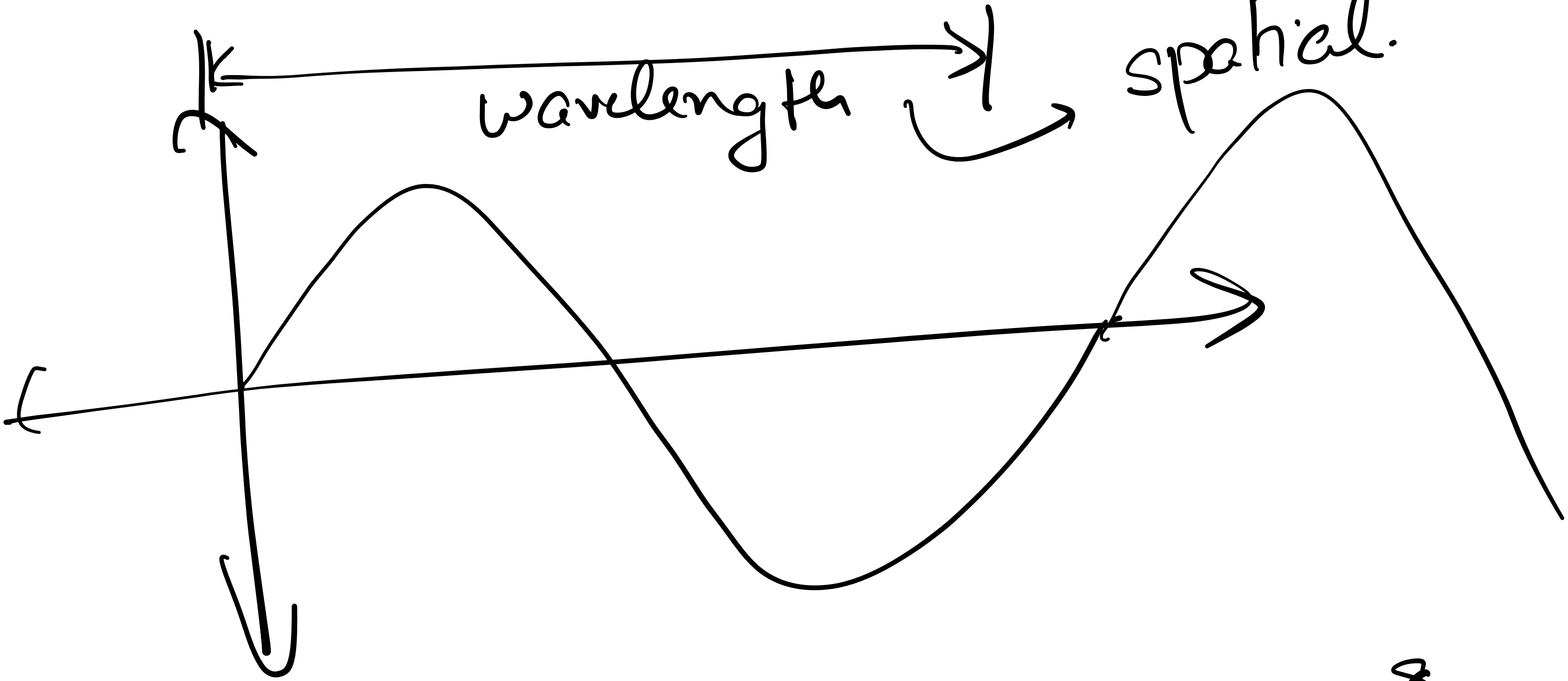
Today

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

Wireless Signals as Waves



speed of light = 3×10^8

$c = f \times \lambda$

- c → speed of light.
- λ → wavelength
- f → frequency ← temporal.

Wi-Fi → 2.4 GHz 2.4×10^9 Hz

5 GHz, 5×10^9 Hz

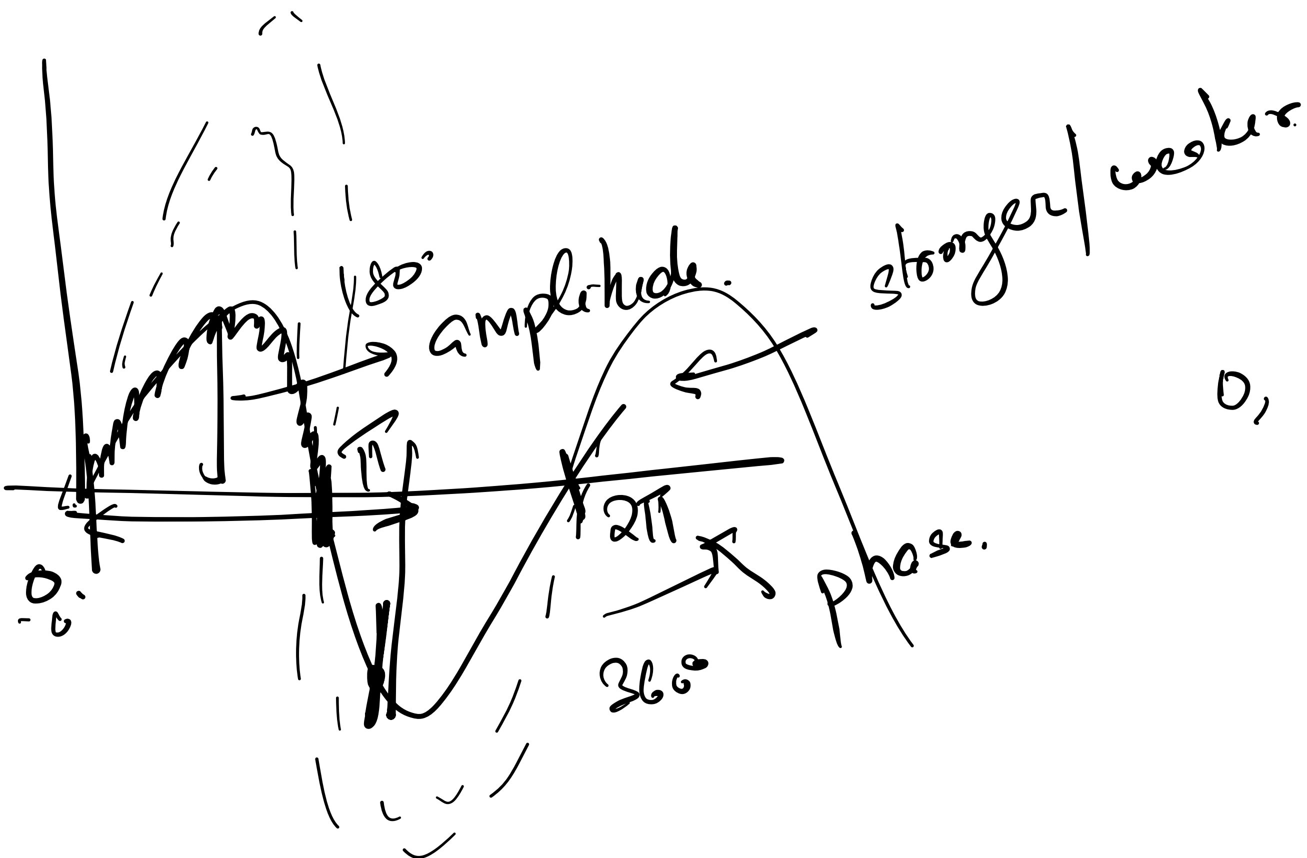
$$\lambda = \frac{3 \times 10^8}{2.4 \times 10^9} \approx 0.1\text{m}$$

= 10cm.

$$\lambda = \frac{3\times 10^8}{5\times 10^9} = \frac{3}{5}\times 0.1 = 0.06\,m = 6\,cm.$$

Cellular → 700 MHz
→ 2100 MHz
→ 3500 MHz

Spectrum allocation



Modulation

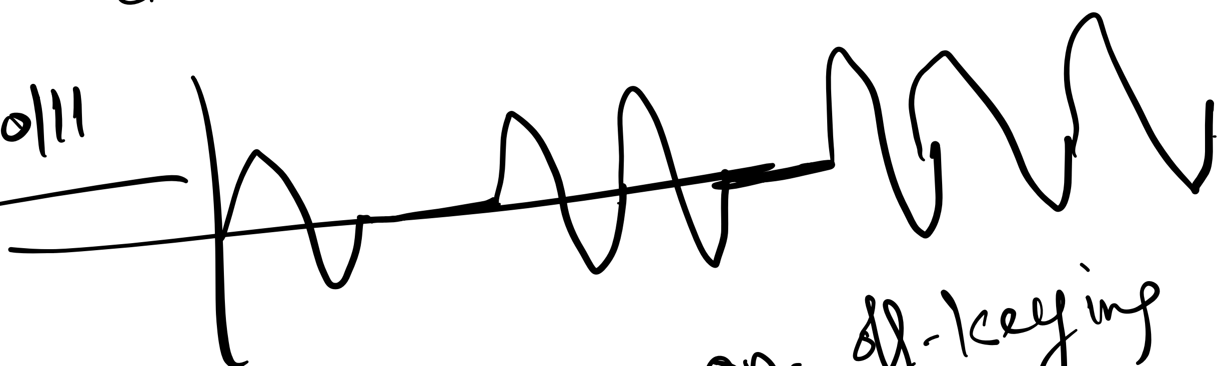
→ AM
→ OOK
→ BPSK
→ 4QAM
→ 16QAM

1 0 1 1 0 1 1 1

seq. of bits → Modulator → wave

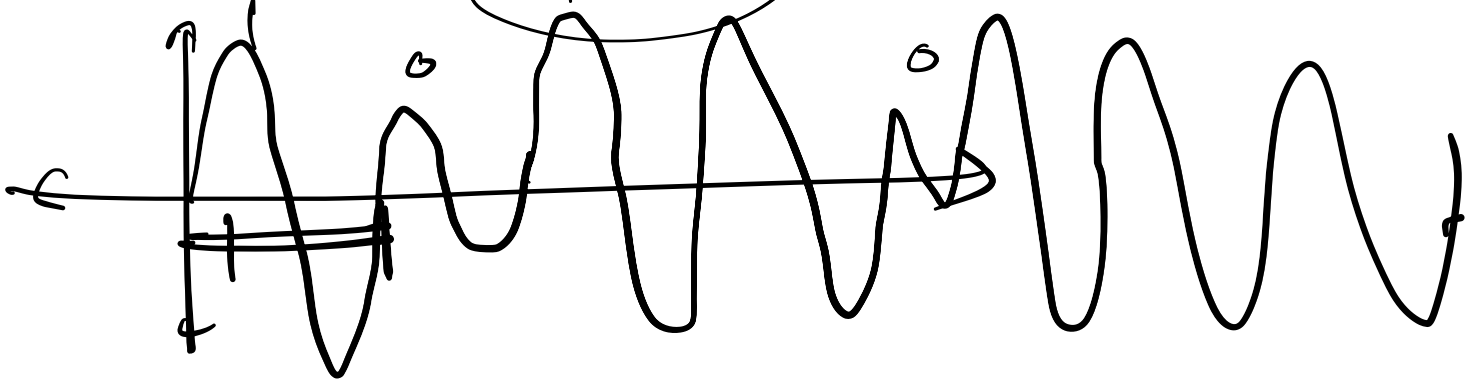
→ send a "wave"
→ do not send a wave

1011 0111

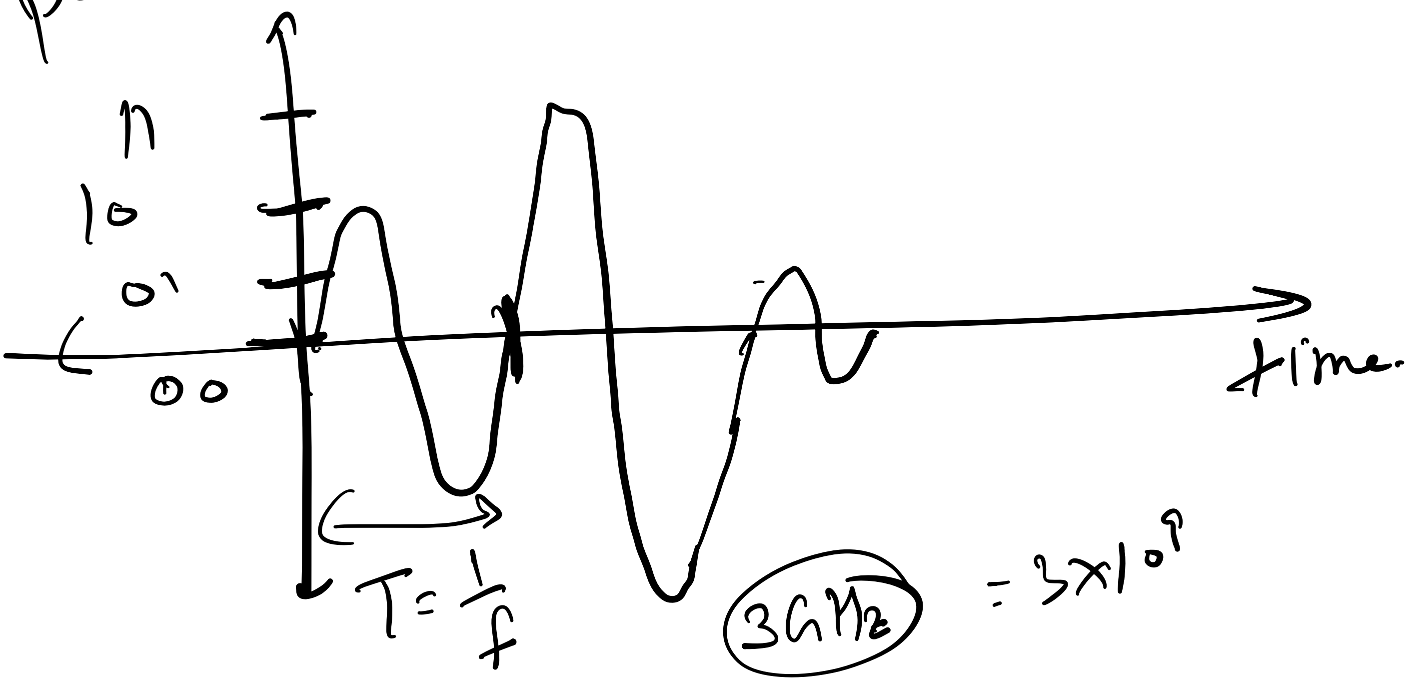


on-off-keying

Amplitude Modulation (AM)



pack 2 bits in each wave period

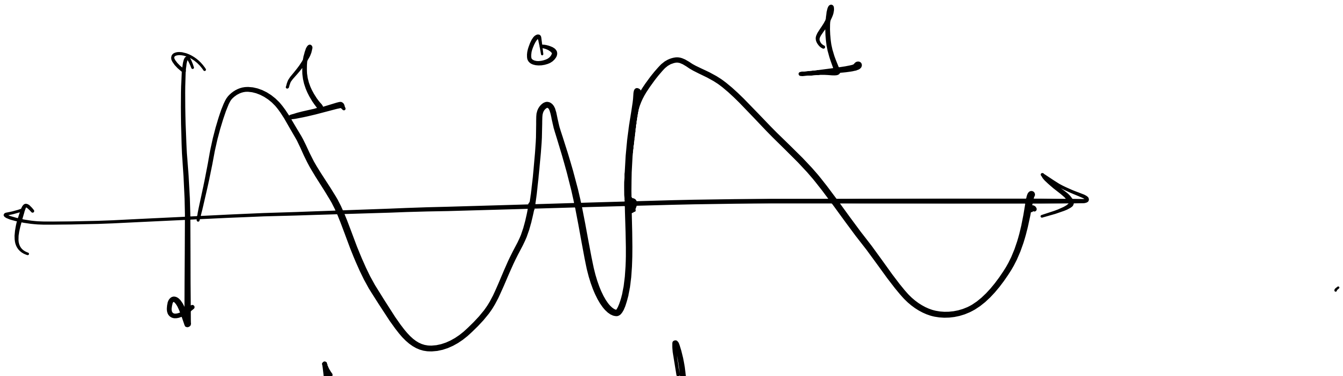


3GHz = 3×10^9

50MHz

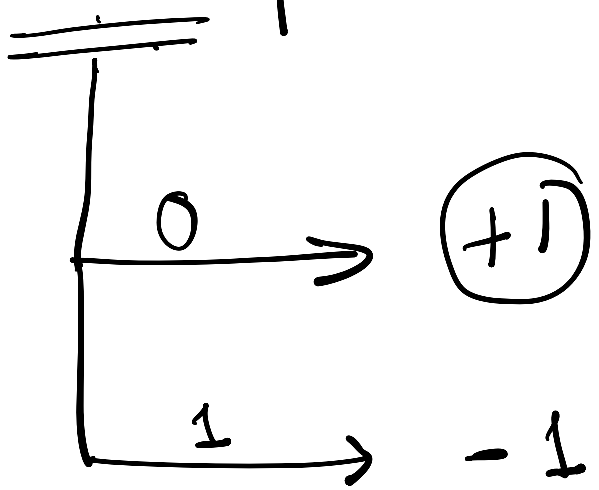
Frequency-Shift Keying (FM)

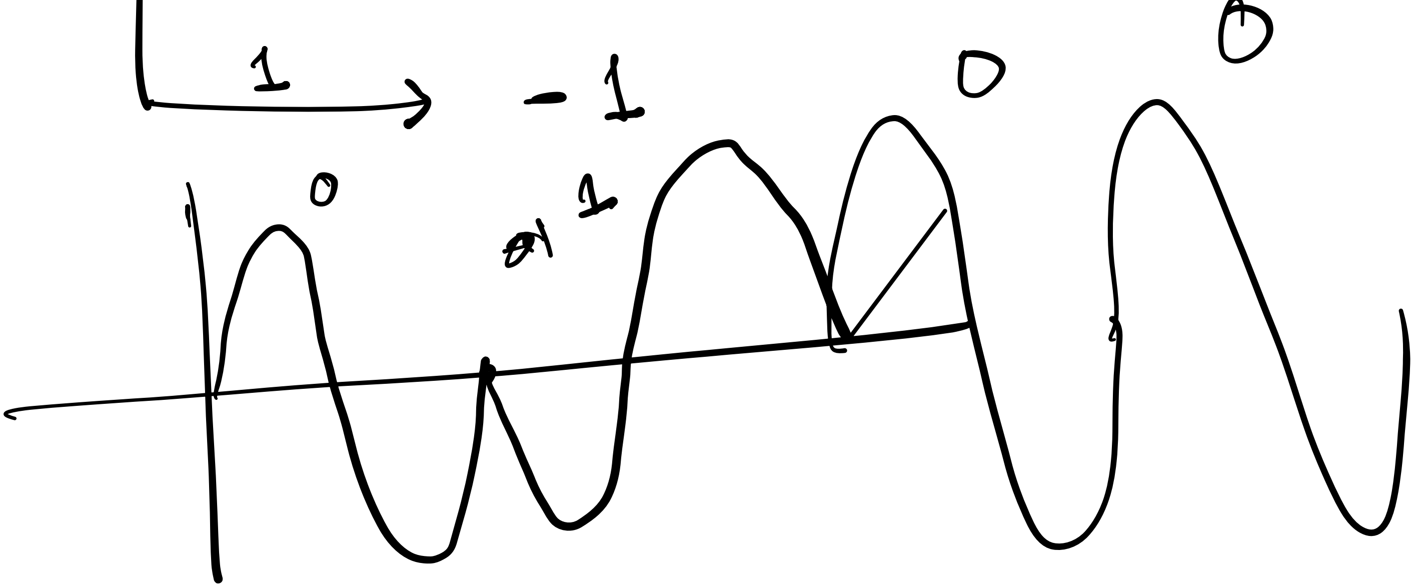
$0 \rightarrow f_1$ $1 \rightarrow f_2$



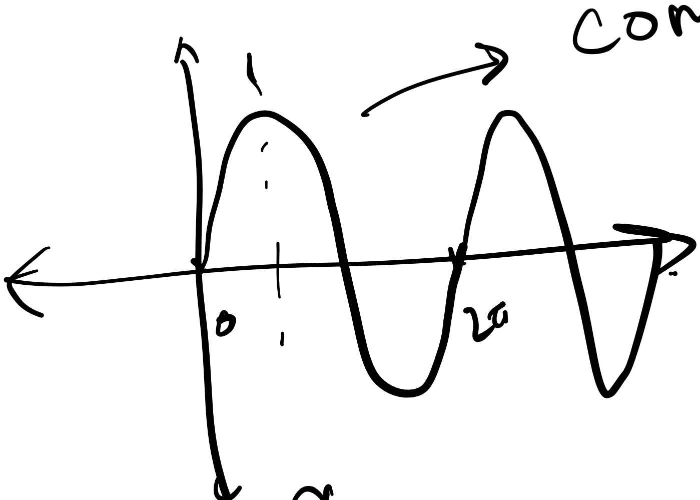
BPSK | 4-QAM | 16QAM.

symbol (complex-valued)





complex numbers



$a e^{j\Phi}$

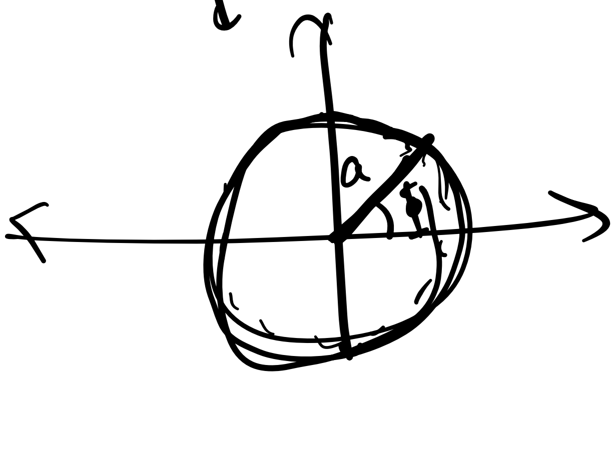
phase

amplitude

$\Phi = 2\pi f t$

time

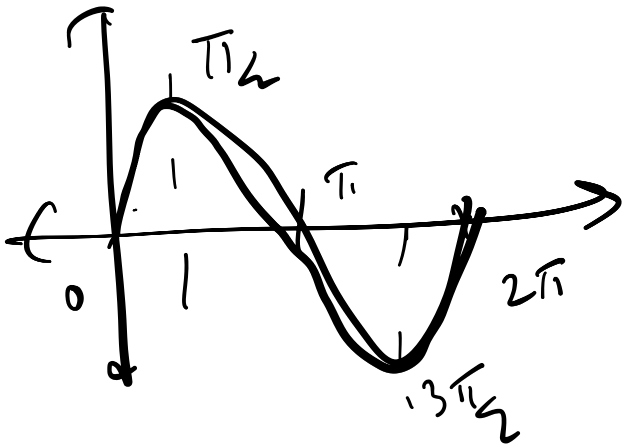
frequency.



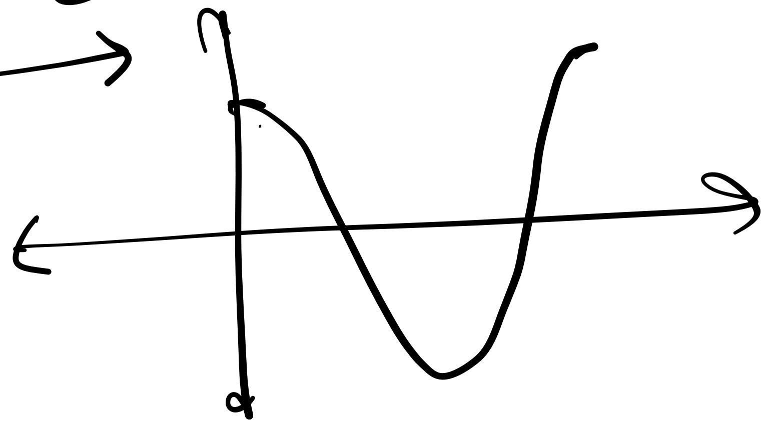
$a e^{j\Phi}$

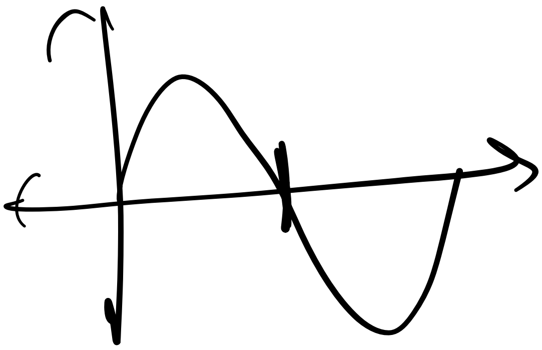
$$a e^{j\Phi} = \cos\Phi + j \sin\Phi$$

$j \rightarrow \sqrt{-1}$

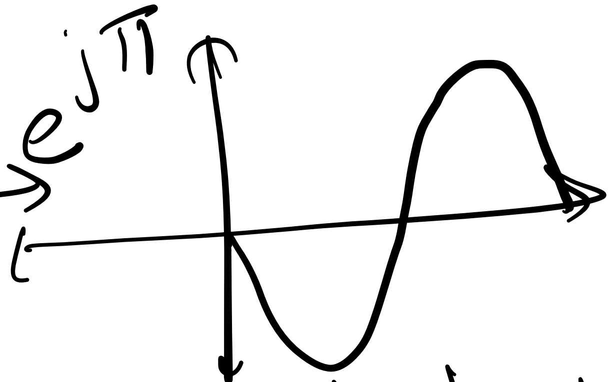


$+1j = e^{j\pi/2}$



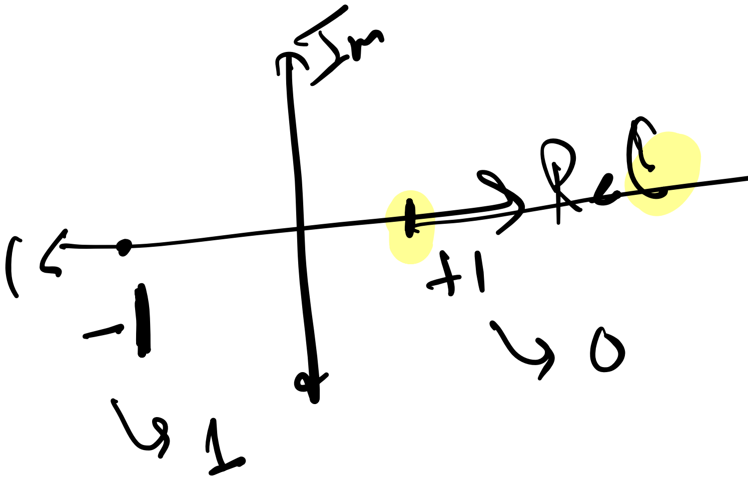


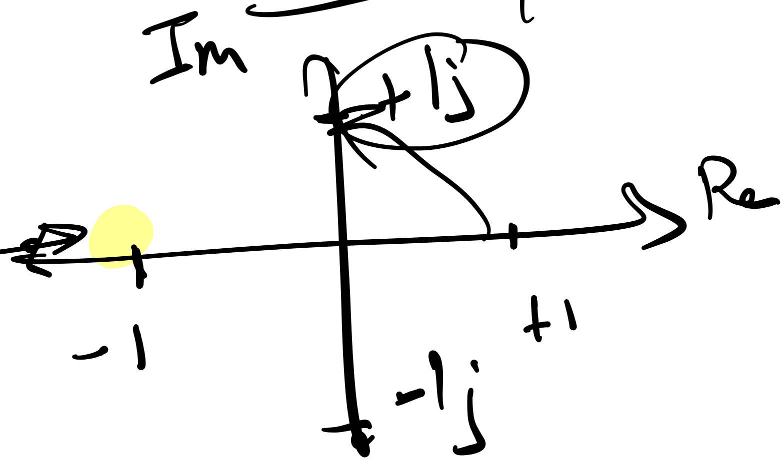
$-1 = e^{j\pi}$

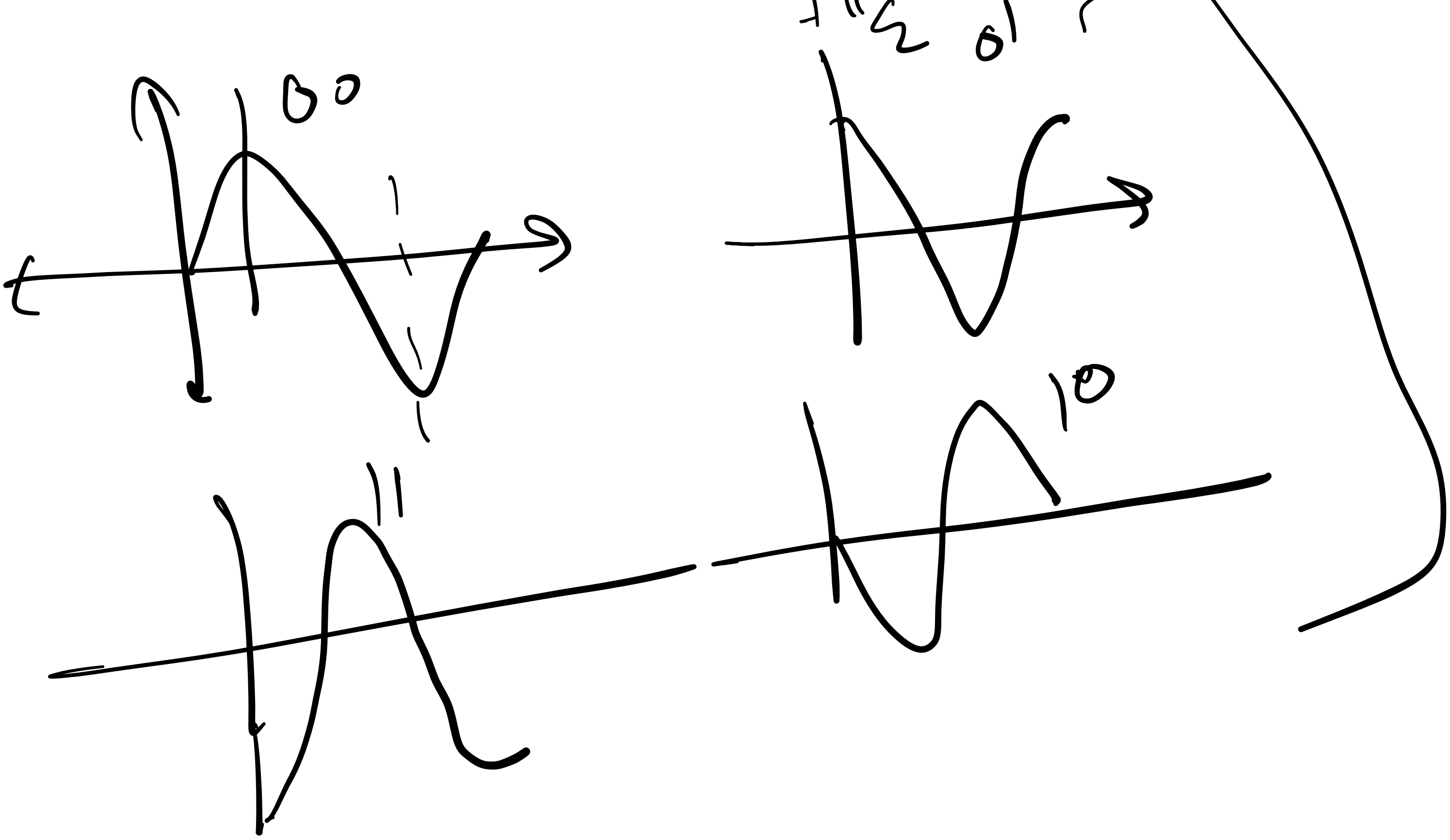


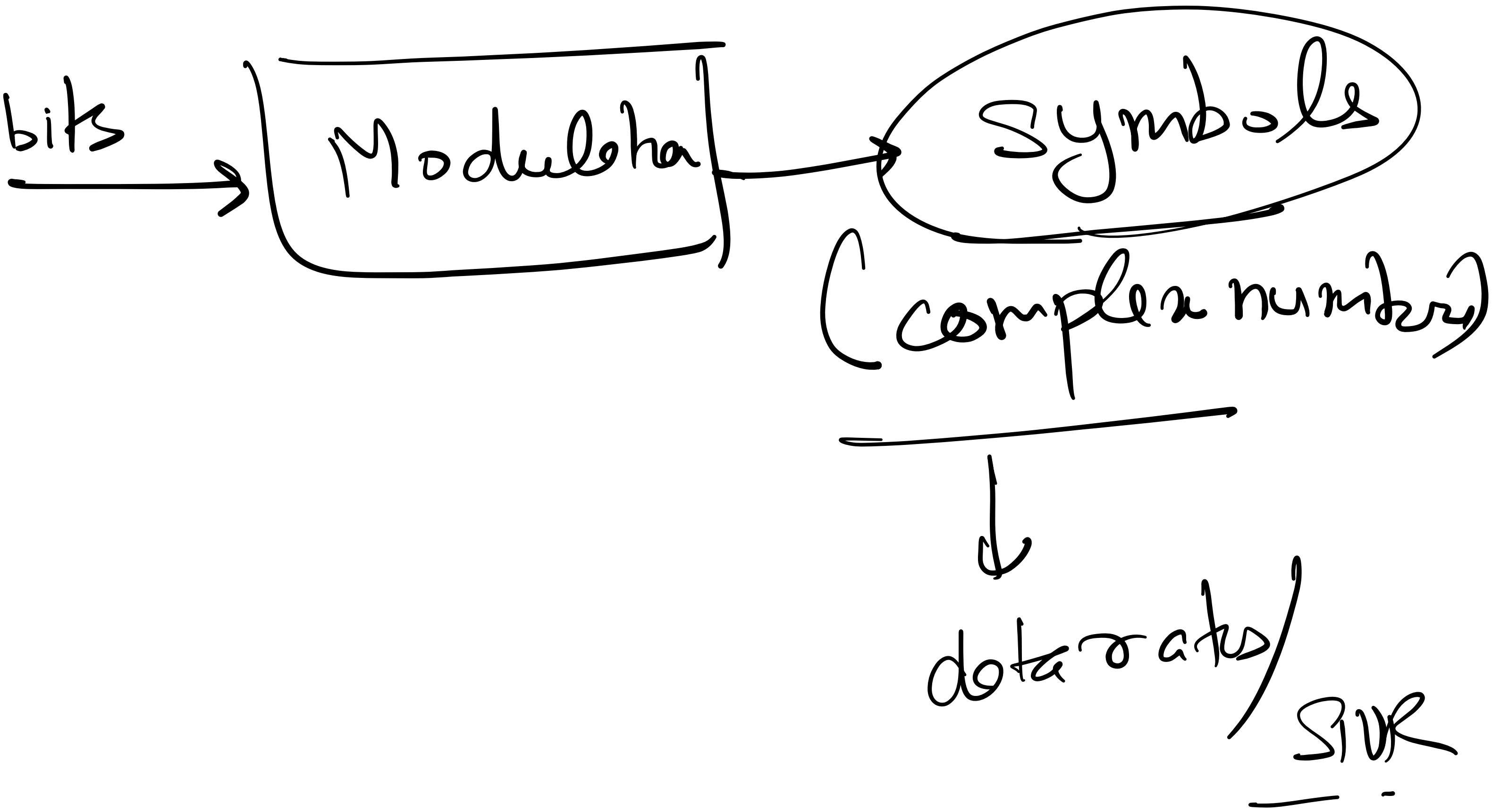
BPSK

4-QAM | 8 | 16



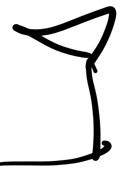


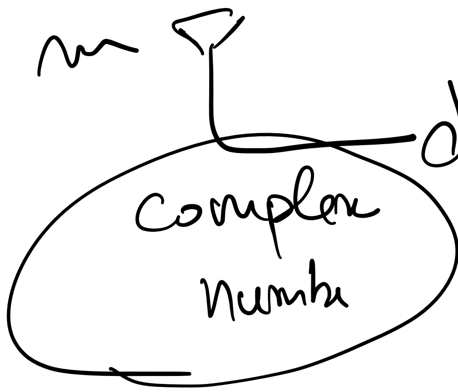

00
01
11
10
t


bits
Modulation
Symbols
(complex numbers)
data rates/
SNR

Channel

1011 → (modulator) [−1, +1, −1, −1]





demodulator

↓

bits

x y

$$y = hx + n$$

h → complex

n → noise << very small

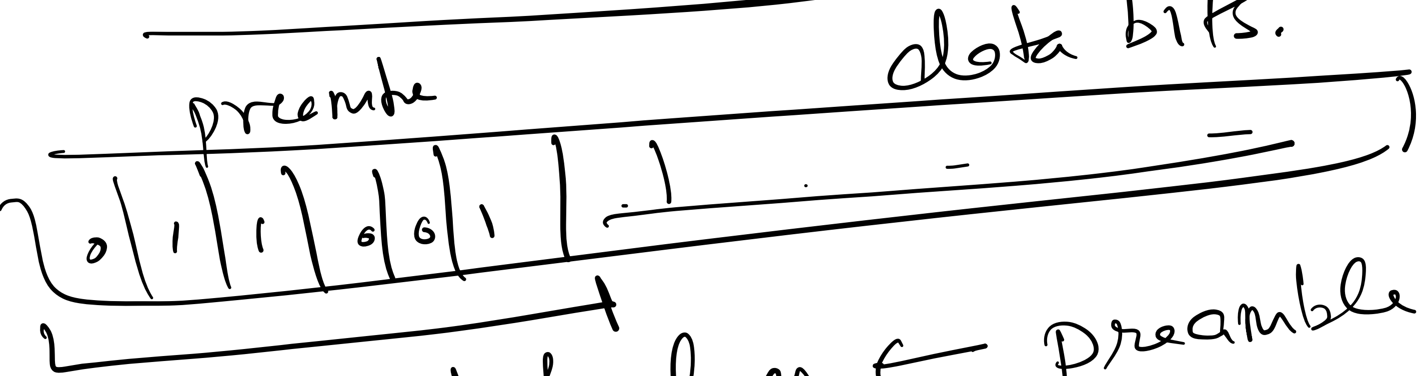
hx → wireless channel.

$$x = \frac{y}{h}$$

→ how do we know h?

→ how do we use h?

wireless packets



fixed set of values. ← preamble.

$y = h x$ $\qquad h_{est} = y/x$

h_{est} to decode data bits

BPSK modulation

0 → +1

1 → -1

4-QAM

00 → +1

01 → +1j

11 → -1

10 → -1j

preamble

01 11 10 11 . . . — — $h \approx 0.5j$

$x = +1j, -1, -1j, -1$

Smaller ~~Shorter~~ amplitude, phase chng.

$y = -0.5, -0.5j, +0.5, -0.5j$

$\frac{0.5j}{0.5} \approx x = 1 \rightarrow 00$

coherence time

coherence freq.

SNR / SINR

$y = h x + n$

y → receive; x → send; n → noise

Signal to noise ratio (SNR) $= \frac{(hx)^2}{n^2}$

$(hx)^2$ → signal power

n^2 → noise power

$SNR_{dB} = 10 \log_{10}(SNR)$ →

$SNR_{dB} \simeq 10_{dB}$ then $\frac{(hx)^2}{n^2} = 10$

20 dB 100

30 dB 1000

3 dB $\approx$ 2

7 dB $\approx$ 5

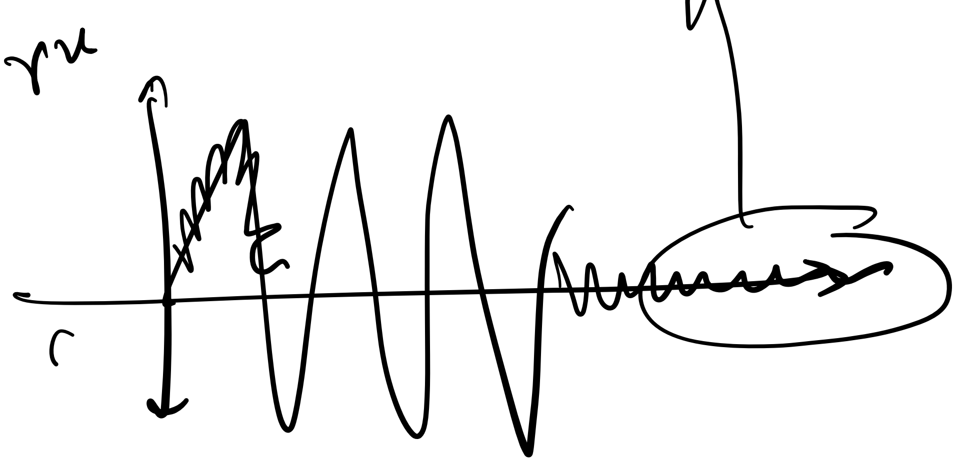
Bad / Low SNR

- → signal is weak → $|h| \approx 0$
- → noise is strong
  - → interference.

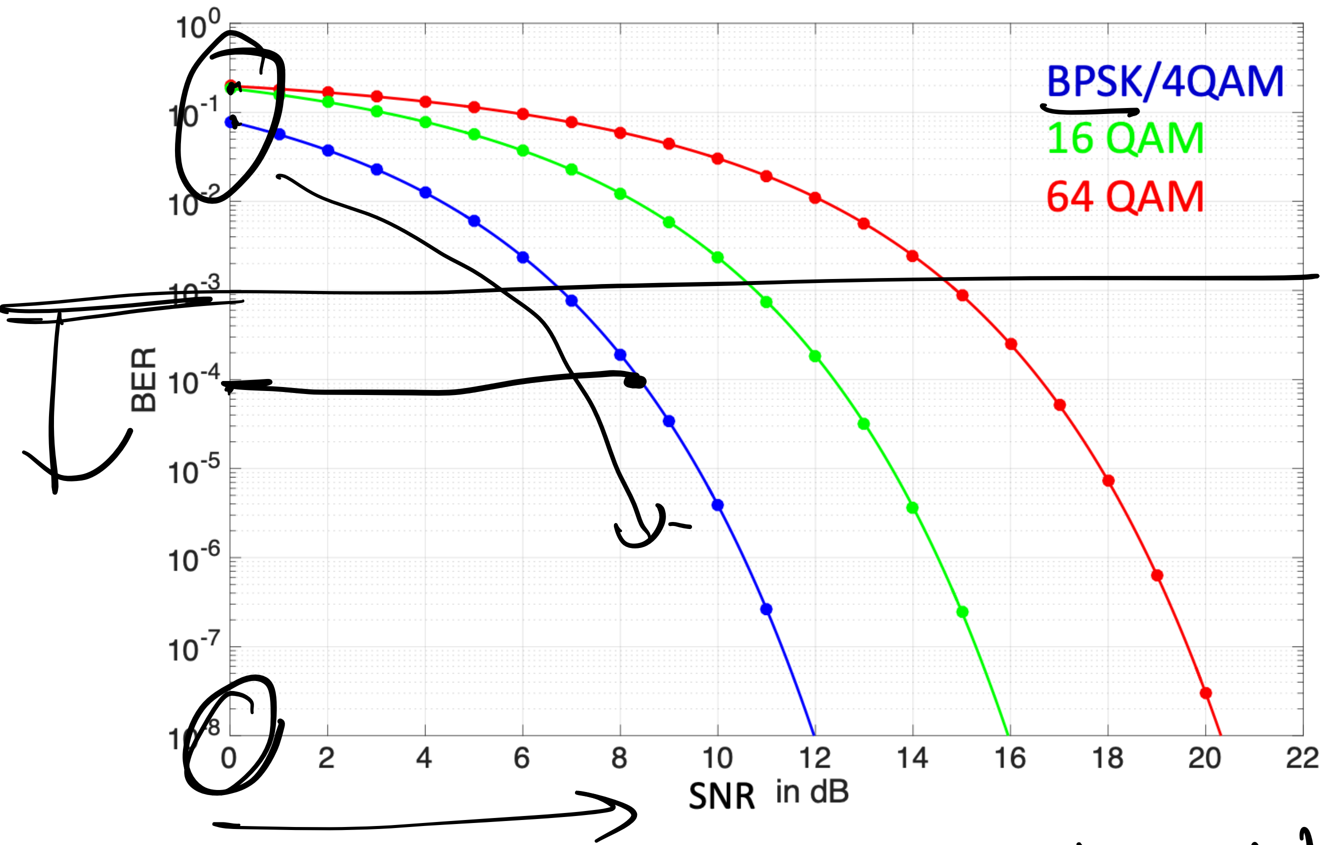
$$\underline{y} = \underline{h}x + \underline{n} + \underline{i}$$

$$\text{SINR} = \frac{|hx|^2}{|n+i|^2}$$

← noise + interference → on the same freq.



BER → bit error rate.



1000 bits → 1000 bits

sender — compare — receiv

$$BER = \frac{\#\text{ bits wrong}}{\text{total bits}}$$

$BER \approx 0.5$

Data Rate / Capacity

Data rate → how many bits can I send per second?

1 Gbps → 10^9 bits per s

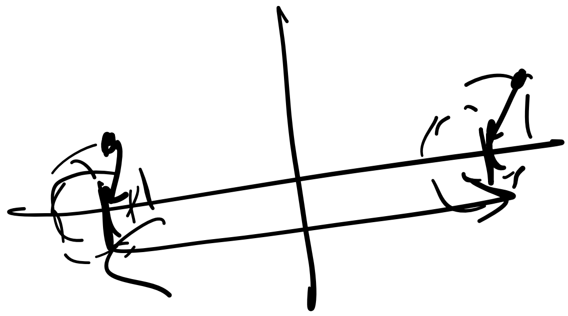
100 Mbps → 10^8 bits per s

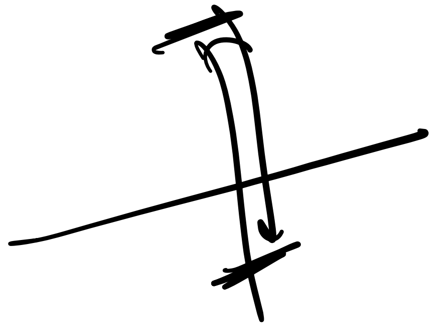
Data rate = bits per symbol (→ modulation scheme) × symbol per second (→ hardware)

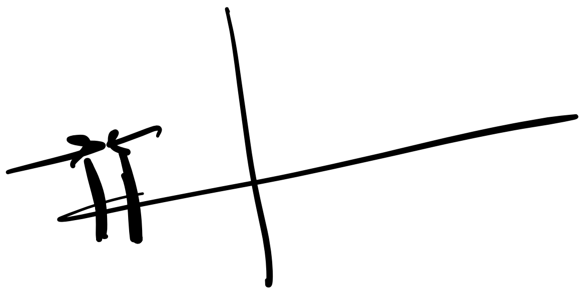
BPSK → bits/symbol = 1 → 10^6 sps → 1 Mbps; 10 Msps

QAM → bits/symbol = 2 → 2 Mbps

Rate adaptation algorithms:







Capacity of a link

$$\propto BW \log_{2/10}(1+SNR)$$

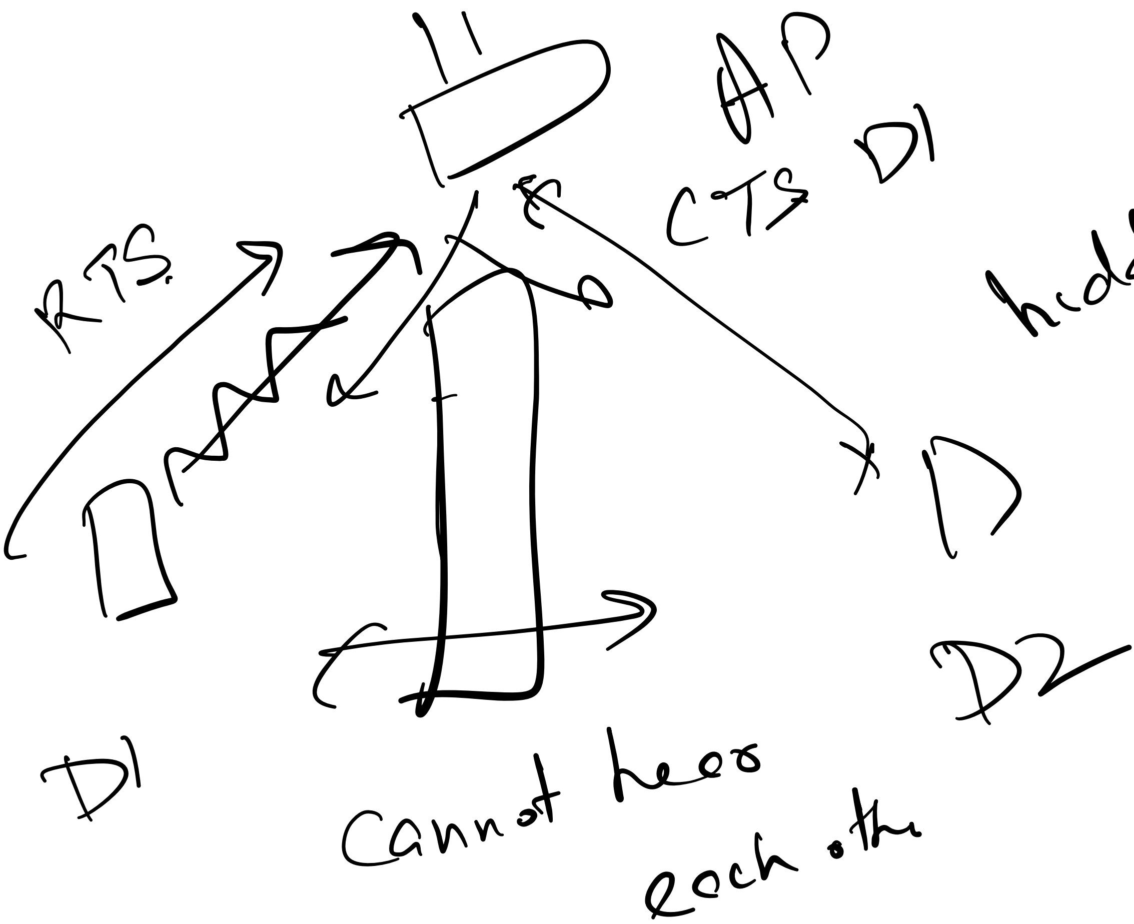
$\hookrightarrow$ not dB

Zigzag
- Channel
- Hidden Terminals
- Decoding Collisions
- Results.

Hidden terminals

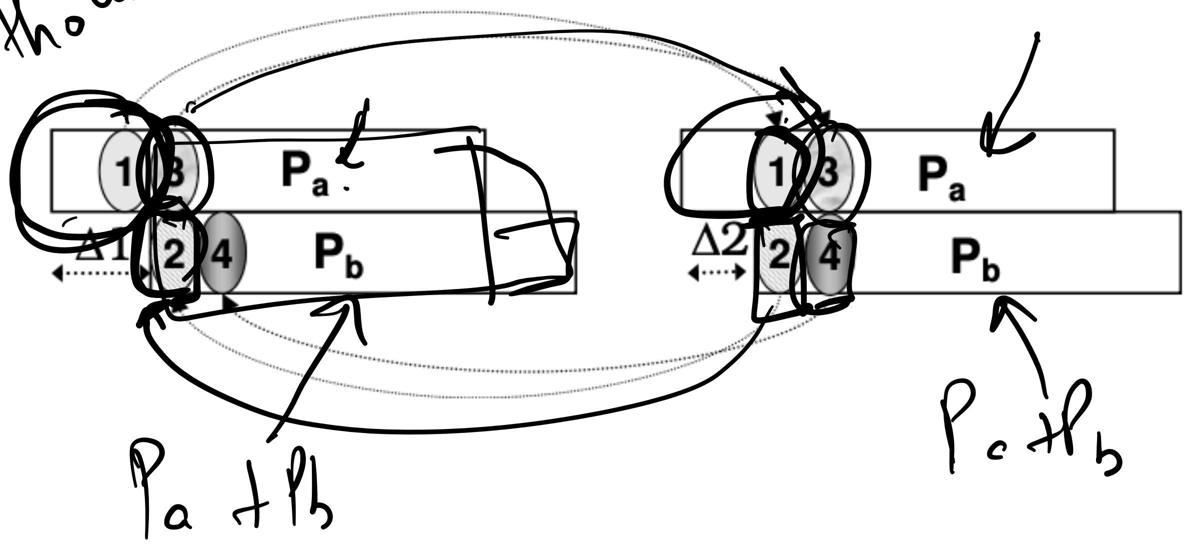
Medium access protocols

listen before talk.



hidden terminal

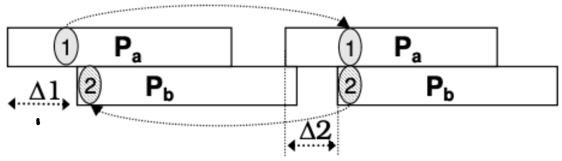
without errors



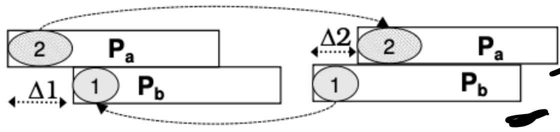
two variables

RTS/CTS → clear to send,

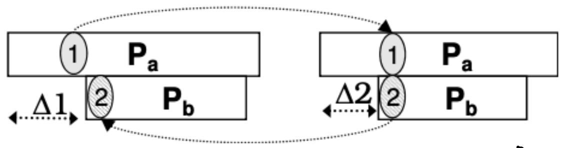
↳ request to send



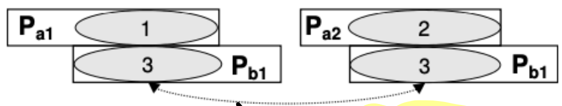
(a) Overlapped Collisions



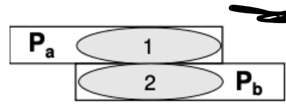
(b) Flipped Order



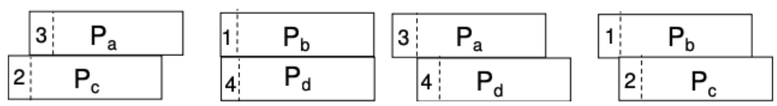
(c) Different Packet Sizes



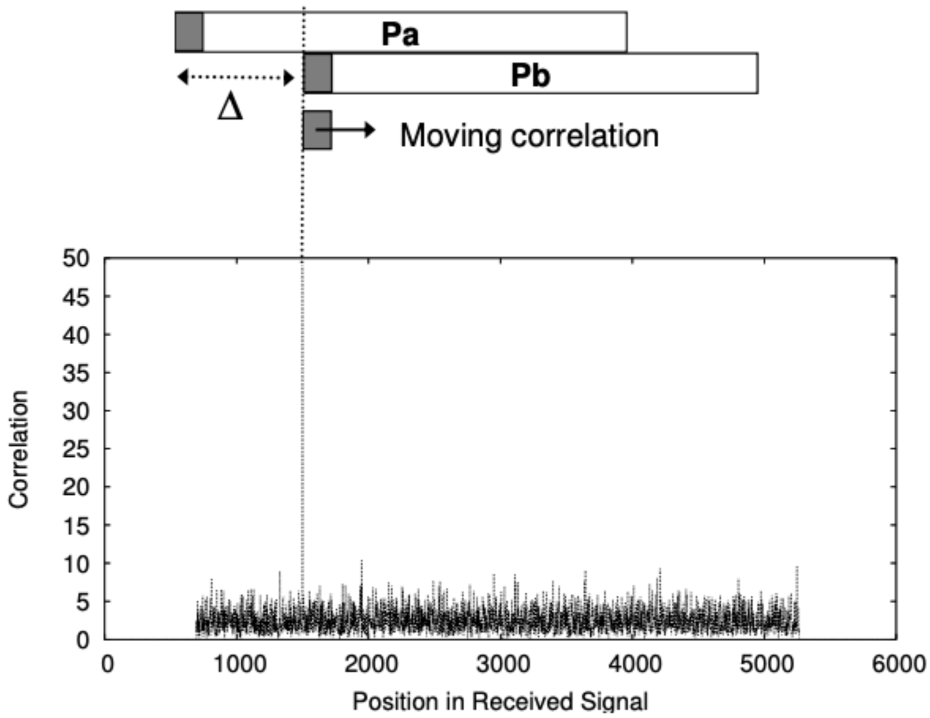
(d) Alice's Packets Enjoy the Capture Effect



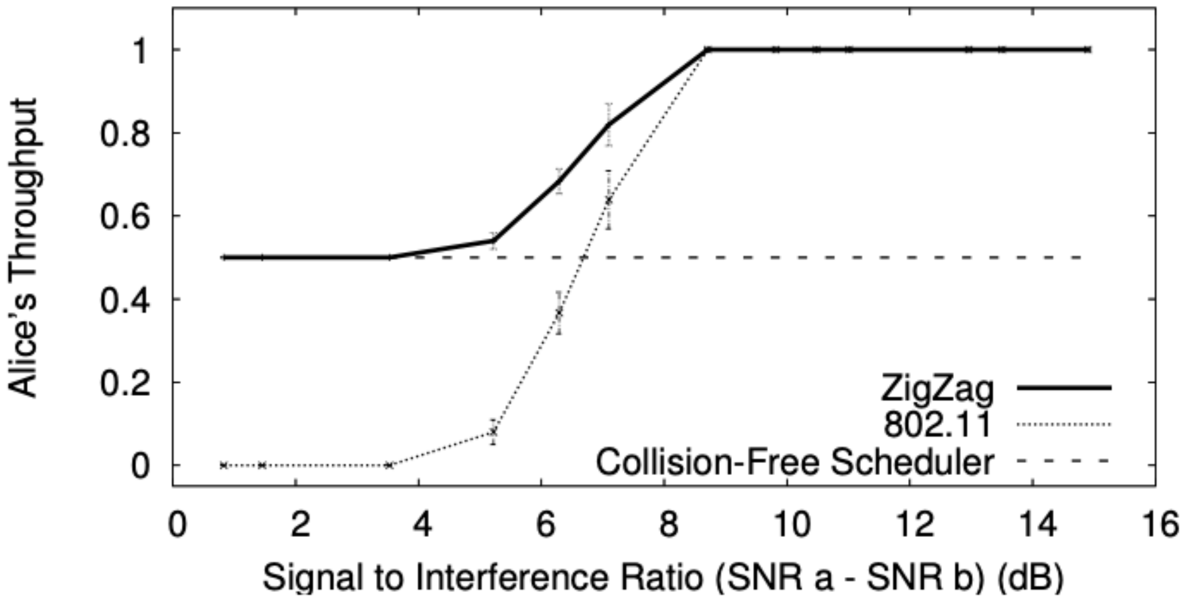
(e) Single Decodable Collision; Inefficient Choice of Bit Rates



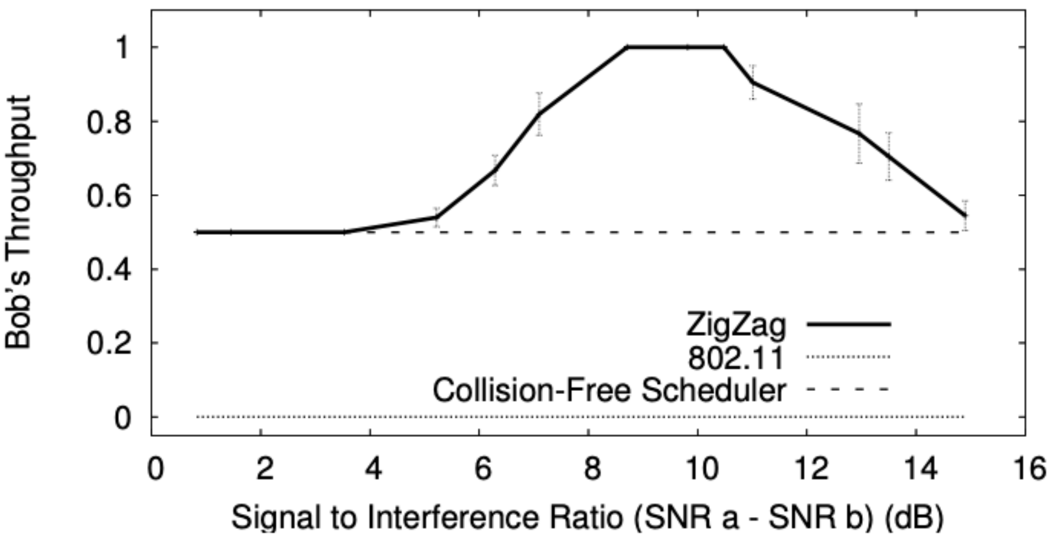
(f) Nodes A and B are hidden from C and D



Pa
Pb
Δ
Moving correlation
Correlation
Position in Received Signal

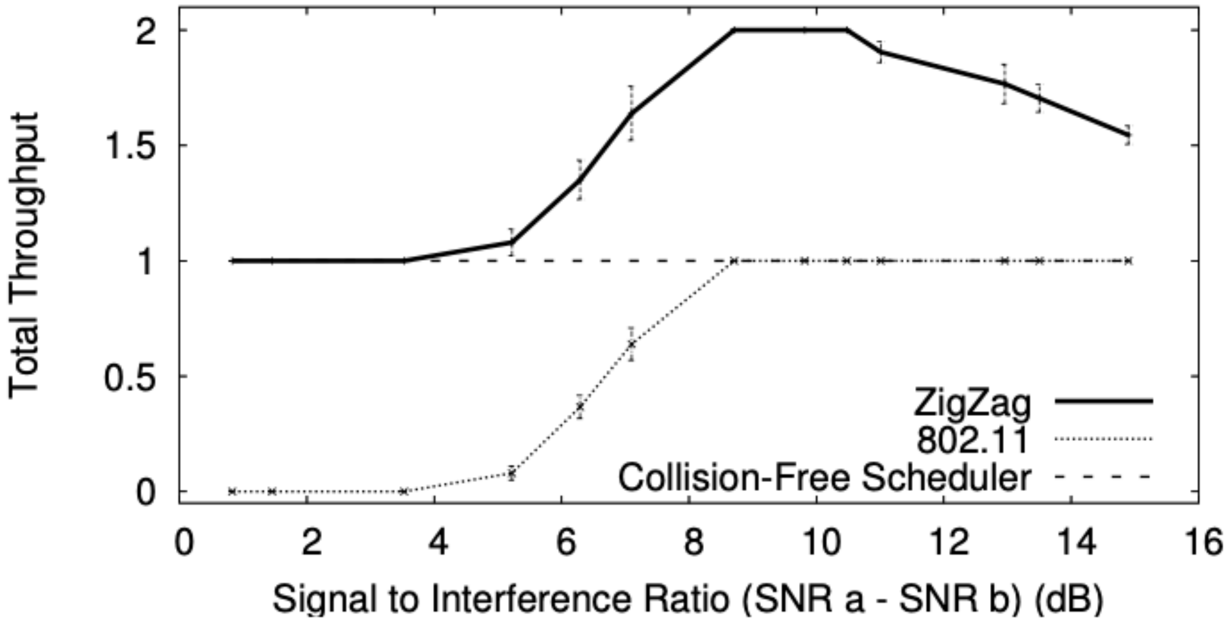


(a) Alice's Throughput



(b) Bob's Throughput

(b) Bob's Throughput



(c) Total Throughput

Figure 14: Impact of SINR. The figure plots the throughput of t