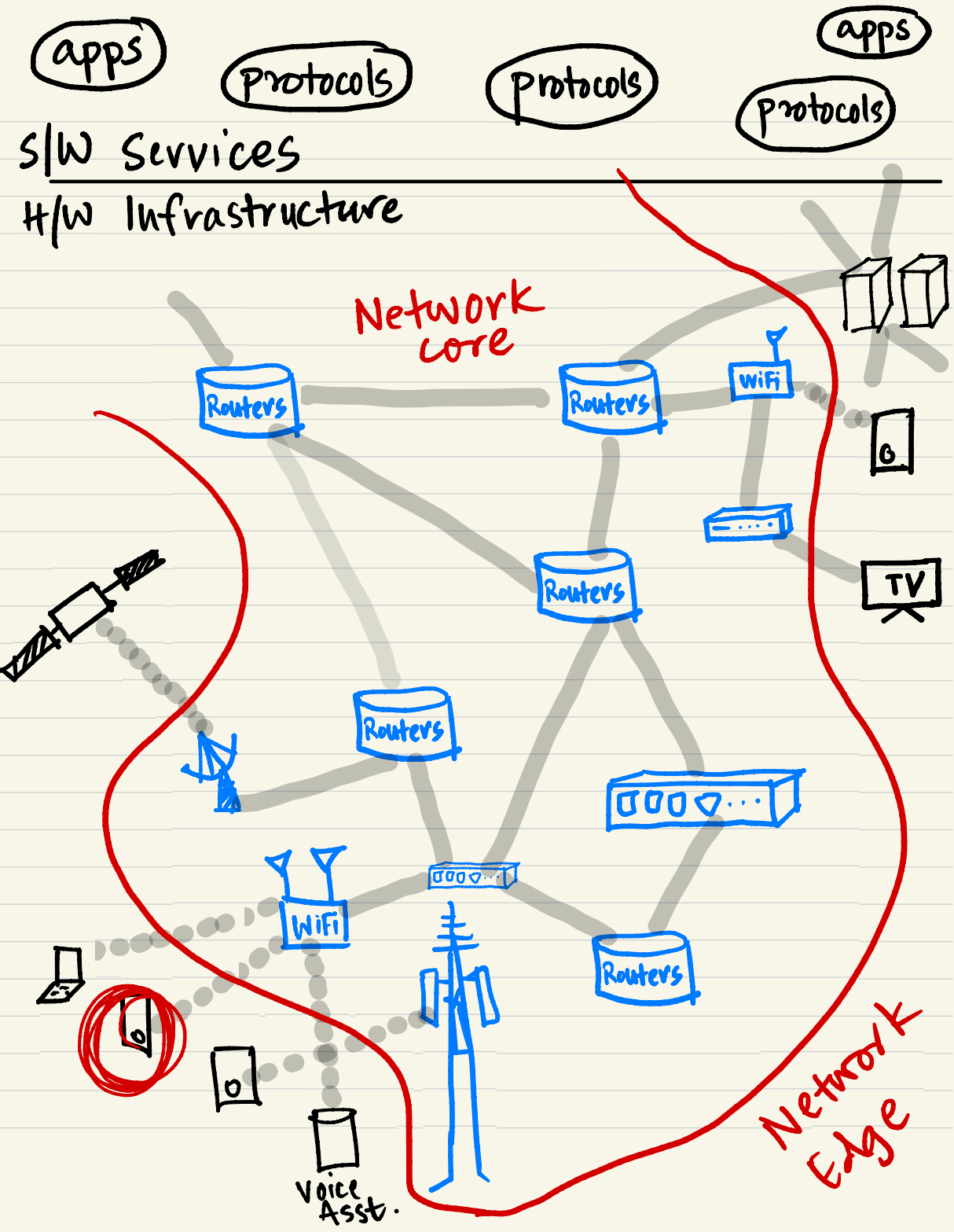

apps
Protocols
Protocols
apps
Protocols
S/W Services
H/W Infrastructure
Network core
Routers
Routers
WiFi
Routers
TV
Routers
Routers
WiFi
Routers
Voice Asst.
Network Edge

Keywords

- Devices, hosts, end-systems, nodes (includes satellites, servers...)
- Routers, switches (includes cell towers, WiFi, ground stations)
- Links (Backbone, access networks, last mile)

- Applications (Zoom, Web, Dropbox, whatsapp, email, DNS ...)
- Protocols (HTTP, TCP, IP, WiFi, OFDM)
  ↳ Internet standards, RFC, IETF

real life protocols analogy?

- Communication service
  ↳ ① Connection-less → Guarantees
  ② Connection-oriented → Best effort (somewhat unreliable)

real life road analogy

- Network Edge
  ① Client/server
  ② P2P
  ③ Hybrid
  → Network computing → Cloud, Fog, Edge
  → Links at the edge (Residential or institutional access networks, last mile networks)

  - Bandwidth
  - Data rate, bit rate
  - Bit error rate, packet error rate
  - Packet loss, congestion

  ① Dial up modem
  ② ADSL
  ③ Cable → cable network architecture
  ④ Wireless → WiFi / cellular / satellite

• Picture
• tradeoff

• Spectrum map

  - Wireless SNR, Shannon's law
  - Carrier frequency

- Network core
  - circuit switching (Deterministic)
    - Resource allocation / Call admission control
      - FDM
      - TDM
  - Packet Switching (stochastic)
    - Statistical multiplexing (Store & forward)
      - Datagram networks
      - Network with VCs

lot of coordinat°, dependencies

Problem to show equivalence

Airline sell more tickets

no guarantees

Numerical problem

(Differential queueing)

Discuss tradeoffs

show taxonomy picture

- Internet service Providers (ISPs)
  - Tier 1, 2, 3 ... hierarchical
  - Partnerships, peering
  - Geo-political, socio-economic factors

- Internet protocol stack
  - 5 Layers (app, transport, network, link, physical)
  - Encapsulation
  - Layering philosophy → horizontal
  - End to end principle

- show headers
- highlight eze layers, and local layers (net, link)

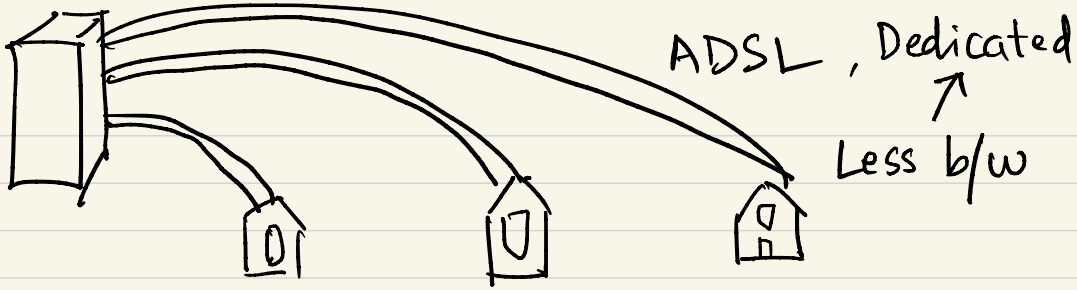
Is high tput ⇔ low latency?

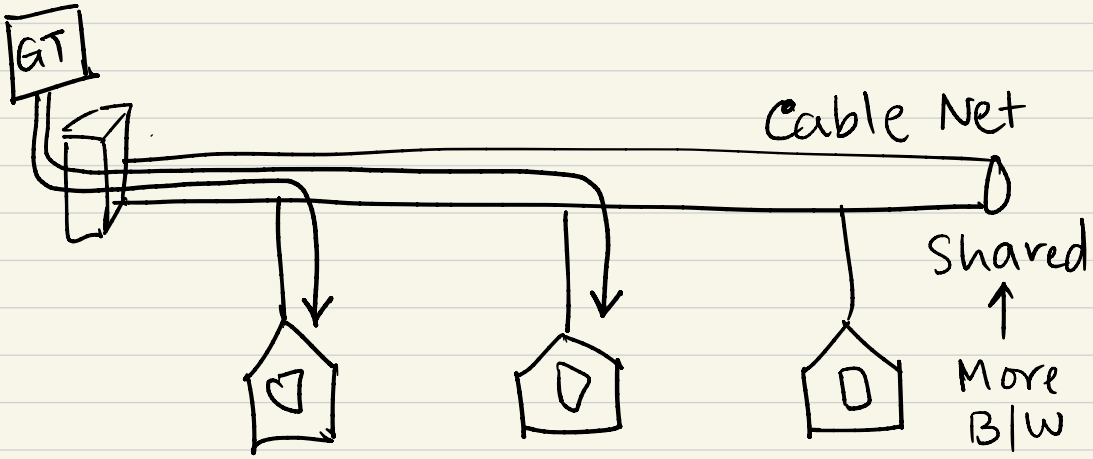
- Throughput, goodput
- Latency, delay
  - ↳ Processing, Queueing delay
  - ↳ Propagation delay, transmit time
- Avg. queueing delay vs. traffic intensity

Vacation analogy

- Real Internet delays
  - ↳ Traceroute

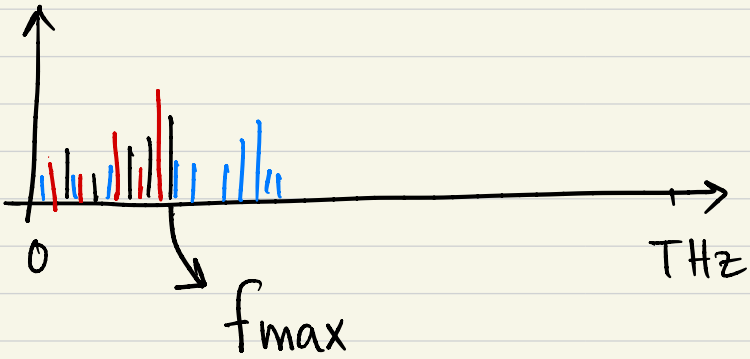
show on laptop

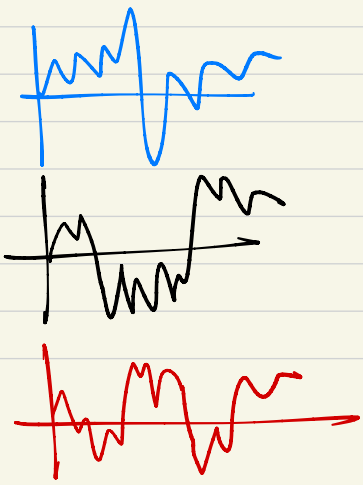




Multicast

Bandwidth



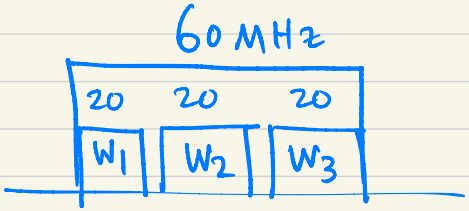


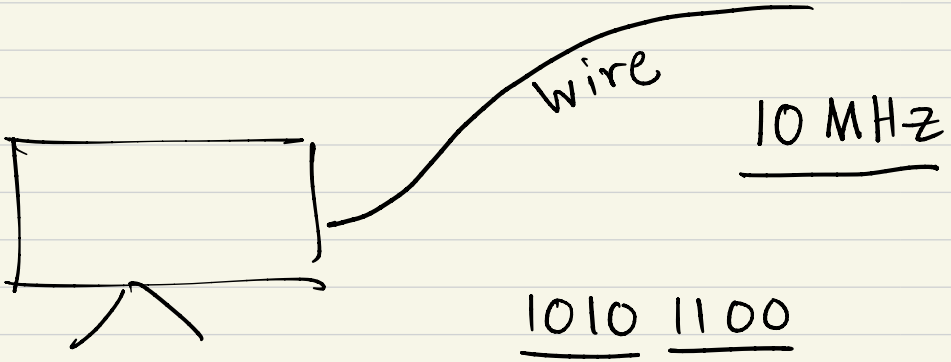
Bits/s ⇒ Bit rate

Bit rate (C) = B log (1 + SNR)

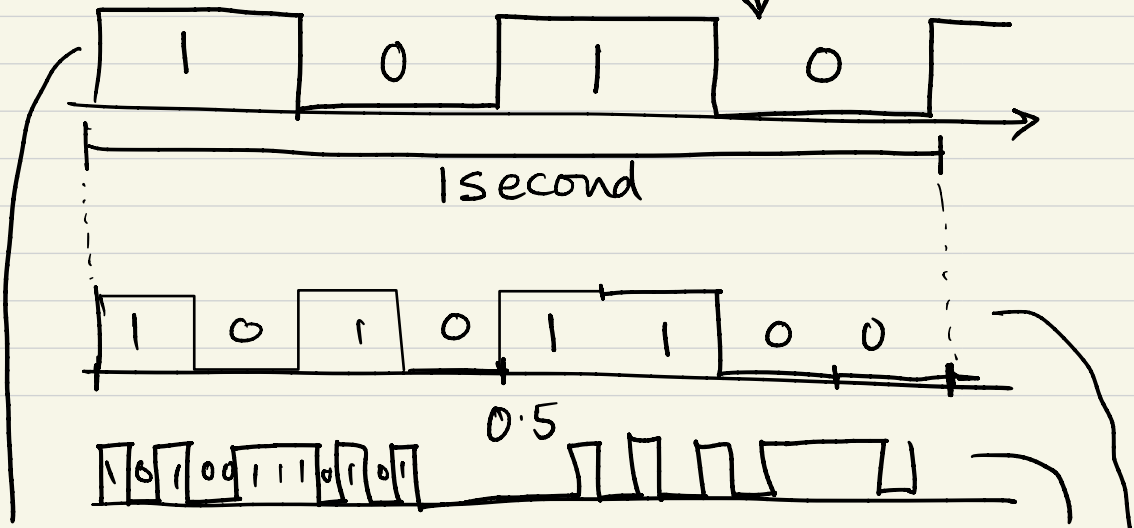
↳ Signal to Noise Ratio

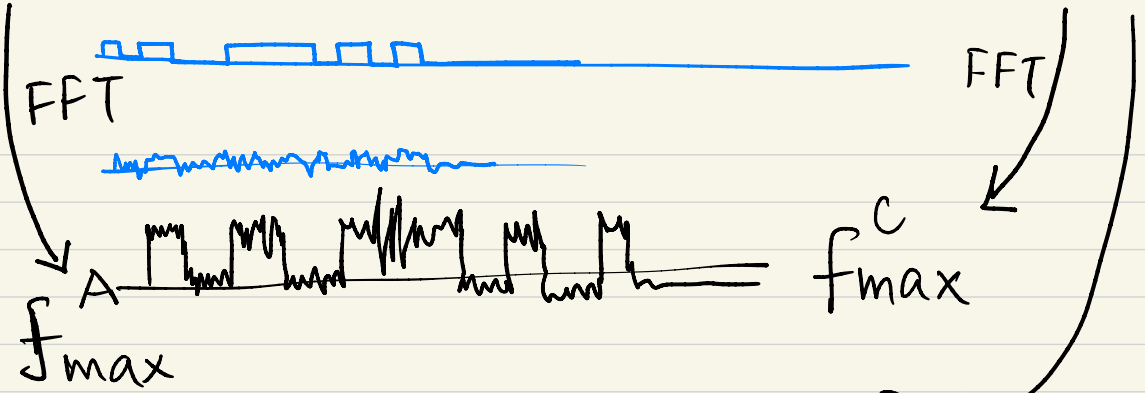
↳ Bandwidth





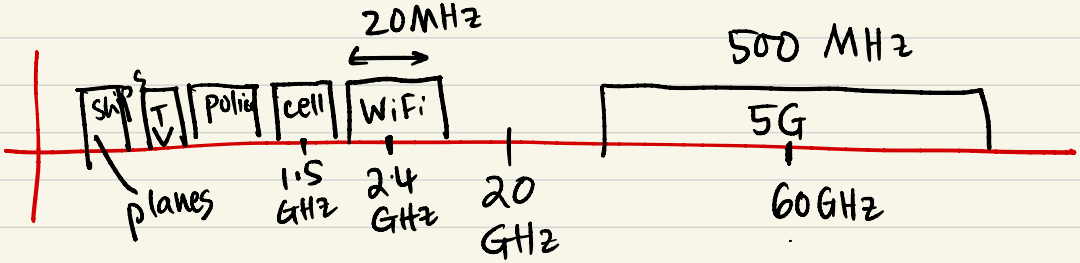
1010 1100

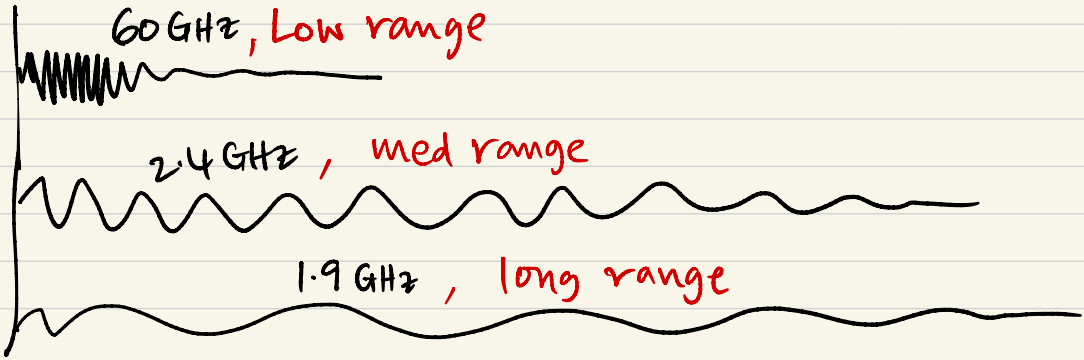


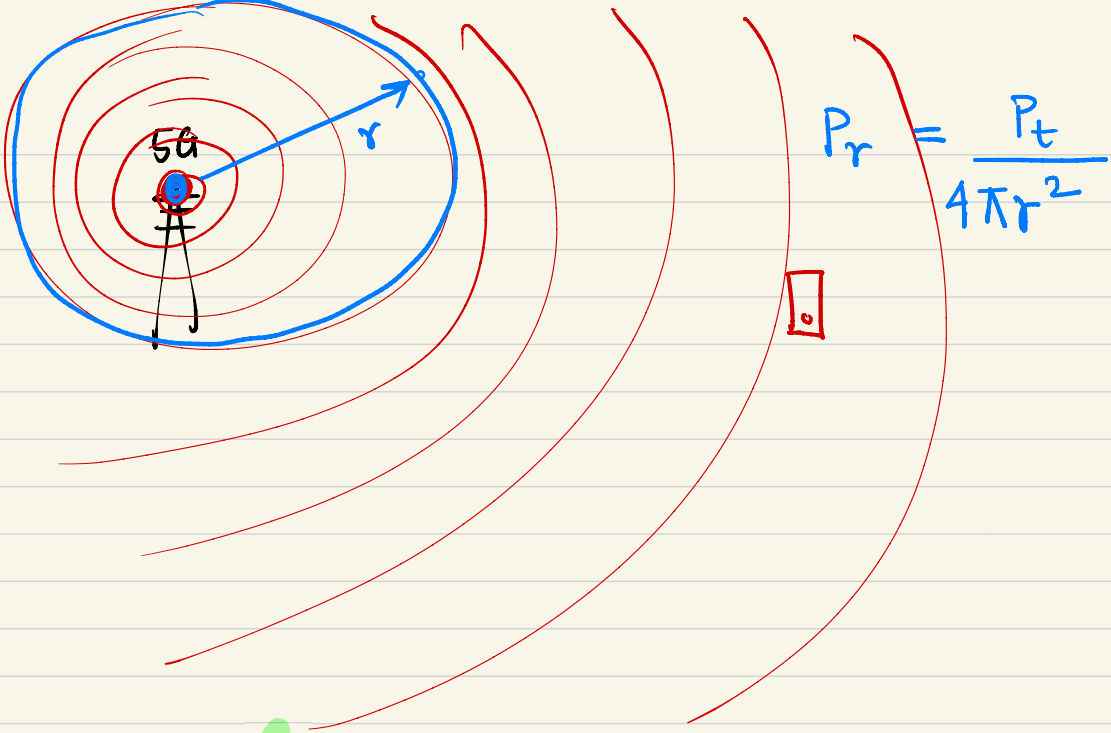


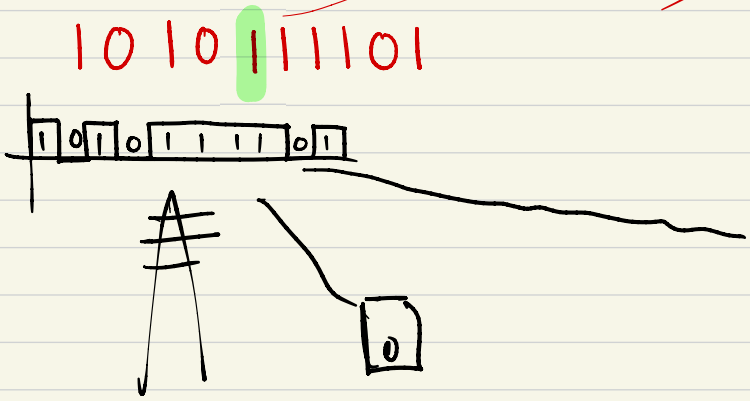
$$f_{max}^{C} > f_{max}^{B} > f_{max}^{A}$$

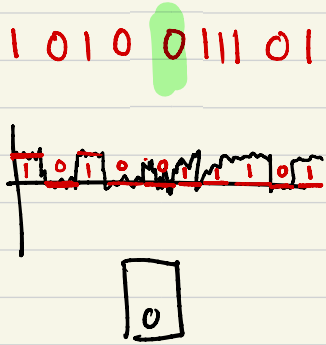
5G

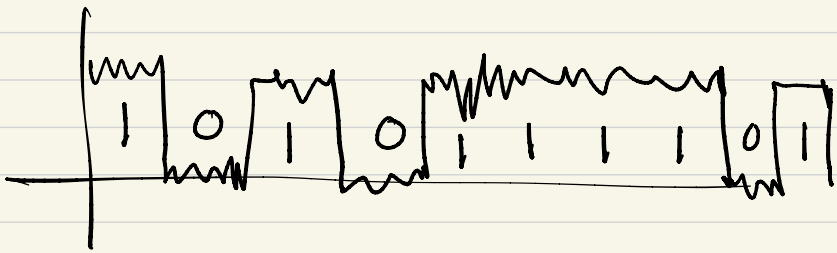




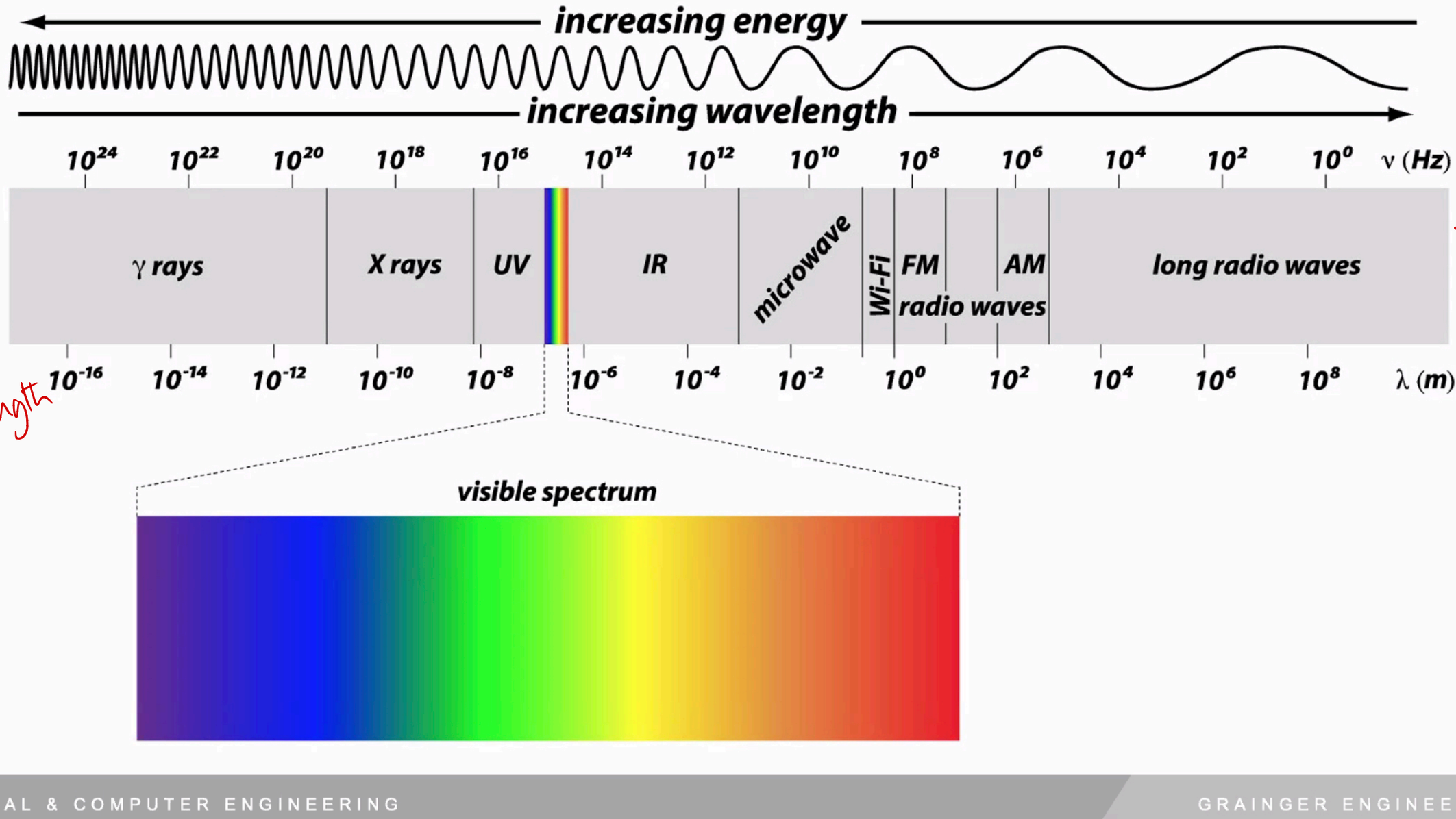

5G
r
$P_r = \frac{P_t}{4\pi r^2}$


10101111101


10100111101



The electromagnetic spectrum is the key to remote sensing

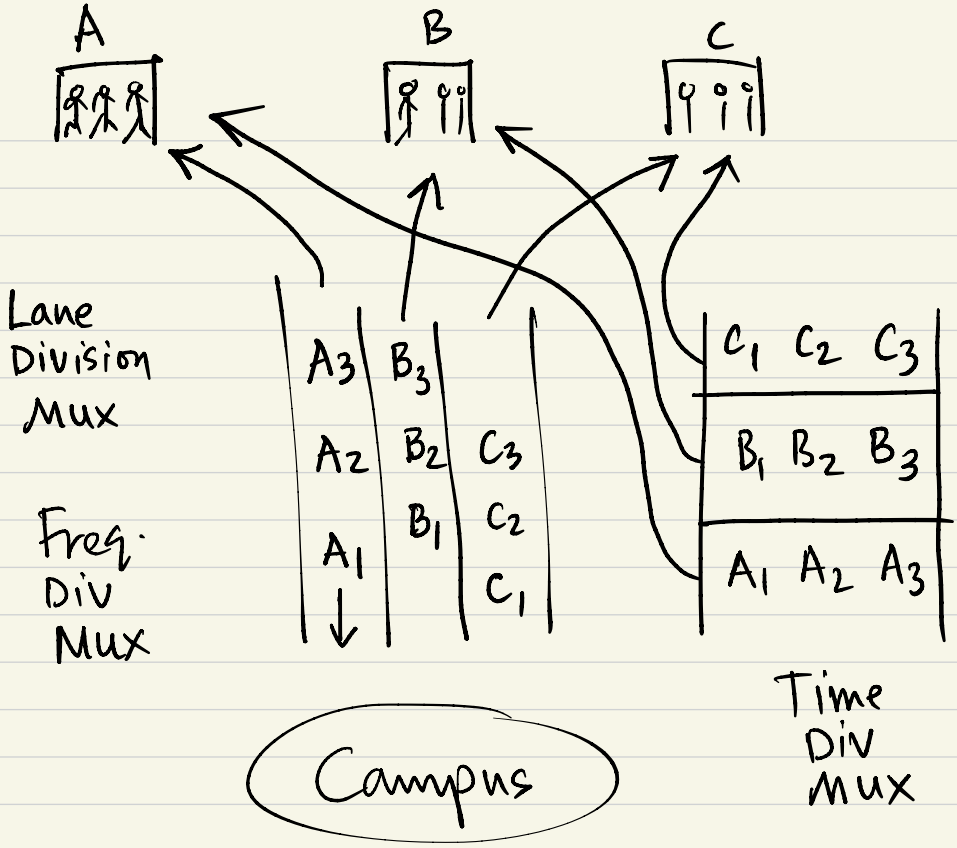


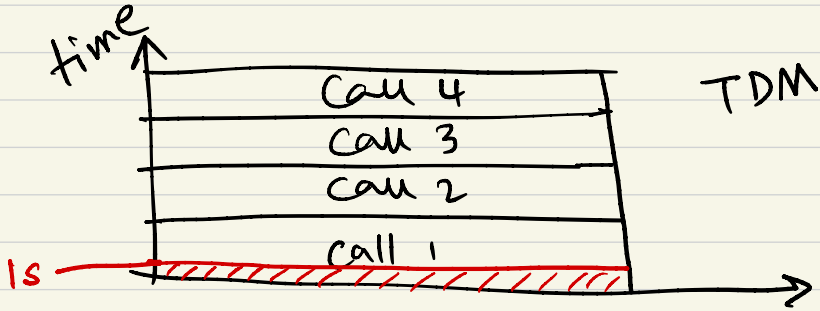
Hi freq

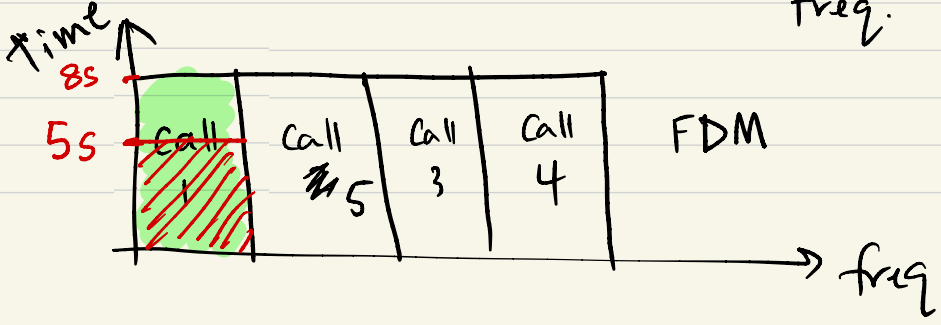
Low freq.

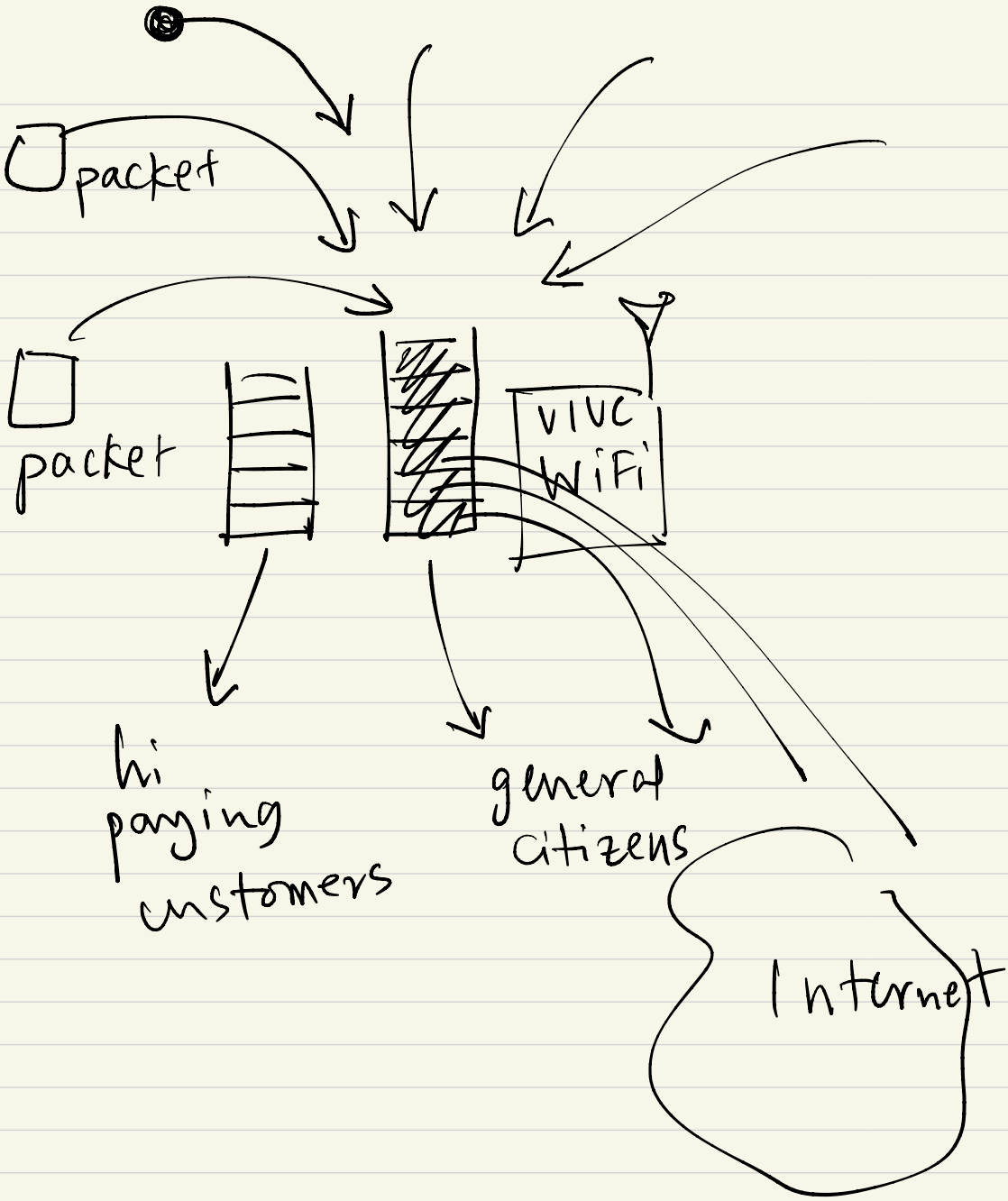
Low wavelength

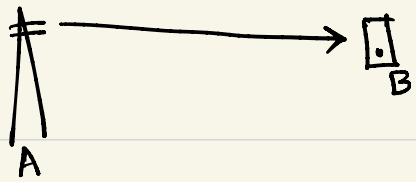
hi wavelength


A
B
C
Lane Division Mux
Freq. Div Mux
A3 B3
A2 B2 C3
A1 B1 C2
C1
C1 C2 C3
B1 B2 B3
A1 A2 A3
Time Div Mux
Campus

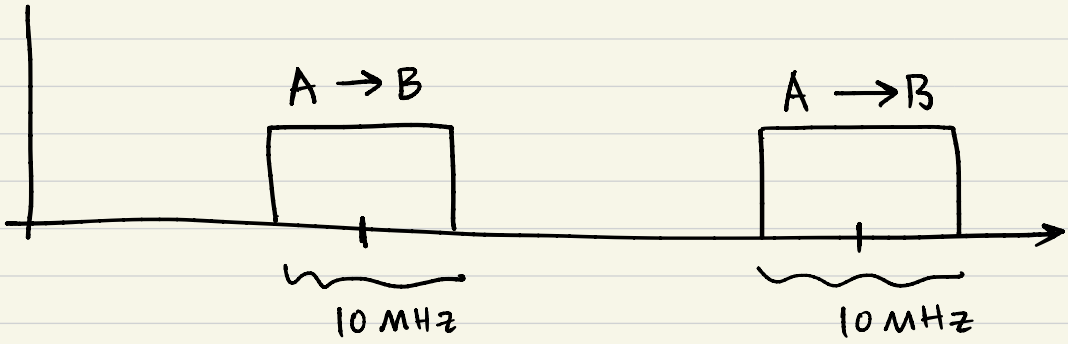

time
Call 4
Call 3
Call 2
call 1
1s
TDM
freq.


time
8s
5s
call 1
call 5
call 3
call 4
FDM
freq


packet
packet
VIUC
WiFi
hi
paying
customers
general
citizens
Internet



$C = B \log(1+SNR)$



Both will have similar bit rate.