Lecture 8: The Physical Layer

How do point-to-point links work?

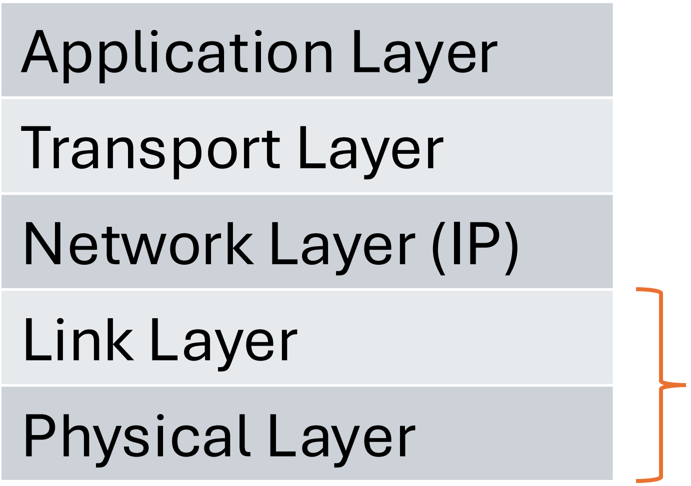
Lecturer: Venkat Arun

Chapter

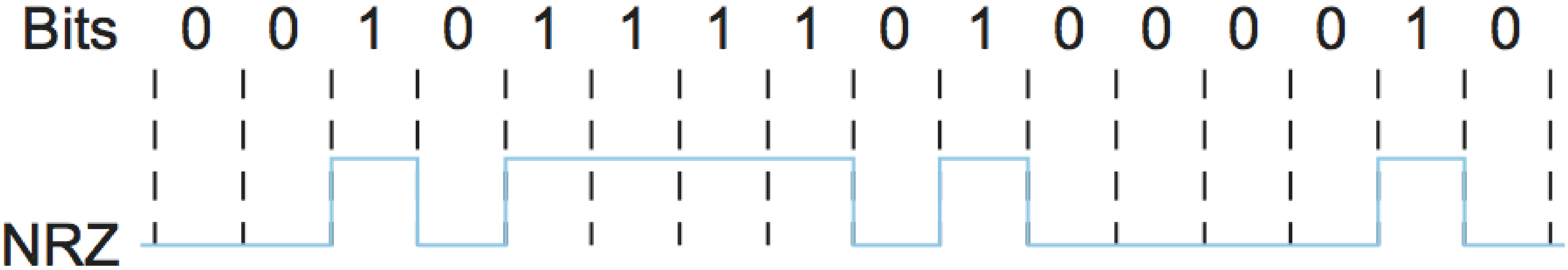
Recap

- So far, we have been studying routing, which tells the “network/internet layer” how to route packets by filling its forwarding table
- For the next several lectures, we will come back to the layered architecture of the internet, and work our way slowly upwards starting from the physical layer

Rough approximation of the layers of the internet



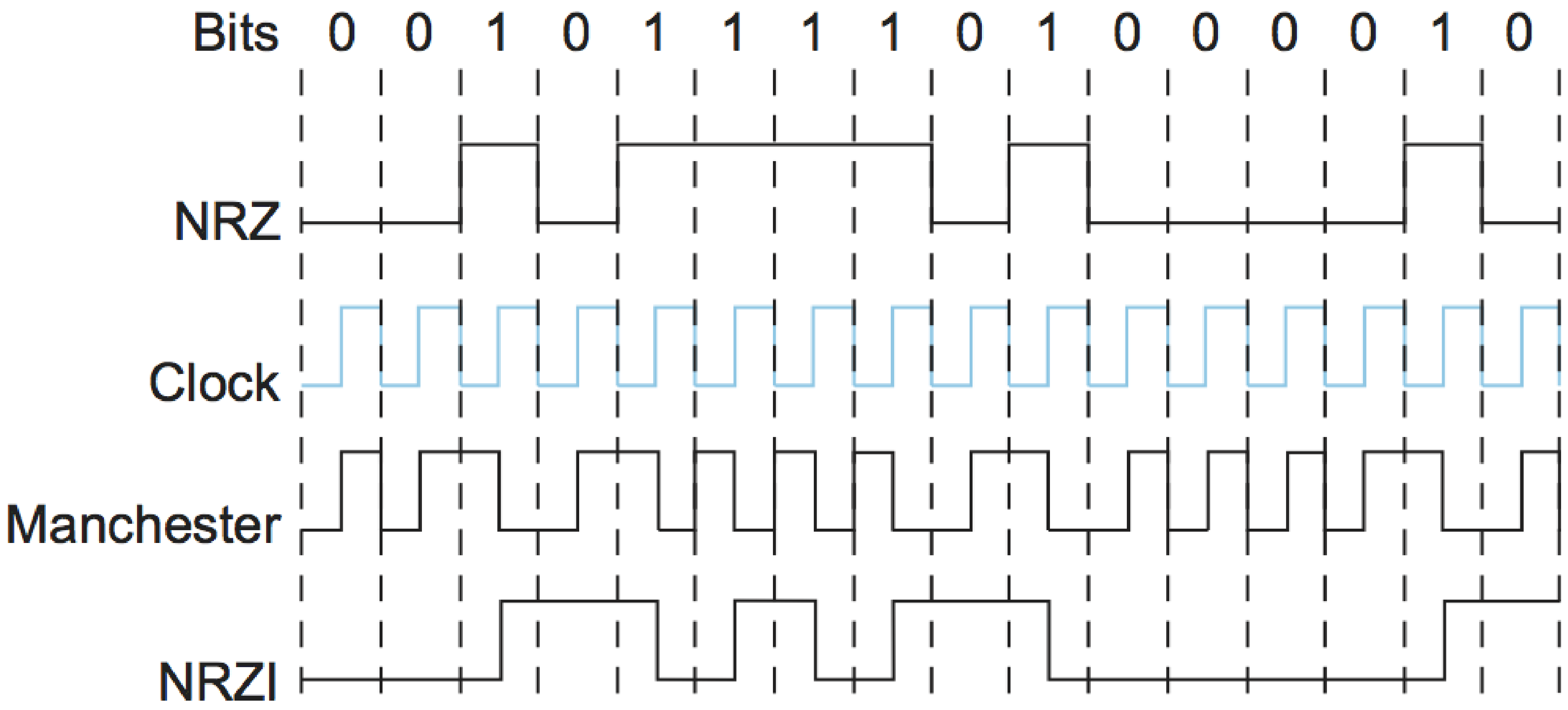
Data encoding strategy (chapter 2.2)



NRZ: High value represents 1, low value represents 0

Problem: Clocks become de-synchronized if there is a very long list of 1s or 0s

Data encoding strategy: Manchester encoding



Manchester: Equal to (NRZ XOR clock)

Solves the clock-sync problem, but the final signal varies twice as fast as the original

Baud rate

The rate at which the signal varies (number of flips/second)

For any encoding, increasing the baud rate increases the bandwidth. Should we increase it to infinity?

Your intuition probably says no. The precise reason is out of scope of this course, but I will explain a little in class

Data encoding strategy: 4B/5B

Replace every 4-bit sequence with a 5-bit sequence that has at least one bit-flip

Each one has no more than one leading 0 and no more than two trailing 0s

80% efficiency + some error detection

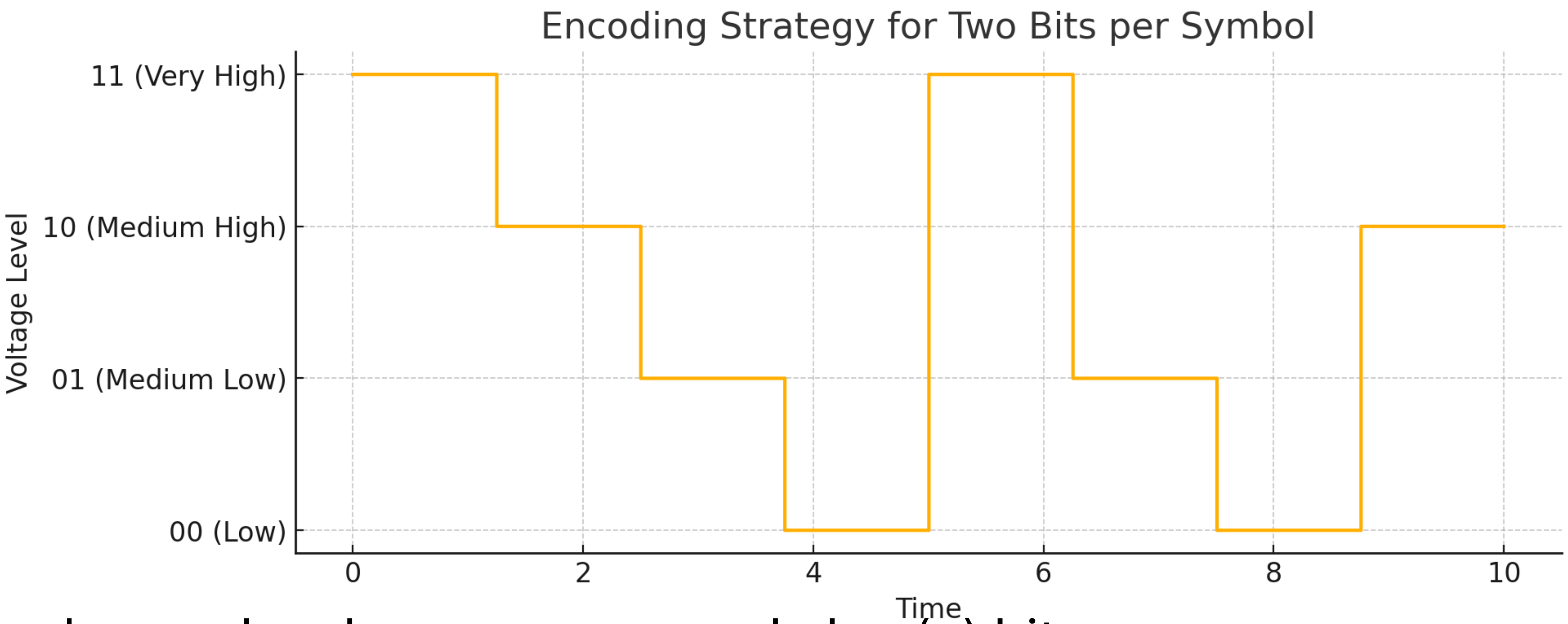
4-bit Data Symbol	5-bit Code
0000	11110
0001	01001
0010	10100
0011	10101
0100	01010
0101	01011
0110	01110
0111	01111
1000	10010
1001	10011
1010	10110
1011	10111
1100	11010
1101	11011
1110	11100
1111	11101

Instapoll

Fundamental capacity of a link

(not in book)

Encoding multiple bits per symbol



If you have n levels, you can encode log (n) bits

E.g. if the noise is ¼ the strength of the signal, you can have 4 levels

In general, you can encode log(SNR) bits, where SNR is the signal to noise ratio

Fundamental capacity of a link

Capacity = number of symbols/second * number if bits/symbol

= baud rate * log(SNR)

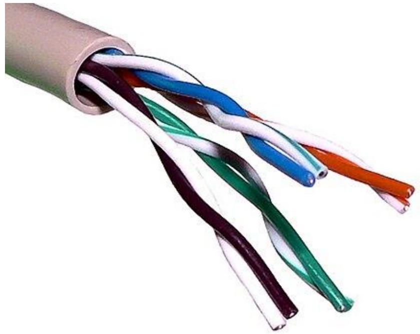
In general, baud rate is proportional to “bandwidth”, an EE term. While this is out of scope of this course, we will discuss briefly ion class.

It is important to understand that different physical limits have different amounts of bandwidth

Types of physical links

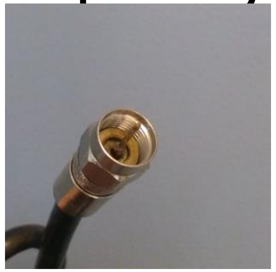
- Wired
  - Copper wires
    - Twisted pair
    - Coaxial cables
  - Optical fibers
    - Uni/multi-modal
- Wireless
  - WiFi
  - Cellular
  - Satellite
    - Low earth orbit (LEO)
    - Geostationary orbit (GEO)

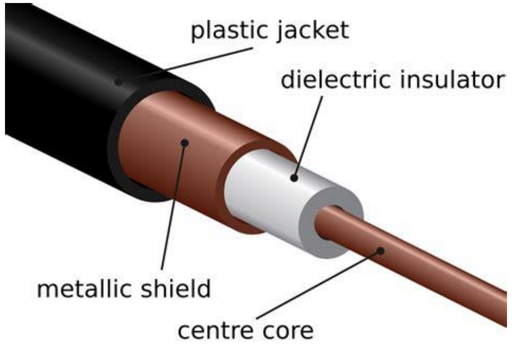
Wired physical layer media



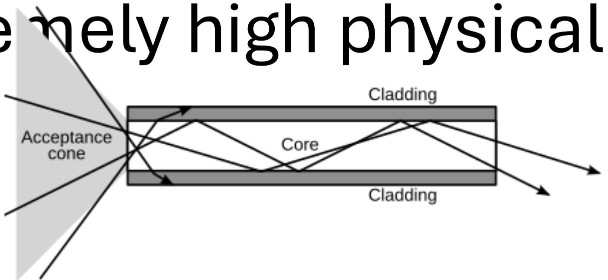
- Twisted pair – inexpensive, lower capacity (e.g. USB)

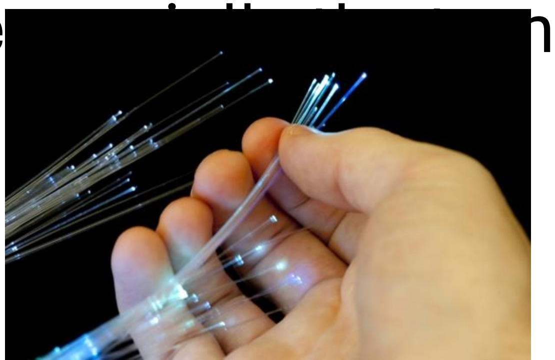
- Coaxial cable – more expensive, higher capacity
  - Why not any old wire? – out of scope, but we will in class





- Optical fiber – even more expensive, e[illegible]nsducers, extremely high physical bandwidth





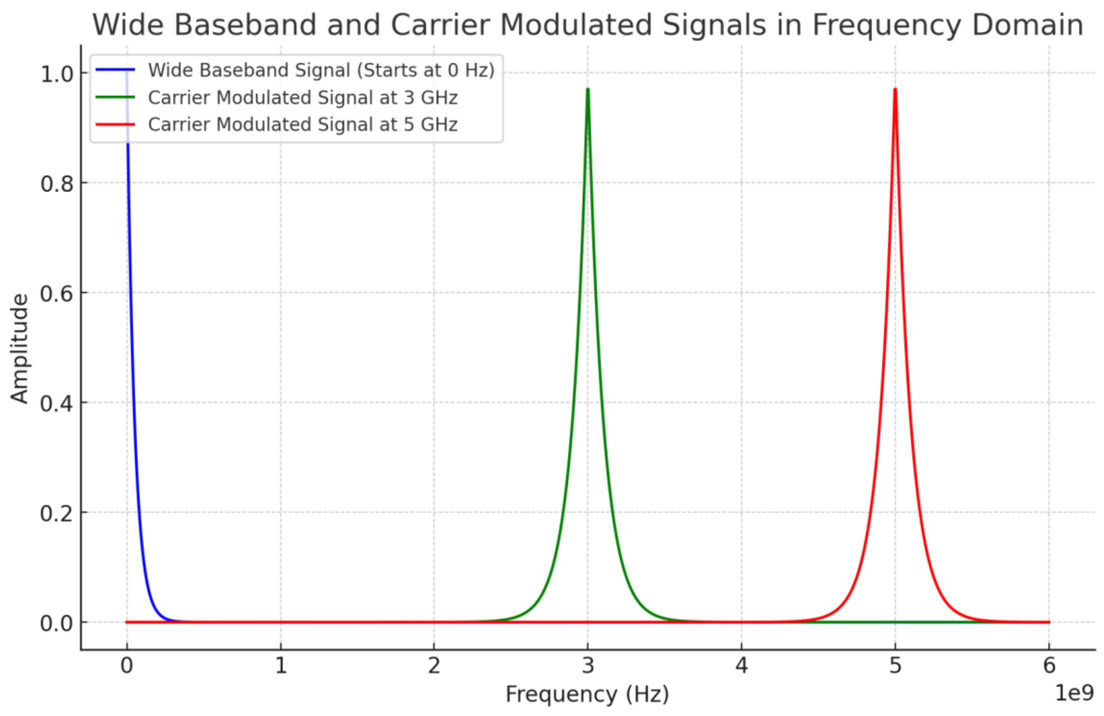
What limits the baud rate

- Transducer limit: How quickly the electronics can switch: usually limited to a few “giga-switches” a second (note, “giga-switch” is not a standard term)
- Physical medium limit: Whether the physical medium can accurately relay signals that vary that quickly

Baseband vs carrier-band modulation

Very approximately, when you take the fourier transform of an encoded signal, you get a peak that is as wide as the baud rate (in Hz)

You can create a “baseband signal” shown by the blue signal. However, sometimes the physical medium will not accept those frequencies, in which case you can “shift” them to higher frequencies that the medium will accept

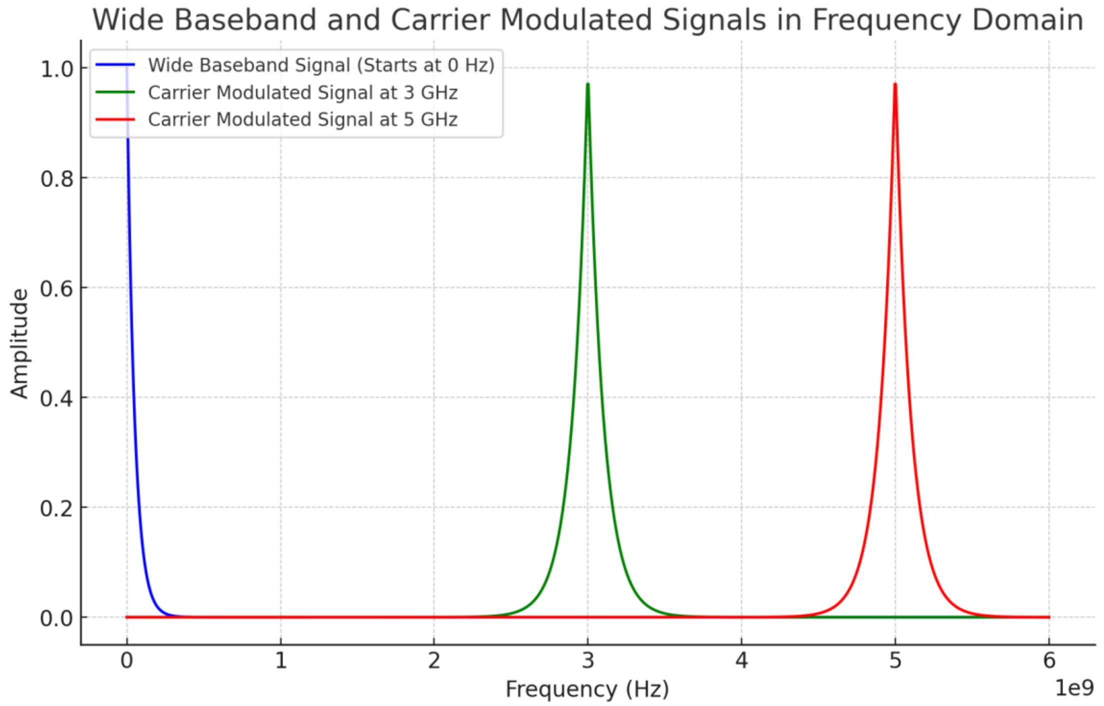


Baseband vs carrier-band modulation

Plus, this way, you can create multiple transducers that produce baseband signals encoding completely different sets of bits.

Then you can shift them by different amounts (green and red) and send both simultaneously

This way, you can overcome transducer limits by simply parallelizing among multiple transducers



Wireless links sharing the air

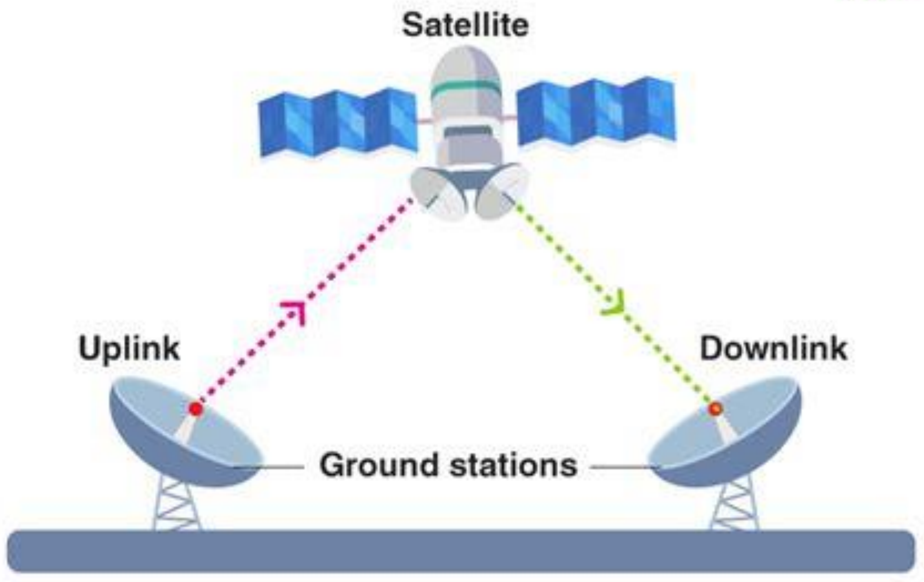
Wireless links such as WiFi and cellular networks need to share the same medium. Thus, if one pair of devices are transmitting, another pair that are close enough to be able to "hear" them, cannot transmit simultaneously

In practice, people allocate different "frequency bands" to different devices. Physics tells us that the frequencies will not mix. Thus they can transmit simultaneously

Sharing policy

- WiFi and Bluetooth
  - There is a portion of the spectrum that is allocated to WiFi
  - While the laws and exact frequencies vary by country, roughly speaking, any device can transmit at 2.4-2.5 GHz and 5-6 GHz.
  - These are called the **ISM** bands. As long as the transmission power is limited, any device may use them. Incidentally, this is why most microwave ovens use 2.4GHz
- Cellular Networks
  - Governments allocate rights to different companies. They say that “company X can transmit at frequency Y in zone Z”
  - These are usually allocated through auction
  - Most of the spectrum in the US is allocated for the military (80% I think)

Satellite communication



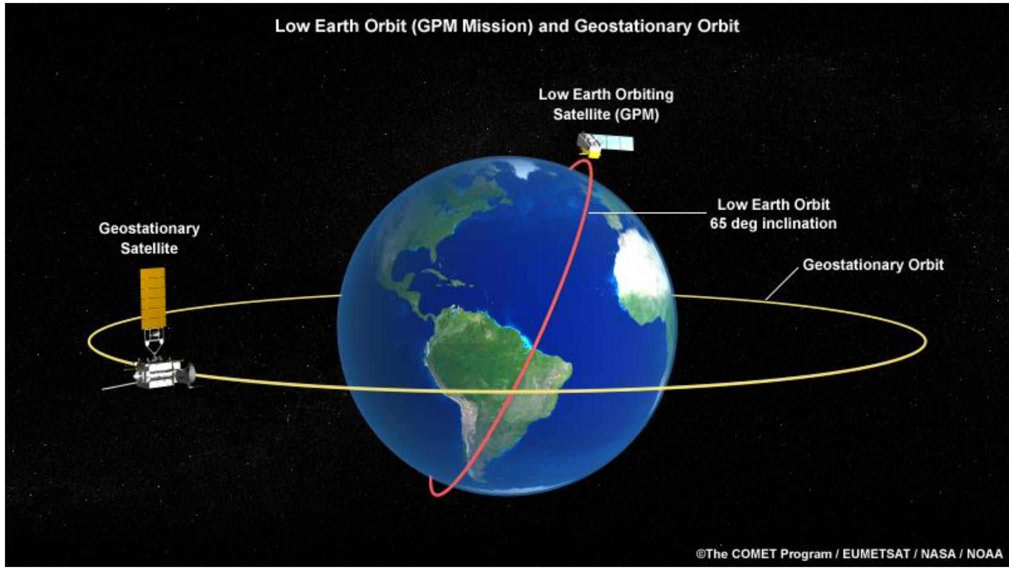
Conceptually straightforward.

Two main types:

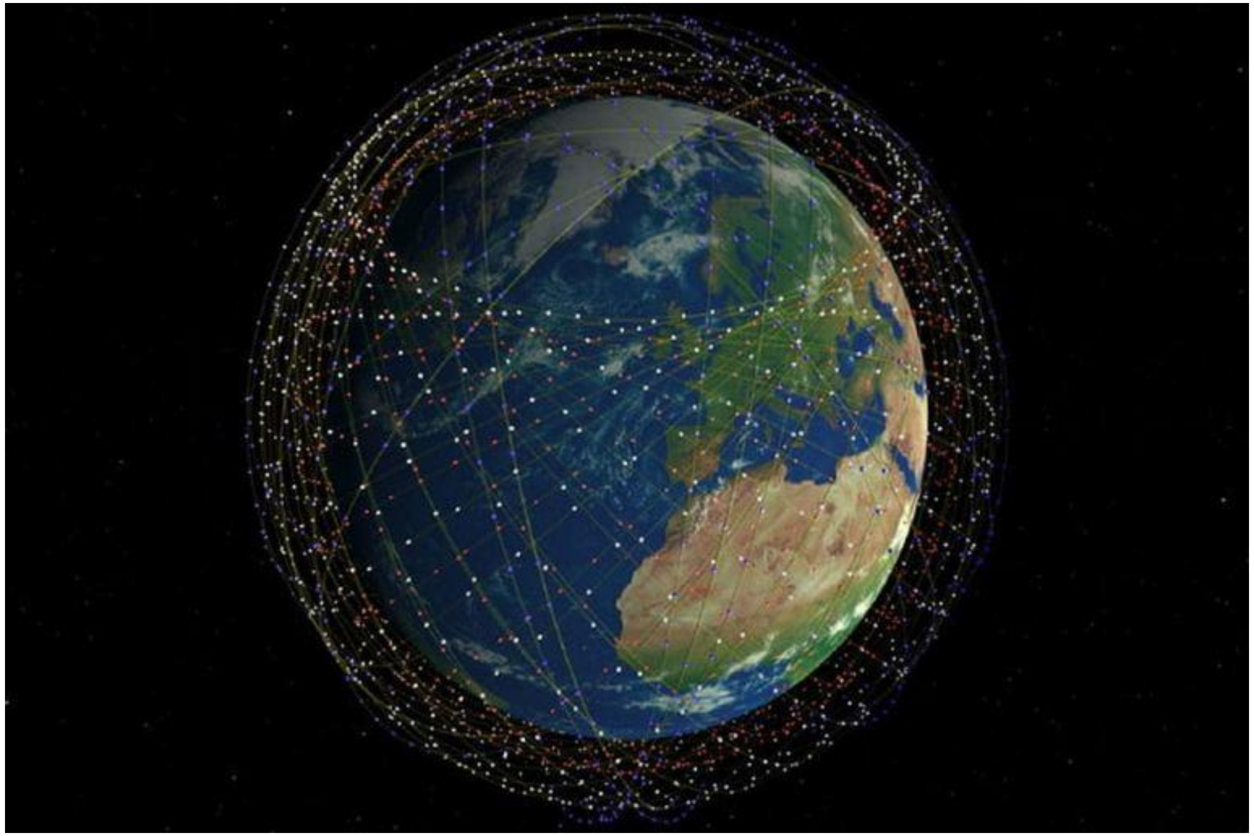
- geostationary satellites (old school)
- Low-earth orbit satellites (new school)

Satellite communication

- Geostationary orbit
  - Each satellite has a lot of range
  - Which means that the same bandwidth is shared across a large swath of the earth
  - Latency is much higher
- Low-earth orbit (LEO)
  - New trend, especially with lowering launch costs
  - Lower latency
  - Needs more satellites to cover the planet, but also means more capacity



LEO Satellites: new technology



Covers the entire planet with a low latency network that is also lower capacity compared to fiber network, primarily because of earth-to-space communication bottleneck