a portion of what is called the electromagnetic spectrum.
- Electromagnetic spectrum also carry other signals such as broadcast radio and television.



Electromagnetic Spectrum

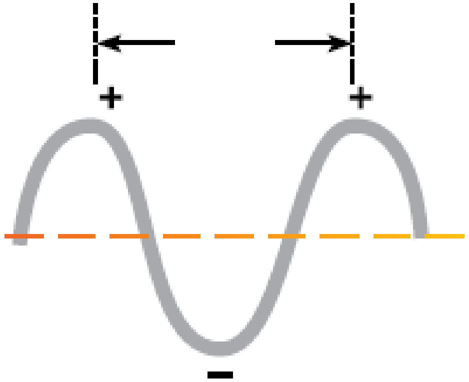
- Portions of electromagnetic spectrum are grouped in “bands” depending on their wavelengths—the distance over which the wave’s shape repeats.
- The full electromagnetic spectrum ranges from three Hz (extremely low frequency) to 300 EHz (gamma rays).
- The portion used for wireless communication sits within that space and ranges from about 20 KHz to 300 GHz.

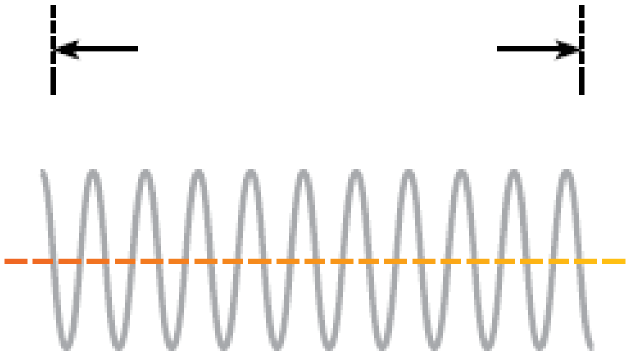


Source: CTIA

Frequency (a little physics)

All electromagnetic waves travel at a constant speed - the speed of light - 30 billion cm, per second





Radio waves oscillate, or flip back and forth, between plus and minus at a predictable rate.

Each complete flip is called a “cycle”. A cycle completes itself traveling from plus to minus back to plus.

The number of cycles in one second gives the frequency. How “frequently” the signal oscillates in one second.

10 cycles here in one second. Frequency is 10 Hertz (Hz)

Wavelength (a little more physics + math)

The distance the signal travels while completing one full cycle is called Wavelength.

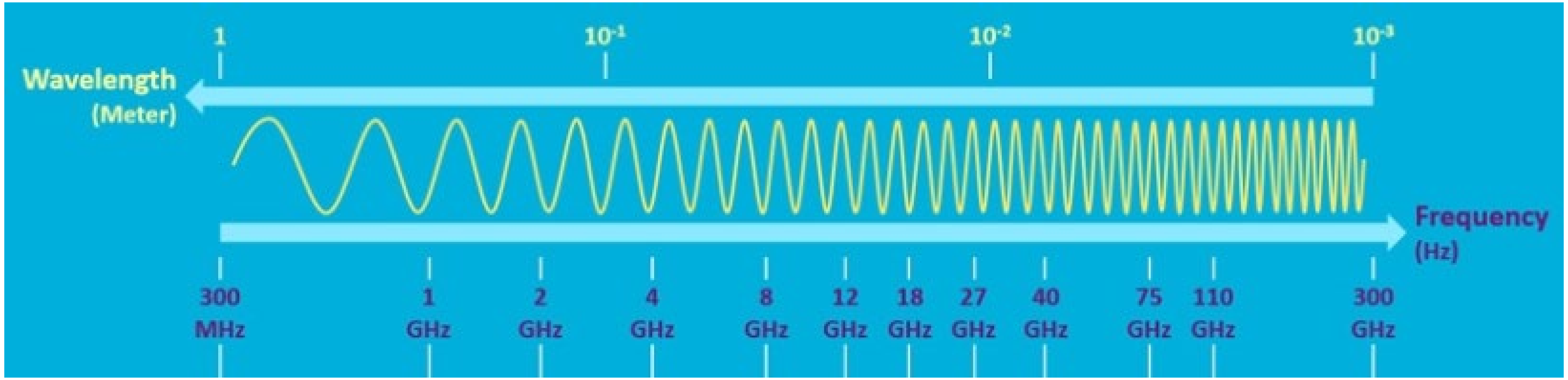
Since it is distance, it is measured in feet, inches, centimeters, millimeters

The speed divided by the frequency gives the distances the wave travels in one cycle.

$\lambda = c / f$

c = Speed of Light

f = Frequency of the wave



Units of Frequency

- Radio frequencies are measured in hertz, kilohertz (kHz), megahertz (MHz), and gigahertz (GHz).
- One gigahertz is a wave that cycles one billion times more per second than a one hertz wave.

hertz	kilohertz	megahertz	gigahertz
a 1 Hz wave is 300,000 km long	a 1 kHz wave is 300km long	a 1 MHz wave is 300m long	a 1 GHz wave is 30cm long

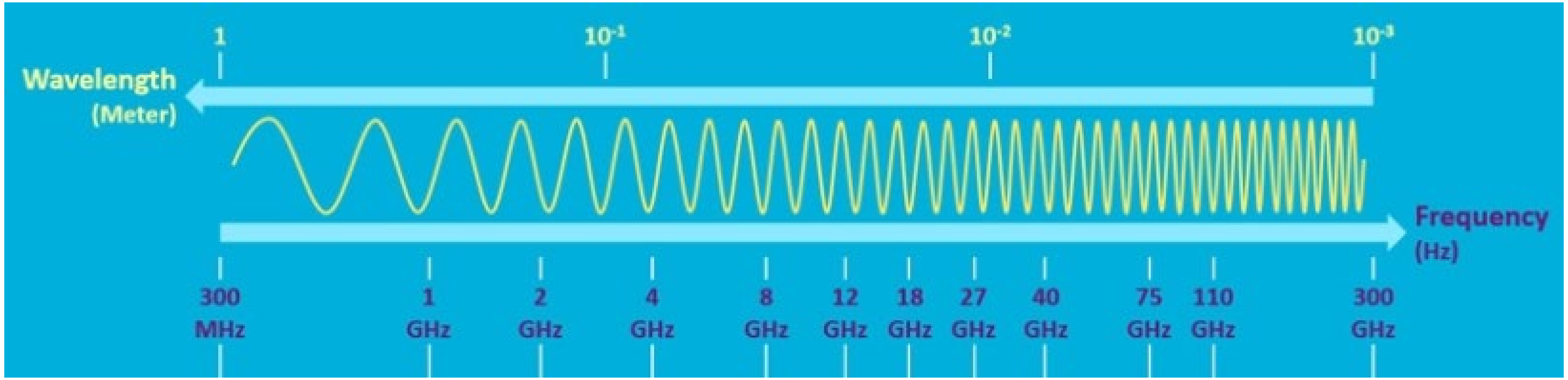
1,000,000,000 Hz = 1,000,000 kHz = 1,000 MHz = 1 Ghz

mmWave Bands: the wavelength ranges from 1 millimeter to 10 millimeters

Spectrum and RF Principles

- The higher the frequency, the smaller the wavelength.
- A higher frequency signal (smaller wavelength) will not travel as far as the lower frequency signal (larger wavelength).
- An RF signal with a smaller wavelength will attenuate faster. The higher the frequency, the less it will penetrate through obstructions.
- The higher the amplitude of wave, the more powerful the wave is and the farther it will travel.

These principles are why 5G needs different spectrum for different things



Spectrum: A finite resource

- Spectrum and cellular networks' capacity to handle more data services go hand in hand:
  - The greater the amount of spectrum assigned to each cell, the greater the speed of data services supported by the cellular networks.
- Spectrum is a finite resource, and we cannot make more of it.
- The good news is that spectrum can be repurposed.
- In the US: Regulation and legislation can help identify bands that the government should reallocate for commercial use.
- South Africa: recent spectrum auctions

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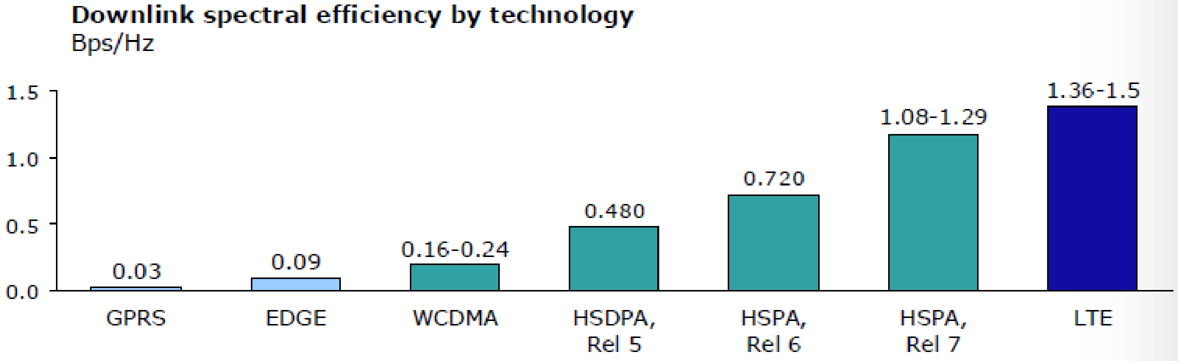
Spectrum and Capacity

To Understand Why Additional Spectrum is So Crucial, One Needs To Understand How Spectrum is related to Capacity

The total capacity an operator has for mobile broadband depends on how much spectrum the operator has and the distribution of cell sites.

More cell sites mean fewer people must share the radio channel, since that radio channel is servicing a smaller area.

The generation of mobile technology also affects the system capacity: more advanced tech serves more users faster



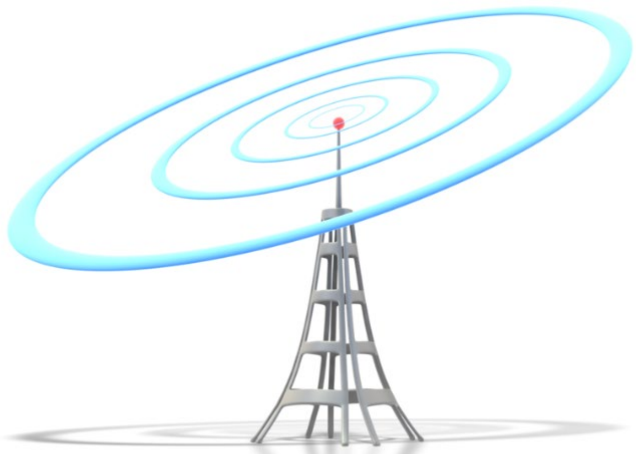
Spectrum Efficiency in Bps/Hz

Source: FCC

How Spectrum Works: Coverage Vs. Capacity

Propagation: How far radio waves travel and their penetration through walls and buildings.

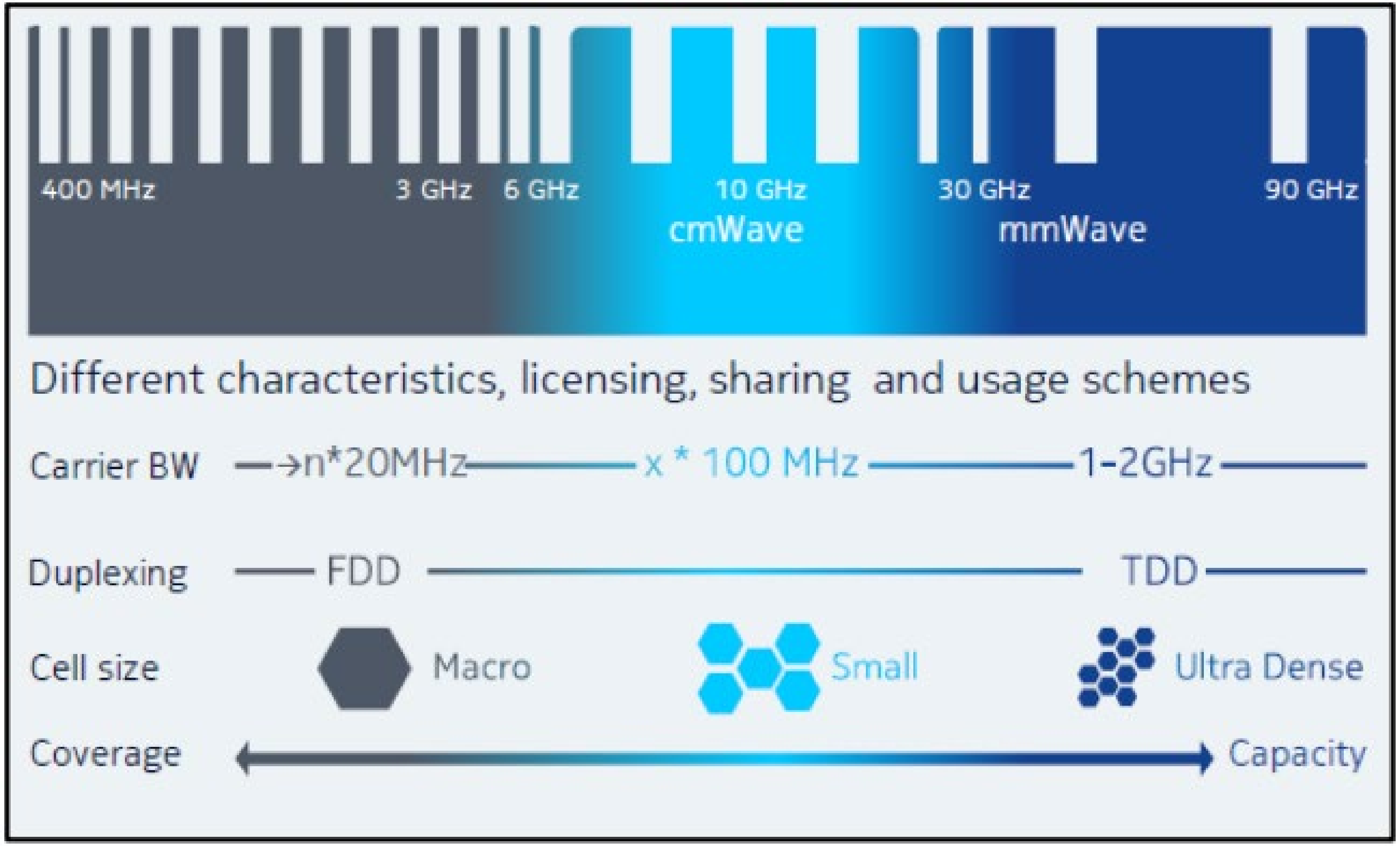
- The lower the spectrum, the better the propagation.
- Lower frequencies can easily travel and penetrate walls.



Capacity: The amount of data that can be carried with a certain bandwidth (a.k.a. channel) – e.g. 20 MHz of LTE channel.

- Greater bandwidth is generally available at higher frequencies.
- Capacity can also be increased by adding additional cell sites.
- Frequency reuse concept with small cells.
- Radio waves don't travel as far with higher frequencies; the spectrum can be reused more often.

How Spectrum Works: Coverage Vs. Capacity



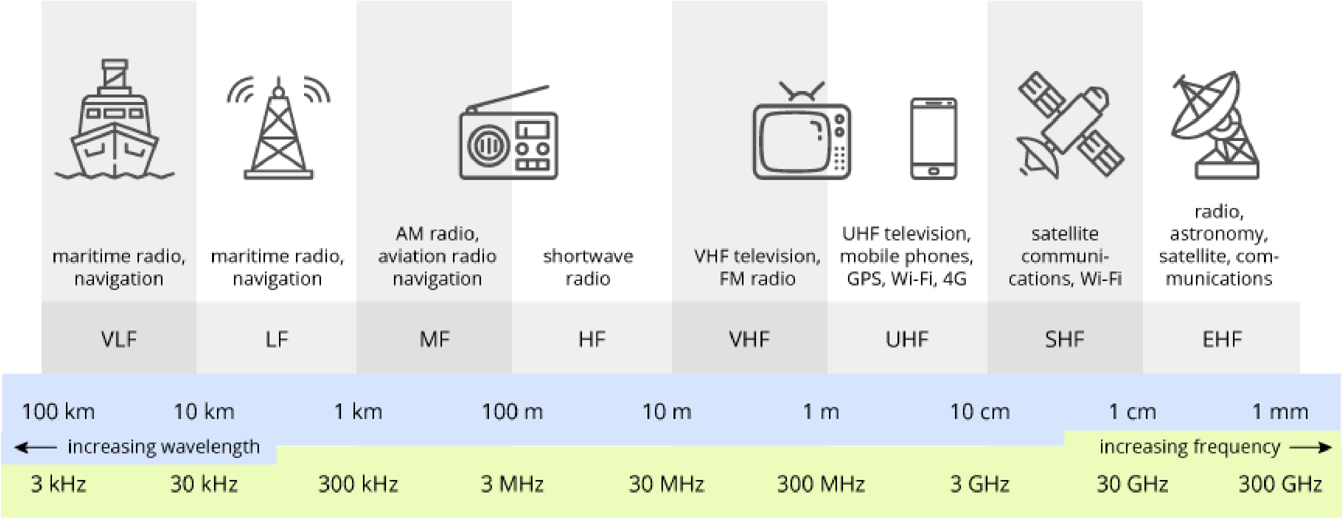
Source: Nokia

Spectrum Regulation in the US

- All US spectrum governed by FCC or NTIA
- The Federal Communications Commission (FCC) oversees commercial spectrum allocation.
- The FCC works with the National Telecommunications and Information Administration (NTIA)—which oversees government use of spectrum—, and US Congress.
- FCC & NTIA work collaboratively with international bodies (ITU) to allocate spectrum bands.
- The FCC often allocates spectrum for commercial use often through a spectrum auction.

Bands for Spectrum

- Global Spectrum Management – Recommendations provided by the International Telecommunication Union (ITU)
- For the purposes of wireless communication, spectrum can be divided in three categories: low-band, mid-band, and high-band spectrum.
- In US: We need more of all three bands for robust cellular networks.
- Each band of spectrum is essential for a different kind of communication and use case.



In U.S. -
Lowest band for Mobile Communication in use
→ 600 MHz
Highest band for Mobile Communication in use
→ mmWave

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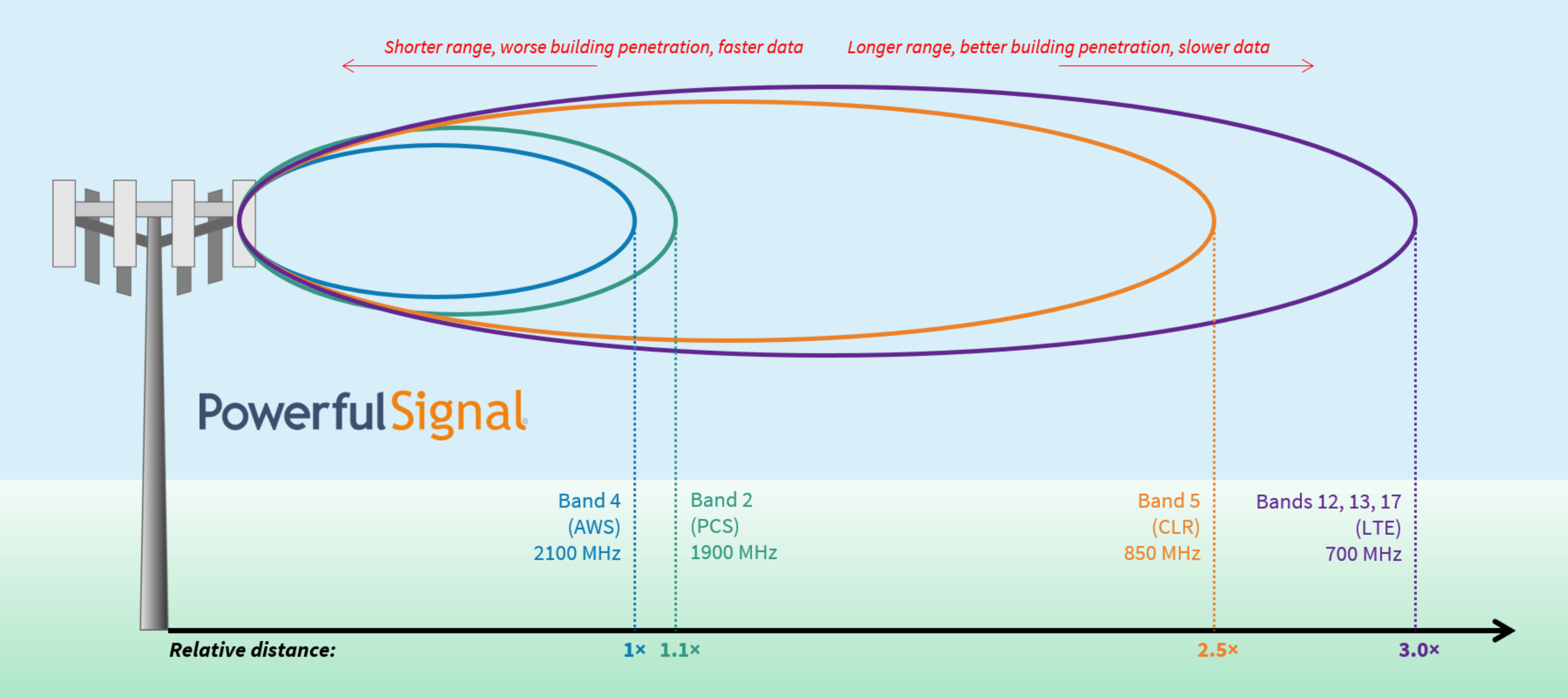
Frequency Vs. Coverage

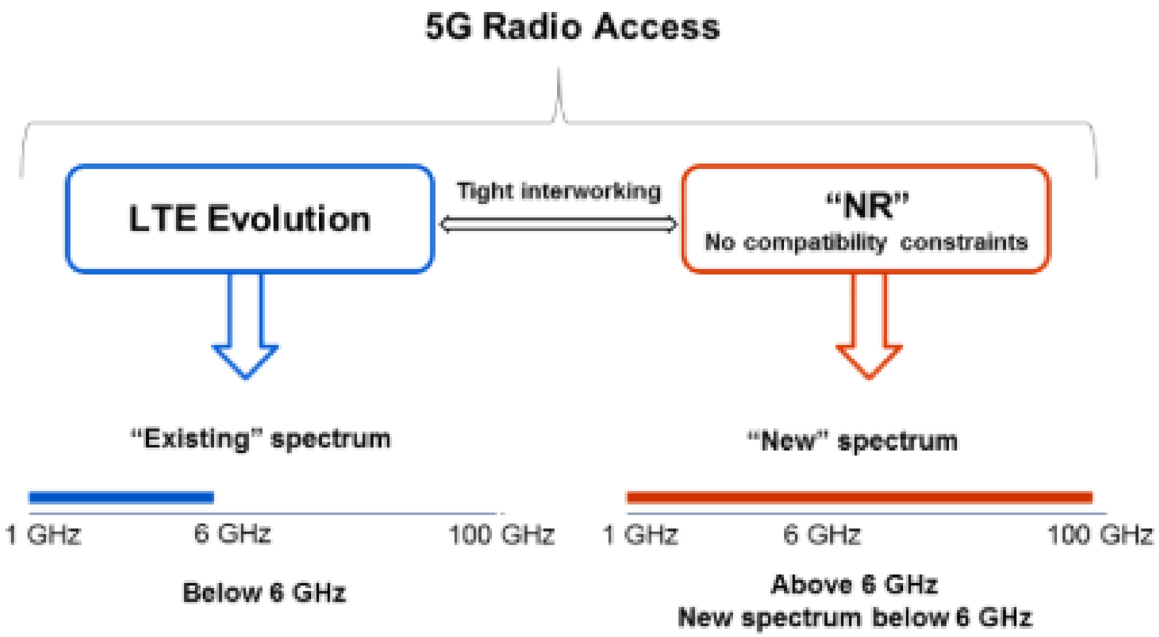


Source: Powerful Signal

4G Vs. 5G – Spectrum Perspective

4G was deployed below 3GHz

5G use-cases need spectrum at low, mid, and high bands



Low-band

In the US, the wireless industry used this spectrum to build high-speed wireless networks that cover 99.7 percent of Americans.

In South Africa: 700/800, 900, IMT450, IMT850

Low-band (600 MHz to 2.5GHz):

Useful for wider coverage for 5G services

1G to 4G networks are built primarily on low-band spectrum.

Characteristics:

- Travels longer distances to provide better coverage
- Better in-building penetration
- Requires fewer towers to cover a given area
- Enables better in-building coverage
- Less contiguous spectrum available limits data capacity

High-band (a.k.a. mmWave bands)

Short range and near LOS requirement necessitates very dense small cell networks: “personal sites”

US has use cases for this. “Your mileage may vary”

High-band (24GHz and above): In the US:

The first 5G spectrum auction was held in the 28 GHz band followed by 24 GHz. With the auction of 37 GHz, 39 GHz, and 47 GHz bands, FCC released almost 5 gigahertz of 5G spectrum into the market—more than all other flexible use bands combined.

Characteristics:

- Operates on line-of sight (LOS) only due to substantial transmission losses
- Significantly higher transmission speeds due to wider available bandwidth
- Extremely limited ability to penetrate objects or buildings
- Spectrum typically sold in large blocks; greatly increasing data capacity in networks

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Mid-band

In US:
CBRS:
- "Innovation" band

C-Band:
- refarmed from satellites

In South Africa:
3500 MHz
3700 MHz

Mid-band (2.5 GHz to 6 GHz):

Blends the characteristics of both low- and high-band spectrum—providing a mix of coverage and capacity.

Characteristics:

- Travels shorter distance due to greater transmission losses, requiring denser networks.
- Shorter transmission distance limits interference with other sites, helpful for urban areas.
- Requires a denser network "grid": i.e. more sites.
- More adjacent spectrum is available, providing capacity in traditional networks.
- Good for Metro Cells

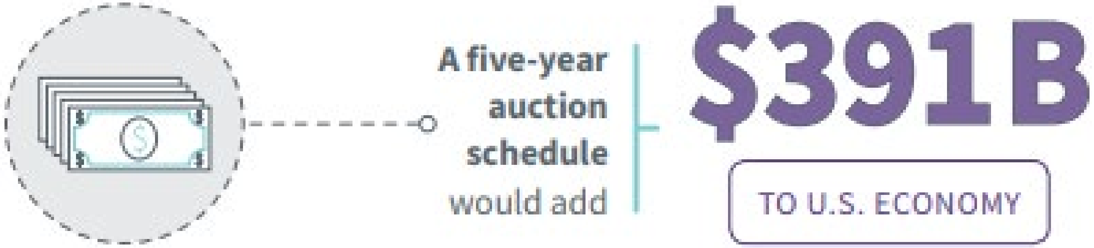
US Spectrum Auction History

To secure the legal right to use parts of the RF spectrum in a particular market:

- Apply to the FCC for a license to use specific frequencies OR
- Participate in a spectrum auction managed by the FCC. (usual case for cellular)

Since the first spectrum auction in 1994, auctions contributed over $116 billion to the U.S. Treasury through investment in spectrum licenses (as of May 2019)

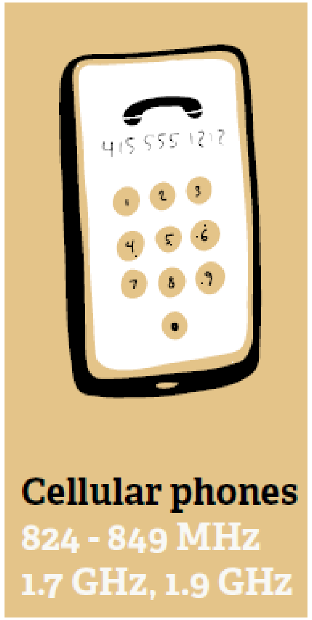
- 28 GHz (2018) raised more than $700 million
- 24 GHz (2019)
- 37, 39, 47 GHz
- CBRS (2020)
- C-Band (2021)



Licensed Vs Unlicensed

Licensed - it is bought for exclusive use by specific providers

Unlicensed - anyone can use the frequency.



In the US, The FCC has set aside spectrum for both.

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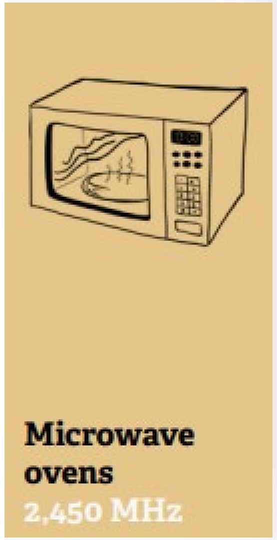
Fun Facts

- The frequency 2.4 GHz is set aside by the Federal Communications Commission as a narrow part of the spectrum that most consumer electronics occupy.
- Engineers call it "junk spectrum." (Read Unlicensed)
- It's the frequency that vibrates water molecules, which is why microwave ovens use the same frequency.
- In some homes and offices, a re-heated lunch may make a Skype call drop on a Wi-Fi signal.



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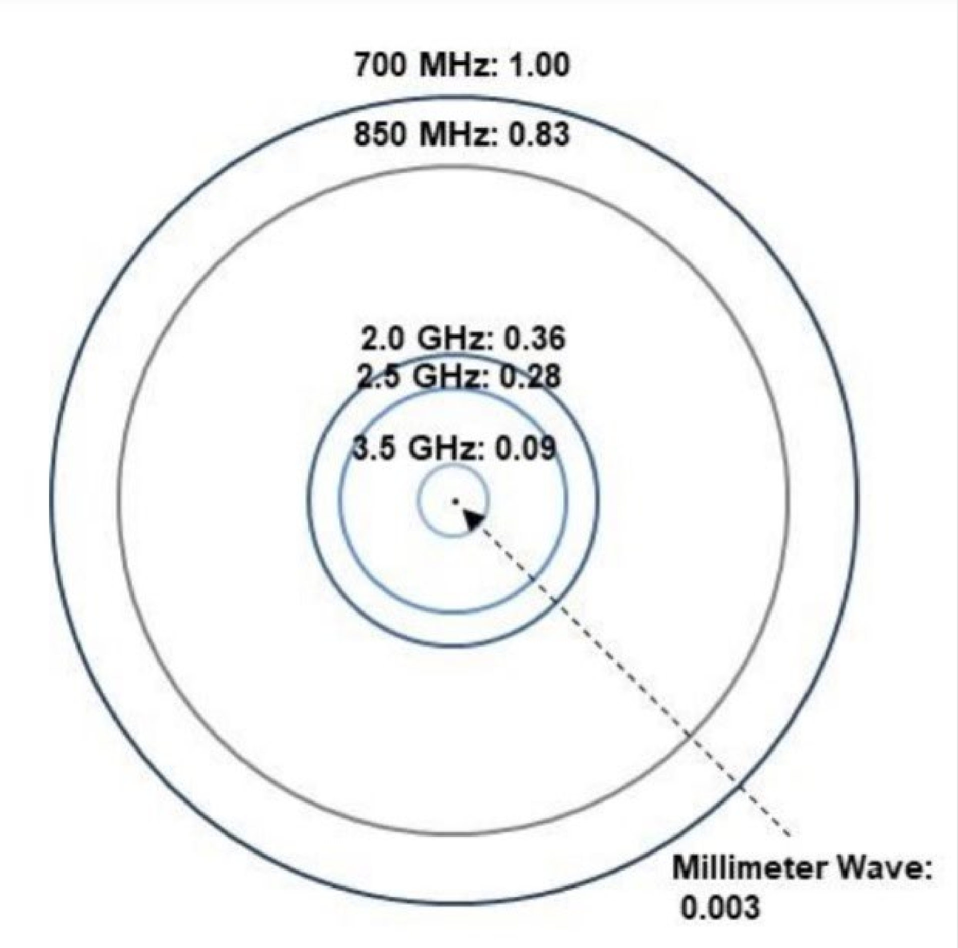
Impact of Spectrum on Wireless Infrastructure

How far a signal will travel, or propagate, in different spectrum bands without any interference from other signals or objects like buildings.

- ➢ Spectrum bands determine # of cell sites needed



Source: MoffettNathanson

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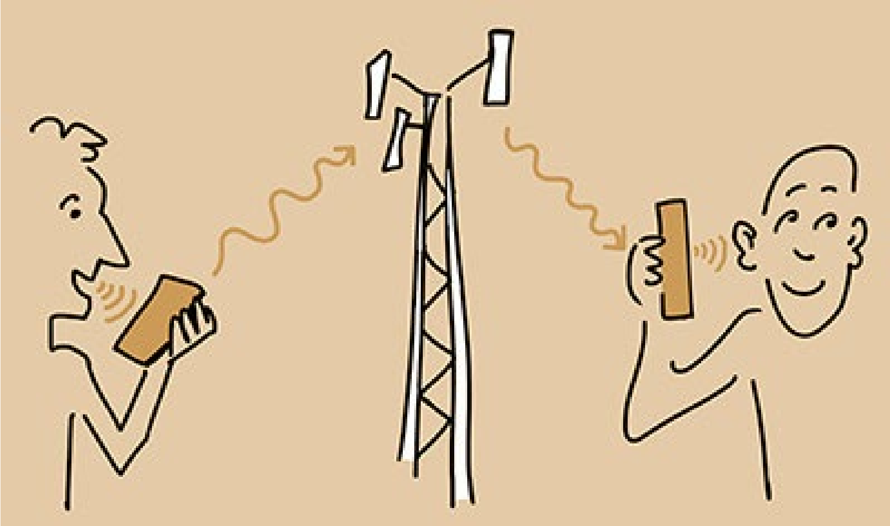
Impact of Spectrum

- Making available additional spectrum has the potential to unleash substantial economic benefits.
- As per Recon Analytics, an additional 10 MHz of licensed spectrum in the US is estimated to increase
  - U.S. GDP by $3.1 billion
  - U.S. employment by approximately 105,000 jobs



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Resources

- FCC 5G/Spectrum Website - https://www.fcc.gov/5G
- Auctions by the FCC - https://www.fcc.gov/auctions
- C-band Spectrum Updates and Charts - https://www.lightreading.com/5g/c-band-auction-maps-and-charts-who-won-what-where-and-how-much/d/d-id/767682
- Radio Frequency Bands - https://terasense.com/terahertz-technology/radio-frequency-bands/
- NTIA Spectrum Chart - https://www.ntia.doc.gov/files/ntia/publications/january_2016_spectrum_wall_chart.pdf

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Thank You

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