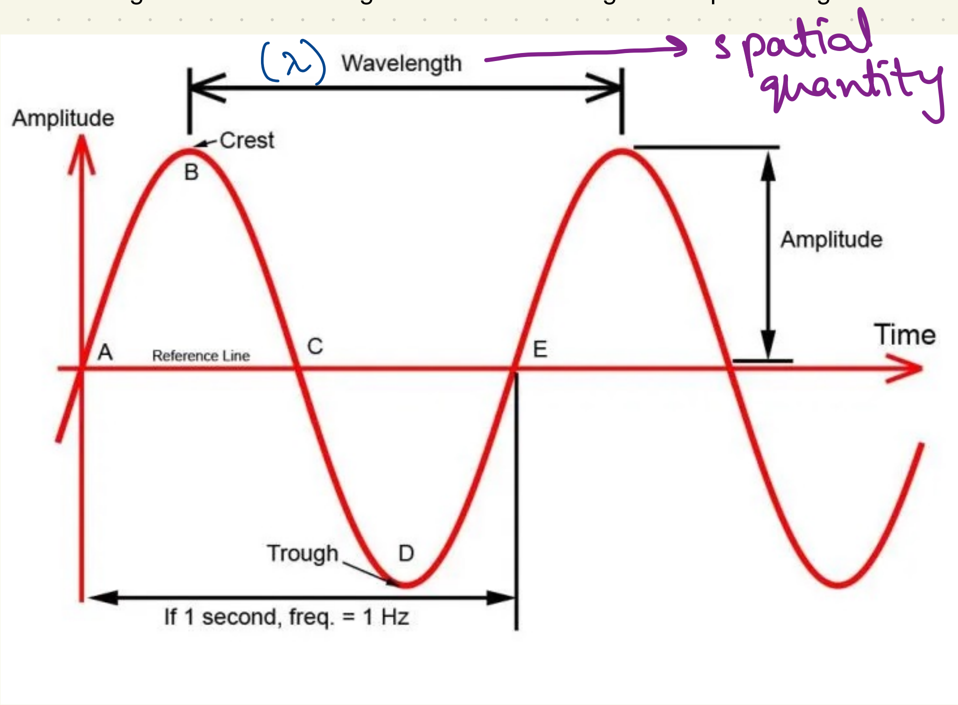
Today's Agenda: Basics of Wireless

- Wireless Signals as EM waves
- Modulations
- SNR/SINR, BER
- Capacity and Data rate
- Zigzag
  - Channel
  - Hidden Terminal
  - Decoding Collisions

Wireless Signals as Waves

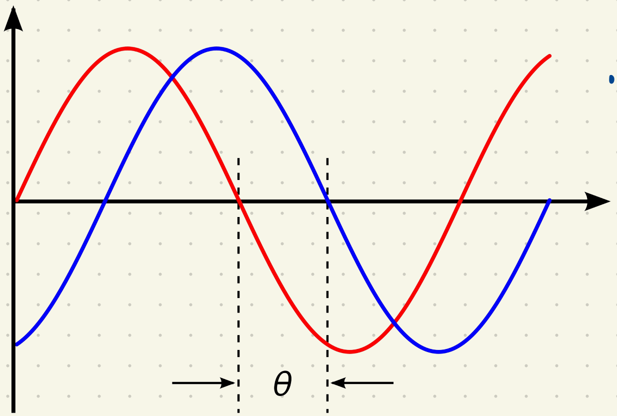
- Wireless signals are electromagnetic waves traveling at the speed of light



- Speed of light, c = 3.0 x 10^8 m/s
- c = f x lambda, where f is frequency in Hz, and lambda (λ) is the wavelength
- Wavelength is a spatial quantity
- Frequency is a temporal quantity
- The larger the amplitude, the greater power in the signal and vice versa.

Phase of a wave:

- Phase describes the position of a point within a repeating pattern of a wave at a specific point in time.
- It tells you where a particular point on the wave is in relation to a reference point, often the starting point of a wave.
- Expressed in terms of **angles** and is a **cyclic** quantity
    - 0 - 360 degrees or 0 - 2pi radians



- Blue wave: Original wave at time ($t = 0$)
- Red wave: Wave at a later time ($t = t_1$)
- θ : phase diff. expressed in angles (degrees or rad)

Represent Wave as a Complex Number.

- Complex Wave Equation: $a e^{j\Phi}$

  a: Amplitude

  $j: \sqrt{-1}$

  Φ: phase

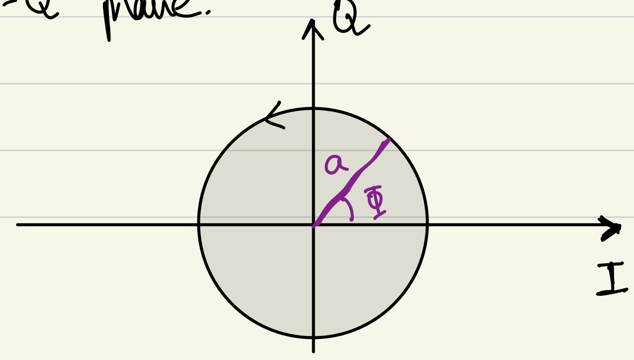
- Apply Euler's formula: ($e^{jx} = \cos x + j \sin x$)

$$a e^{j\Phi} = a(\cos\Phi + j\sin\Phi)$$

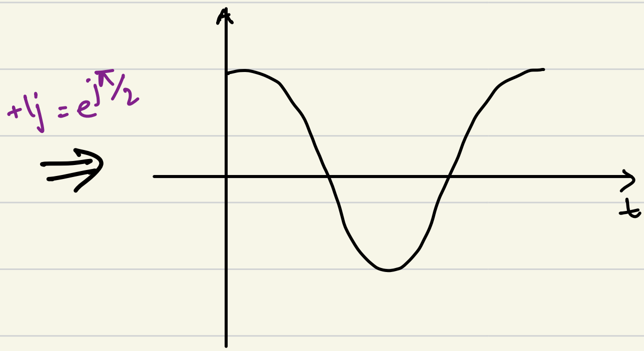
- Relationship between phase / Φ and frequency / f

$$\Phi = 2\pi f t$$

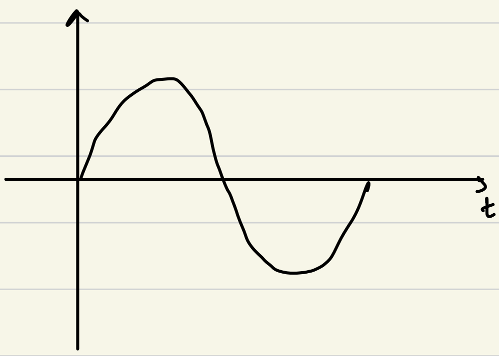
- $a e^{j\Phi} = a e^{j2\pi f t}$ can be interpreted as a spinning stick in the I-Q plane.

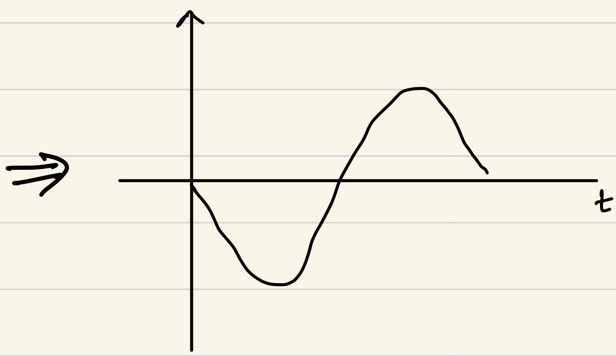


• Ex: $ae^{j\Phi} \times +1j$ Note: $+1j = e^{j\frac{\pi}{2}}$, so this term will introduce $\frac{\pi}{2}$ phase shift.



• Ex: $ae^{j\Phi} \times -1$ Note: $-1 = e^{j\pi}$





WiFi Bands

→ Almost all WiFi (802.11) devices use 2.4GHz or 5GHz frequency.

1) 2.4 GHz (2.4×10^9 Hz)

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8}{2.4 \times 10^9} = 12cm$$

2) 5 GHz (5.0×10^9 Hz).

$$\lambda = \frac{3.0 \times 10^8}{5.0 \times 10^9} = 6\ cm.$$

Tradeoff between high frequency vs low frequency.

- High frequency signals have a greater data rate, but at the cost of lower range because high frequency signals attenuate at a greater rate when compared with low freq. signals.

Cellular Bands.

→ Assigned by government (Spectrum Allocation)

- → 700 MHz
- → 2100 MHz
- → 3500 MHz

Increase Range of network coverage

- ↳ Denser networks i.e more cell towers per unit area
- ↳ Transmit with more power from each cell tower.

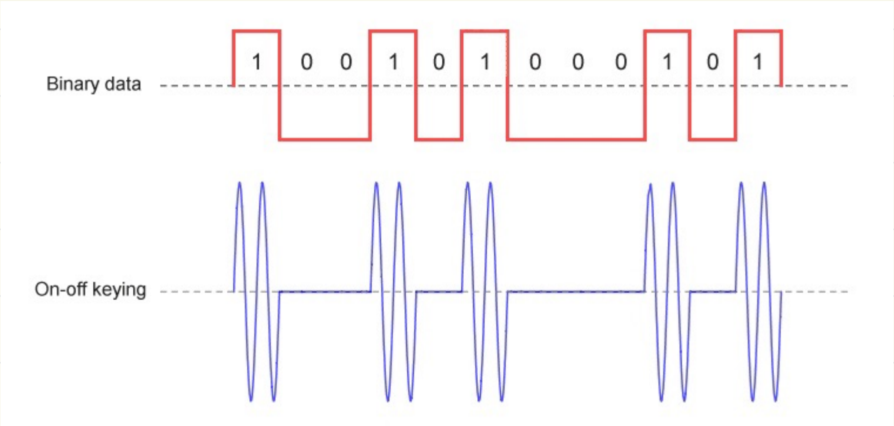
Modulation

- → AM
- → OOK
- → BPSK
- → 4QAM
- → 16 QAM

sequence of bits → Modulation. → wave.

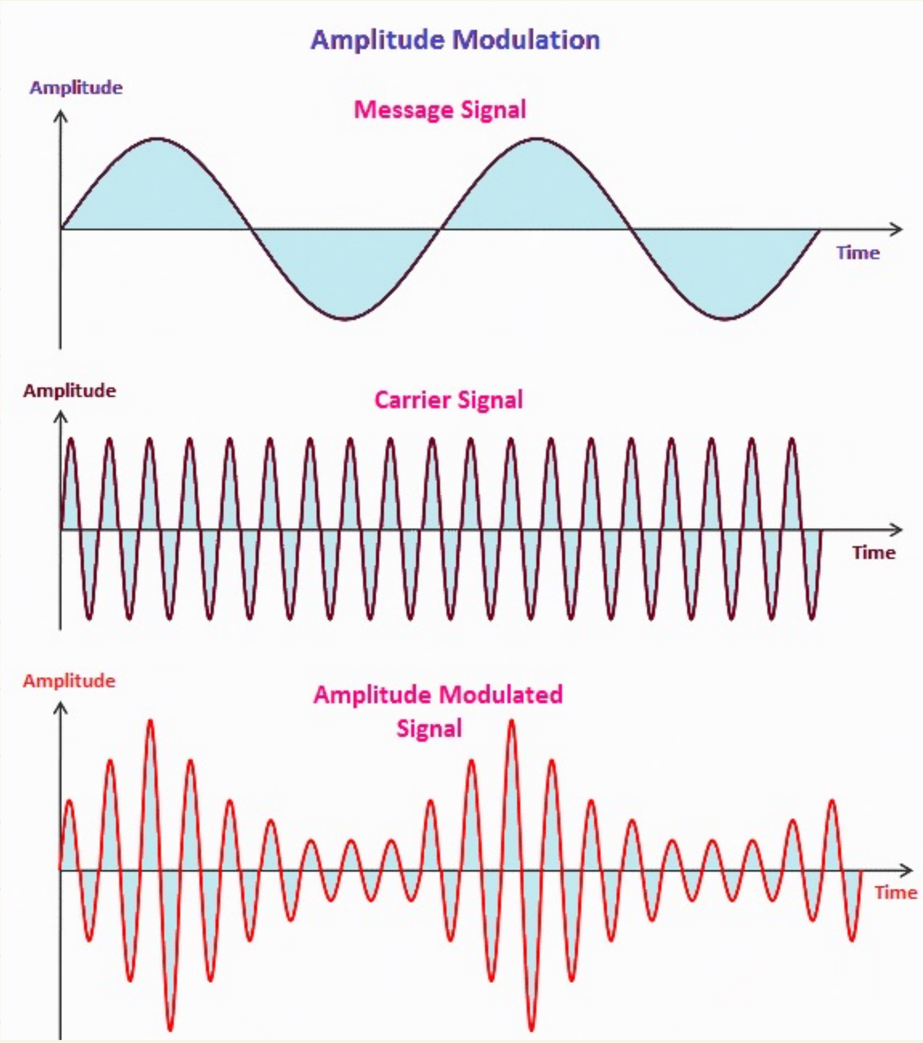
Example : on-off-keying.

- bit 1 : send a wave
- bit 2: do not send a wave.

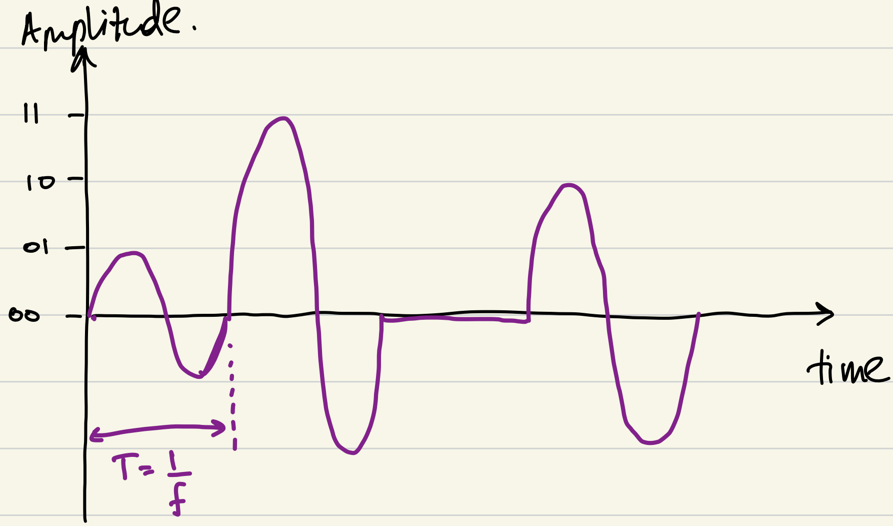


Example: **Amplitude Modulation.**

- send strong signal for bit 1 and send weak signal for bit 0.



- Pack 2 bits in each wave period.

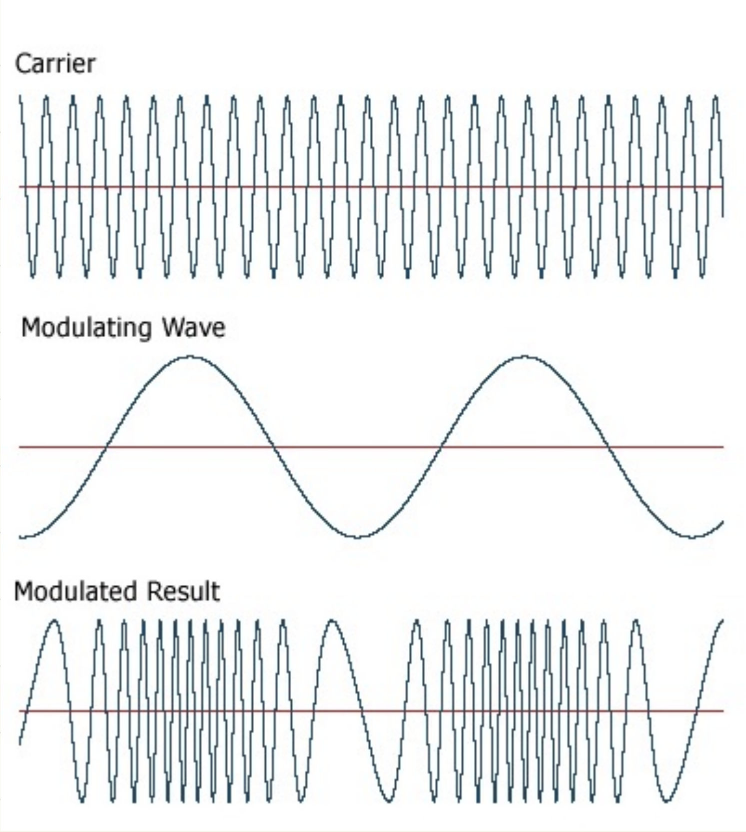


↳ Likewise, more and more bits can be packed in a single timeperiod T.

↳ However, there is a tradeoff. More bits per T reduces the amplitude difference between consecutive bit values which can cause demodulation errors at the receiver.

Example: **Frequency Modulation / Frequency Shift Keying**

- Alter the frequency of the carrier signal wrt the amplitude of the message signal.

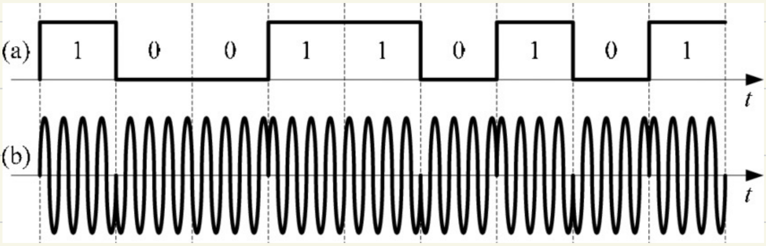


Example: BPSK / 4-QAM / 16-QAM

BPSK

- Transmit bit 0 : multiply by +1
- Transmit bit 1 : multiply by −1

Note: The multiplication factors +1 and −1 are called symbols.



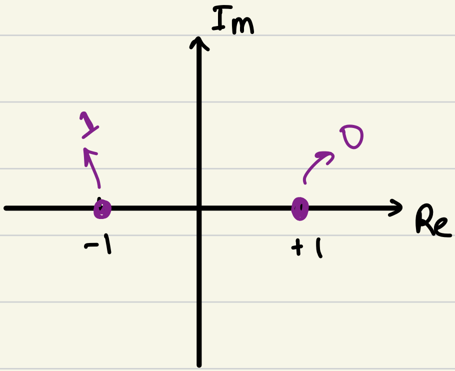
BPSK vs 4-QAM

BPSK	4-QAM
• 2 symbols	• 4 symbols
• Phase modulation	• Combination of amplitude and phase modulation
• less bits packed per time period	• More bits packed in a time period.

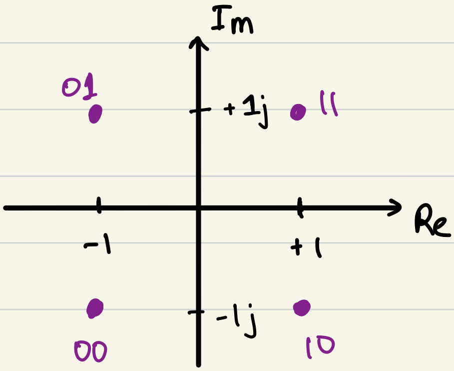
bits → **Modulation** → Symbols.

(These are multiplied with carrier signal).

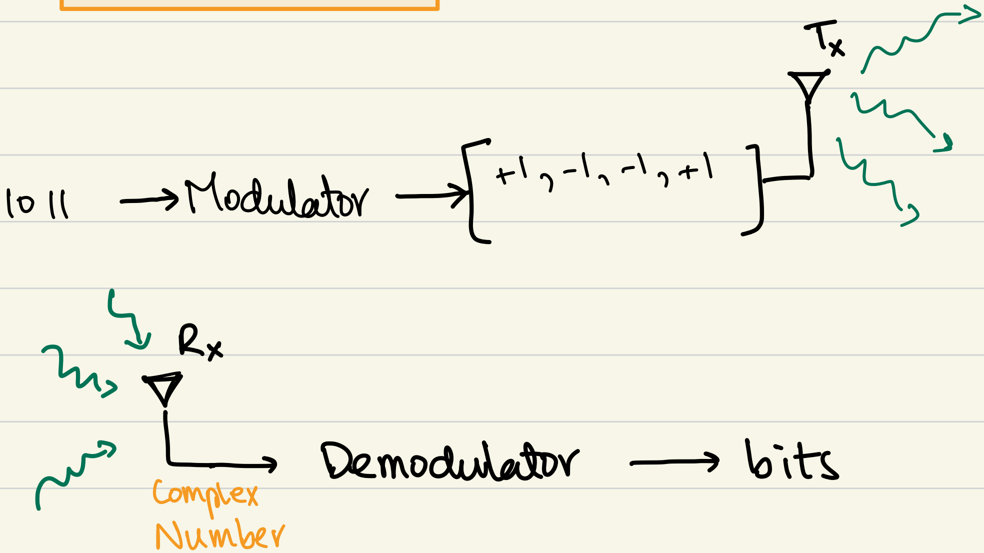
BPSK



4-QAM



Channel

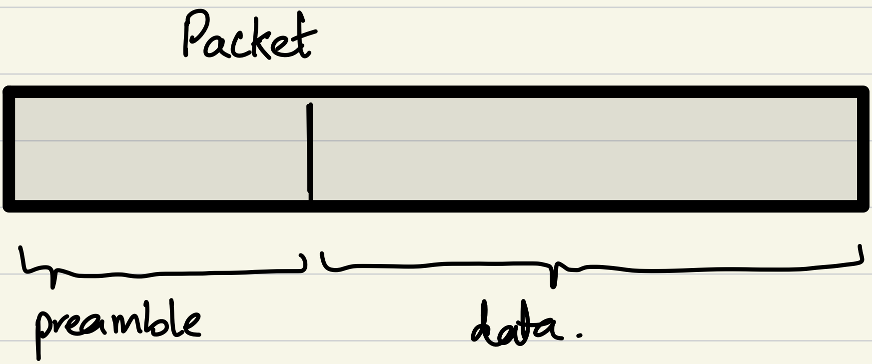


- $y = hx + n$.
  - y → received signal
  - h → complex channel characteristics.
  - x → transmitted signal
  - n → noise << very small

- channel is the physical medium through which wireless signals travel.

How to estimate h ?

- Send a known signal at the beginning of packet called "preamble"



$h_{est} = \frac{y}{x}$ (using preamble).

- Coherence time : Time interval during which channel's characteristics remain relatively unchanged.
- Coherence frequency : Frequency range within which the channel's characteristics remain relatively constant.

SNR / SINR

- $y = hx + n$ (n = noise.)

- Signal to Noise Ratio (SNR) $= \dfrac{(hx)^2}{n^2}$ — $(hx)^2$: signal power; n^2: noise power.

- $\text{SNR dB} = 10 \log_{10}(\text{SNR})$.

10 dB	≈	10	times
20 dB	≈	100	times
30 dB	≈	1000	times
3 dB	≈	2	times
6 dB	≈	4	times

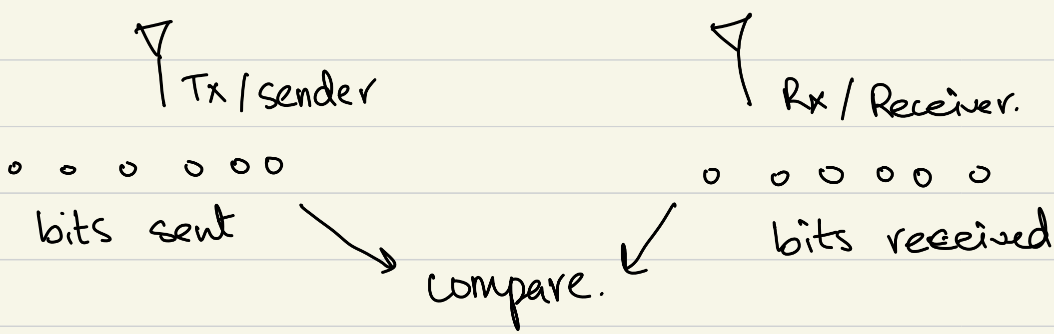
- Bad / low SNR
  - ↳ signal is weak → $|h| \approx 0$
  - ↳ noise is strong
    - ↳ interference. ($y = hx + n + i$) — i: interference

- $SINR = \frac{|hx|^2}{|n+i|^2}$ ← noise + interferance

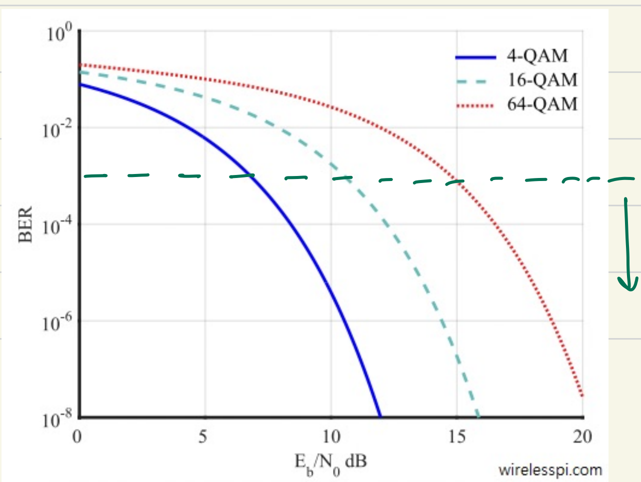
- How does receiver find the noise power or noise + interferance power:
  → Estimate these when the receiver is idle and no one is transmitting to receiver.

BER : Bit Error Rate

- $BER = \dfrac{\text{\# of bits wrong}}{\text{total bits sent}}$.



- BER should be low for successful transmission



Ideally, BER should be lower than 10^{-3} for overall successful data transmission

Data Rate vs Capacity

- **Data Rate:** How many bits can I send per second.

1 Gbps : 10^9 bits/s

100 Mbps : 10^8 bits/s

Data Rate = bits per symbol × symbol per second

bits per symbol → modulation scheme.

symbol per second → hardware determined

Ex: BPSK : 1 bit/symbol → 1 Mbps

10^6 symbol/s

4QAM : 2 bit/symbol → 2 Mbps

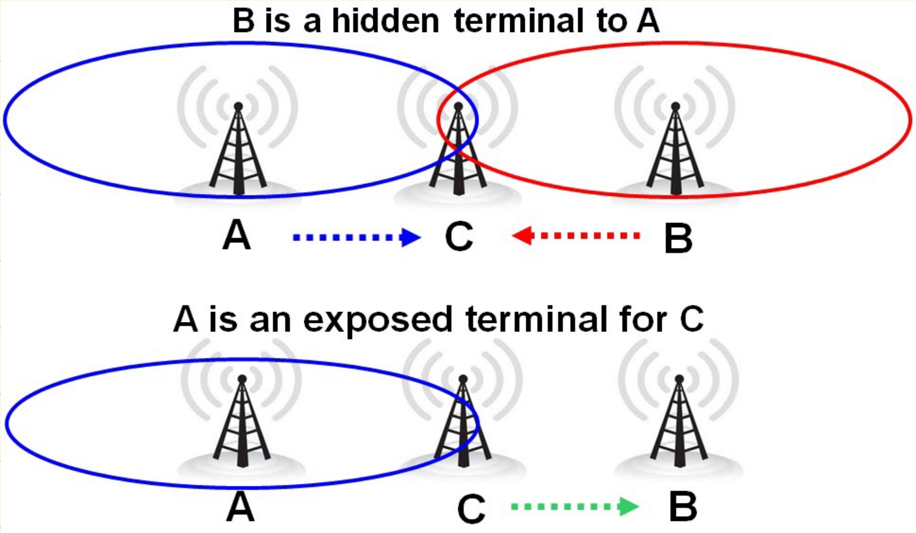
- Capacity: Maximum achievable data rate of a communication channel

$$C = B \log_2 (1 + SNR)$$

B → bandwidth

Hidden Terminals

These are devices that are out of range of each other, but both are within range of an access point or base station.



- Hidden terminals cannot directly sense each other's transmissions, which results in collisions and reduced network efficiency
- Medium Access Protocols:

→ Used to manage how devices share wireless medium/ channel and avoid such issues.
e.g CSMA / CA, RTS / CTS

Zig Zag Paper

→ Protocol designed as a solution to hidden terminals.

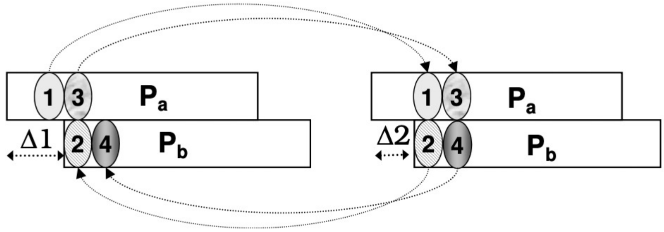


Figure 2: ZigZag Decoding. ZigZag decodes first chunk 1 in the first collision, which is interference free. It subtracts chunk 1 from the second collision to decode chunk 2, which it then subtract from the first collision to decode chunk 3, etc.