Wireless Communications & Networking

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Main Difference between Wired and Wireless

- Signal not “sealed” in the cable -
  power loss over long distance & obstructions
  - Low Signal-to-Noise Ratio (SNR)
    —> erroneous transmission
- Multi-path
  - Rapid signal fluctuation and self-interference
- Shared medium
  - Shared bandwidth & interference

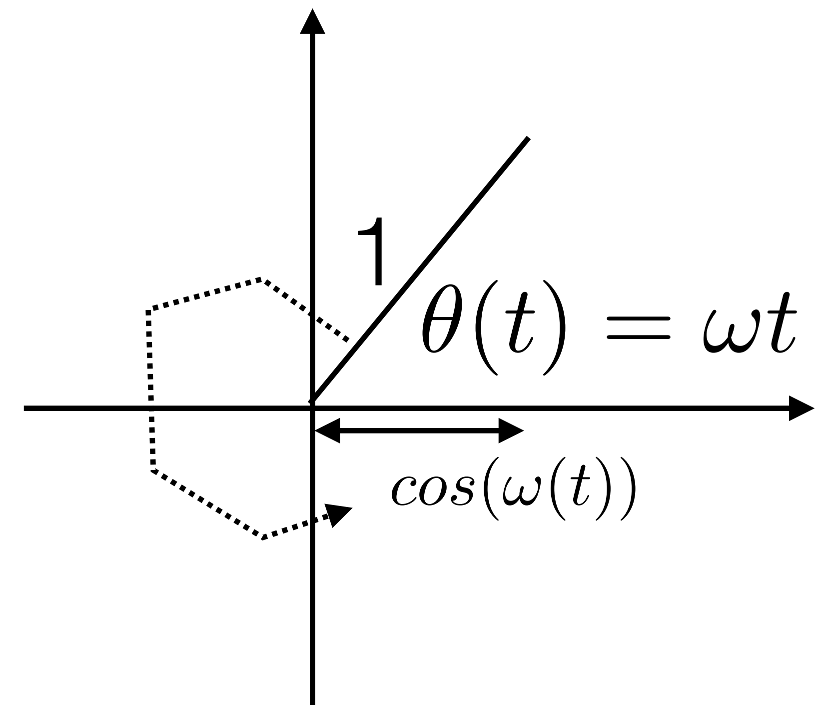
Outline

- Modulation - how to represent information with waveform
- Path loss - power loss over distance
- Multi-path fading -
  rapid power fluctuation & self-interference
- Multiplexing - how to share
- Additional MAC designs
- Rate adaption
- What can we do (for WiFi systems)

The fundamental waveform - sinusoidal wave

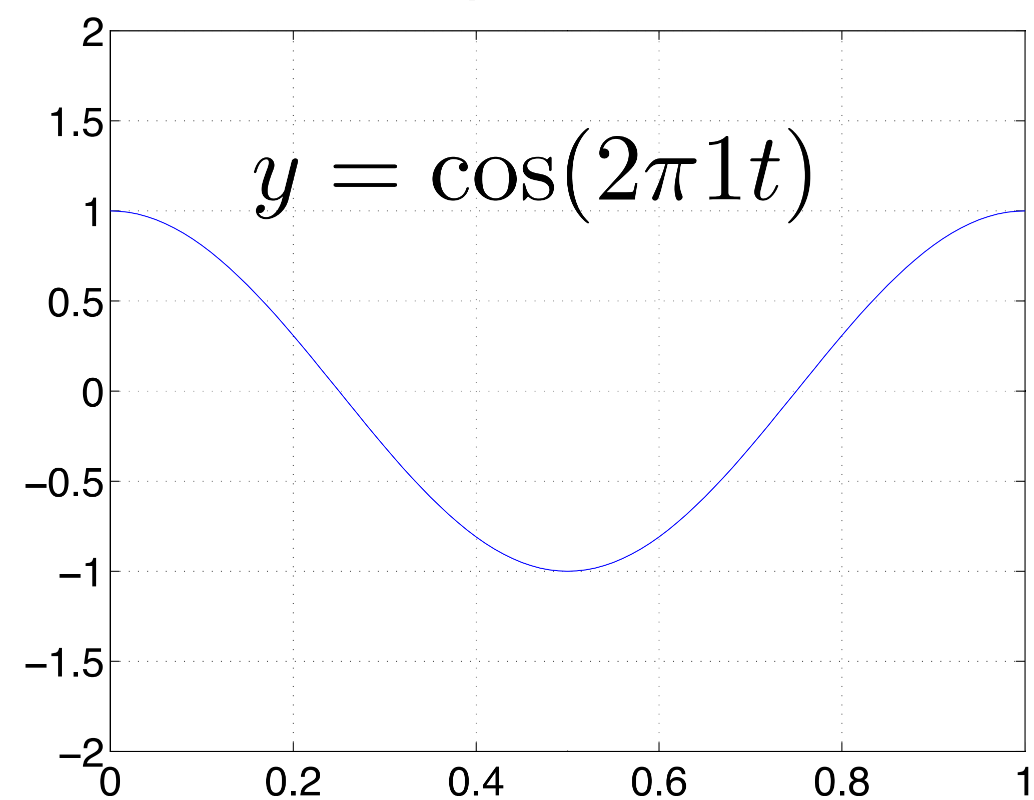
$$y = \cos(\omega t) \ = \cos(2\pi f t)$$

ω : angular frequency
(每單位時間轉多少弧度)



$$\omega = 2\pi f$$

f : frequency (Hz)
(每單位時間轉多少2 pi, 圈)



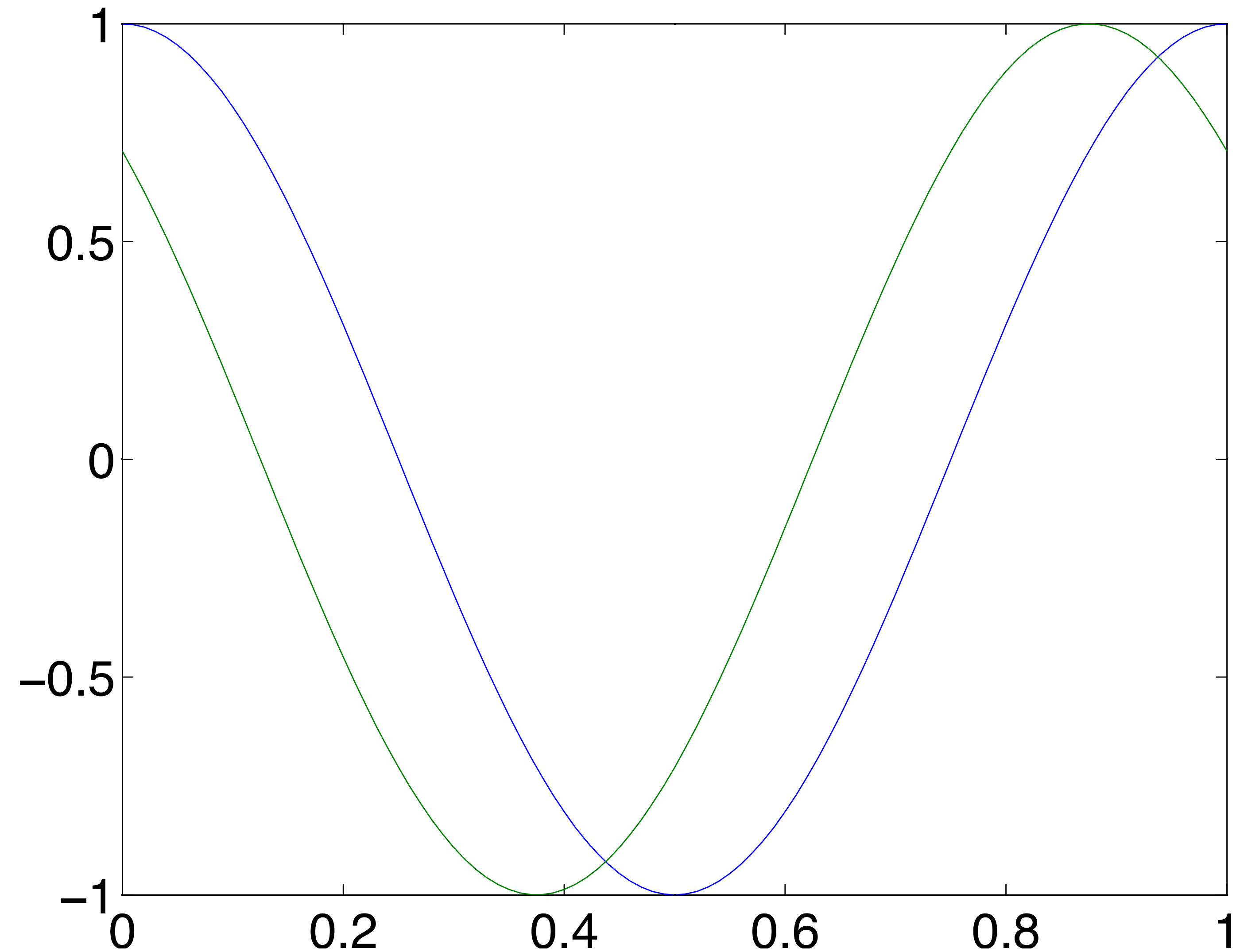
How about
$y = \cos(2\pi \cdot (2.4 \cdot 10^9) \cdot t)$?

Sinusoidal Wave - Initial Phase

Initial phase created "shifted" waveform

$$y = \cos(2\pi f t + \phi)$$

$$\phi = \frac{\pi}{4}$$



Modulation - How to represent information?

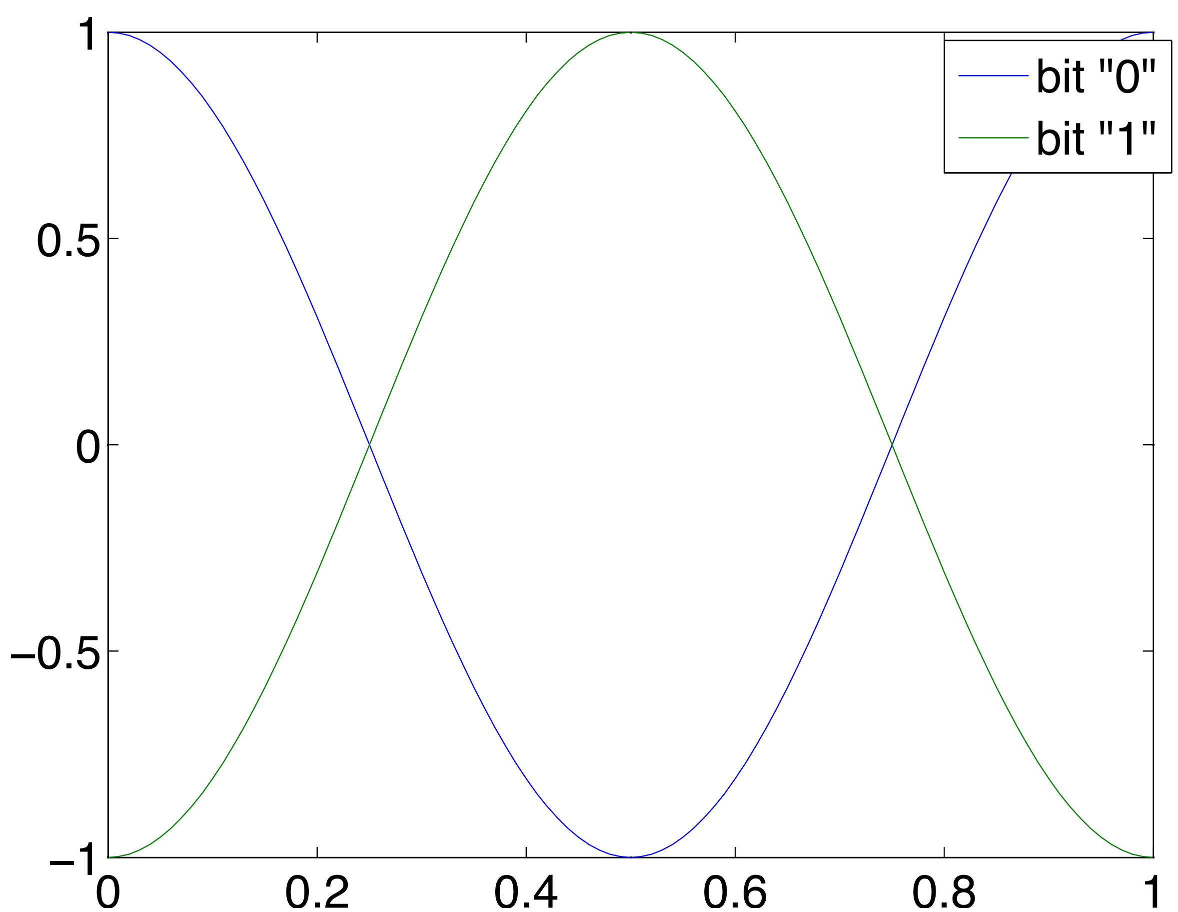
- Symbol: map to a number of bits
- Example: When one symbol map to:
    - 1 bit, then there are 2 kinds of symbol, mapping to “0” and “1”
    - 2 bits, then there are 4 kinds of symbol, mapping to “00”, “01”, “10”, and “11”
- Each symbol corresponds to a particular waveform

Phase Shift Keying (PSK)

Binary Phase Shift Keying (BPSK, or 2-PSK)

$$s(t) = \cos(2\pi f_c t + 0)$$ bit "0"

$$s(t) = \cos(2\pi f_c t + \pi) = -\cos(2\pi f_c t)$$ bit "1"



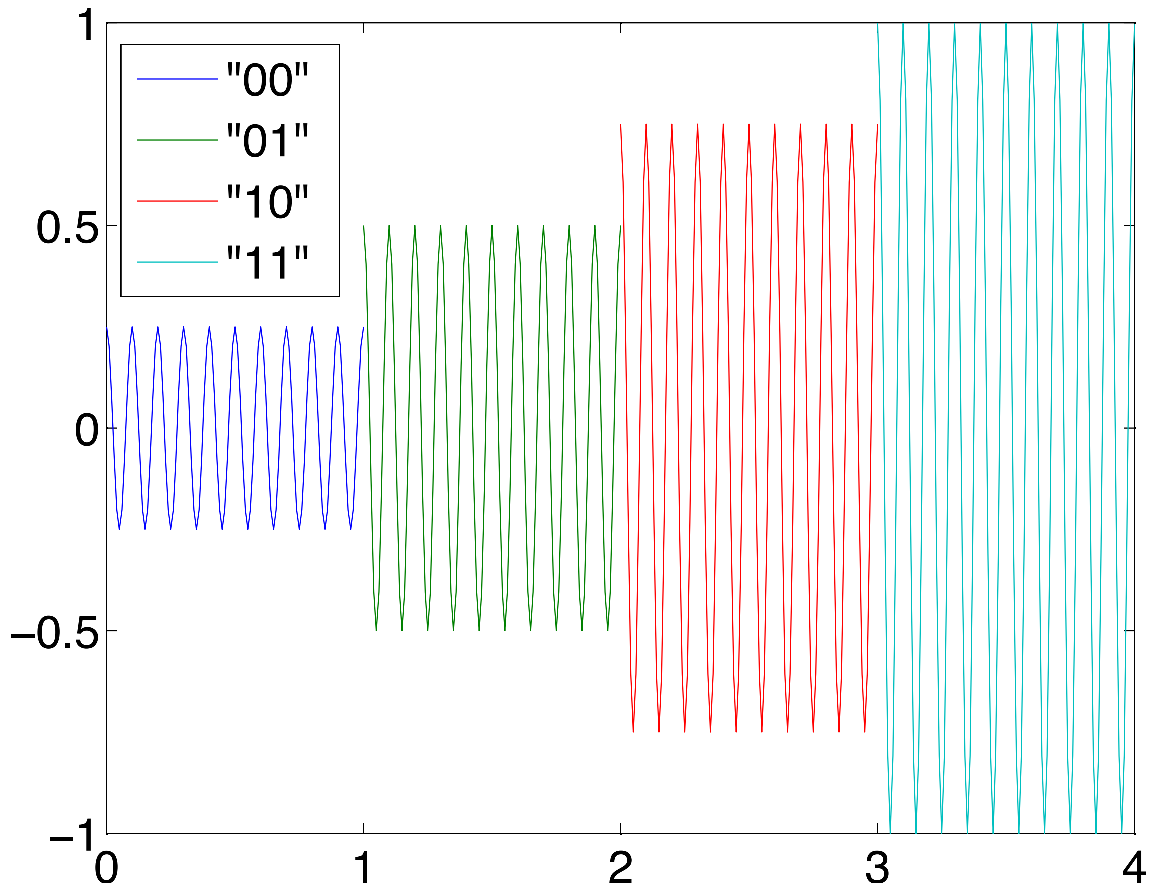
$$s(t) = \cos(2\pi f_c t + \phi_i)$$

$$\phi_i = \{0, \pi\}$$

Amplitude Shift Keying (ASK)

4-Amplitude Shift Keying (4-ASK)

$$s(t) = a_i \cos(2\pi f t) \qquad a_i = \{\frac{1}{4}, \frac{2}{4}, \frac{3}{4}, 1\}$$



Q: Think about 8-ASK, what would the waveforms look like?

Power loss and noise

$$r(t) = \frac{1}{a(t)} s(t) + n(t)$$

n(t): noise

a(t): path loss

$$SNR = \frac{P_r}{\sigma_n^2}$$

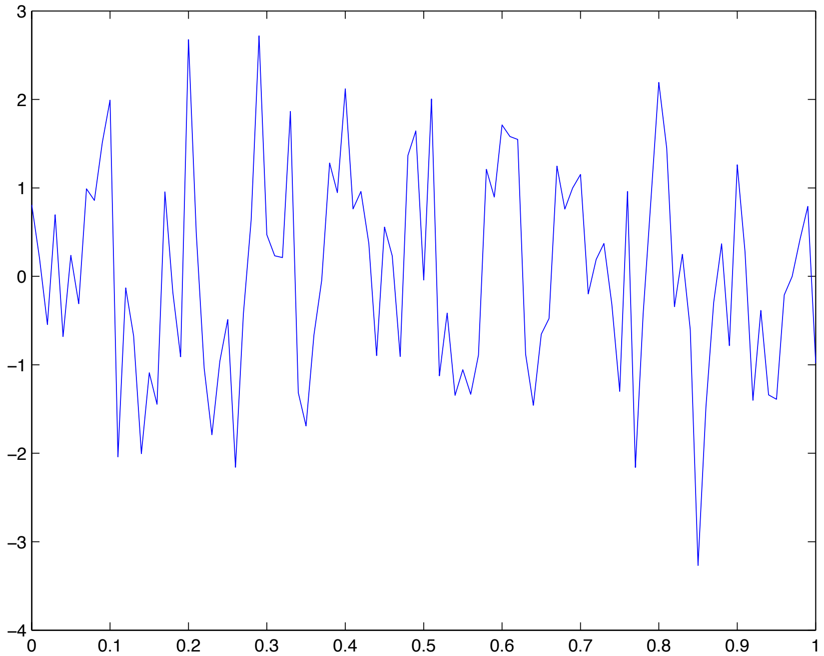
signal power (P_r)

noise variance (power) (σ_n^2)

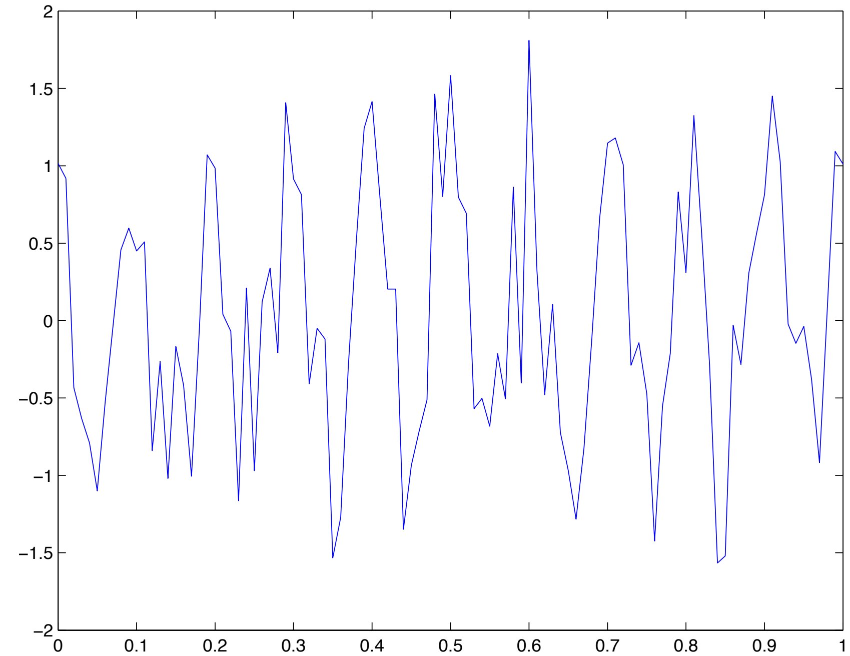
SNR versus Error Rate

Low SNR —> hard to decode
—> higher error rate

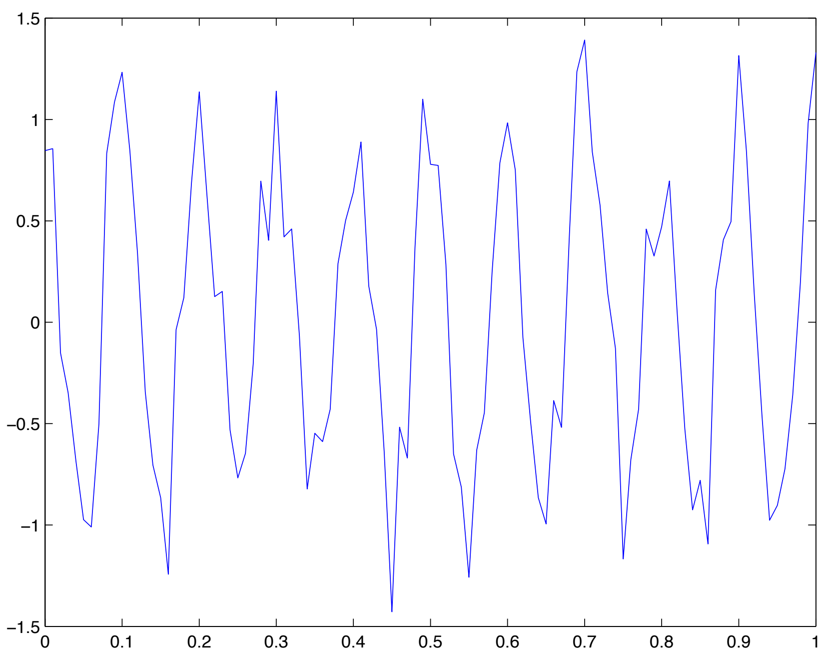
SNR=0 dB



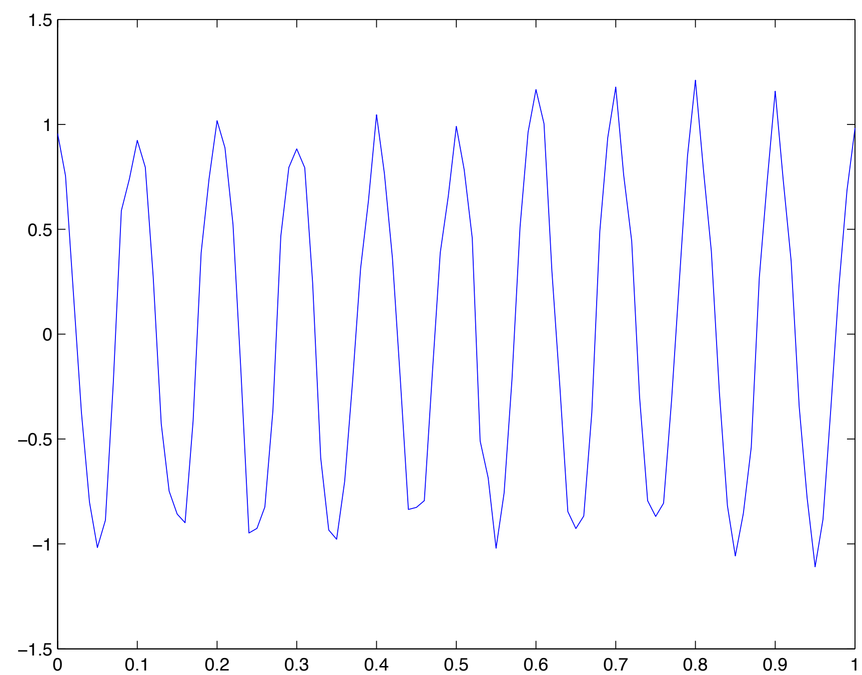
SNR=6 dB



SNR=12 dB



SNR=20 dB



Path Loss

$$r(t) = \frac{1}{a(t)} s(t) + n(t)$$

- Noise level is usually fixed
  (given a particular environment)

- Path loss determines the SNR (and error rate)

- Path loss is usually determined by
  distance & obstruction

Friis Formula

TX Antenna

d

RX Antenna

$\cdot A_e$

Antenna gain *G*

EIRP= $P_t G_t$

$$G = \frac{4\pi}{\lambda^2} A_e$$

Power spatial density (W/m²)

$$\cdot \frac{1}{4\pi d^2}$$

$$P_r = \frac{P_t G_t A_e}{4\pi d^2} = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2}$$

Friis formula & path loss exponent

- Free space path loss exponent = 2 (power attenuates with a factor of $1/d^2$)

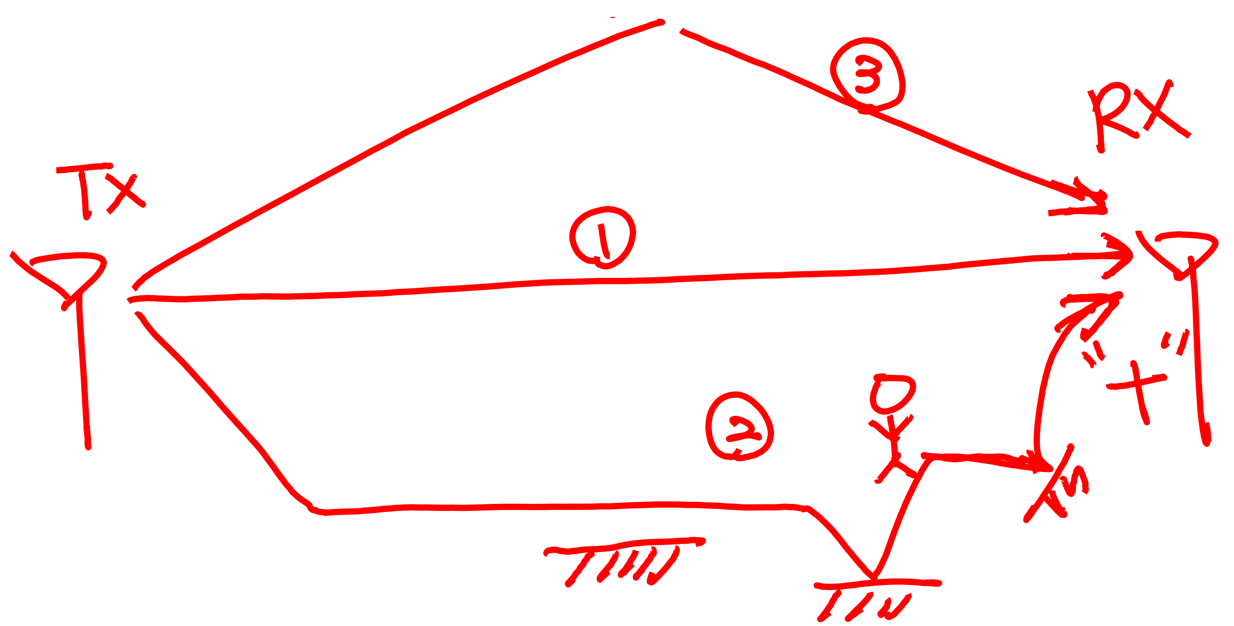
- **Higher frequency** signal experiences larger path loss (with the same antenna gain)

- In reality, $P_r \propto \frac{1}{d^\gamma}$

  γ : path loss exponent

Environment	Path-loss Exponent
Free-space	2
Urban area cellular radio	2.7-3.5
Shadowed urban cellular radio	3-5
In building LOS	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Multi-(propagation-)path



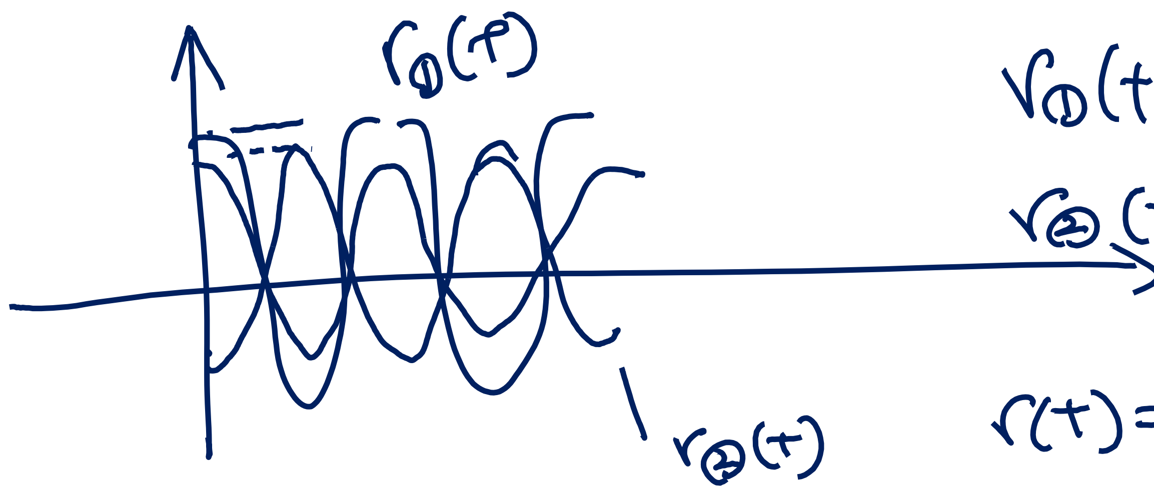
$$r_i(t) = \frac{a(t)}{\boxed{\rho}} \cos\left(\omega_c\left(t - \boxed{\Delta t}\right) + \phi\right)$$

$i =$ ①, ②, ③

$$r(t) = r_1(t) + r_2(t) + r_3(t) + \cdots$$

$$= \frac{a(t)}{\rho_1} \cos(\omega_c t + \phi_1) + \frac{a(t)}{\rho_2} \cos(\omega_c t + \phi_2) + \cdots$$

Multi-path —> power fluctuation (fading)



$$r_1(t) = \cos(\omega_c t)$$

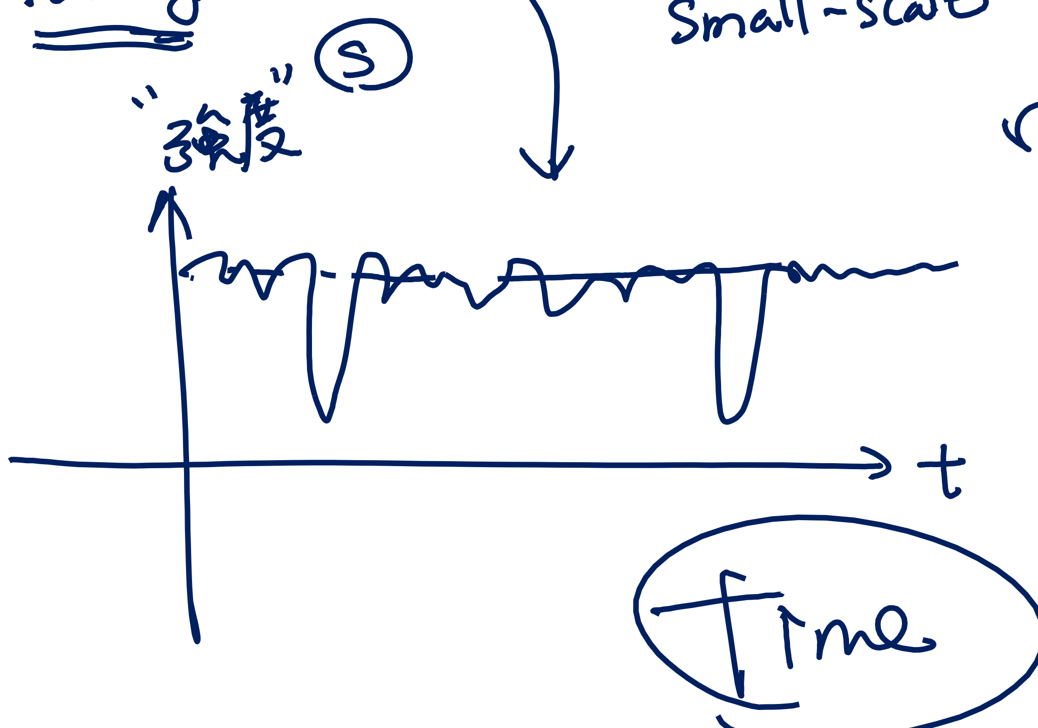
$$r_2(t) = 0.8\cos(\omega_c t + \pi)$$

$$r(t) = r_1(t) + r_2(t) = \cos(\omega_c t)(1 - 0.8) = 0.2\cos(\omega_c t)$$

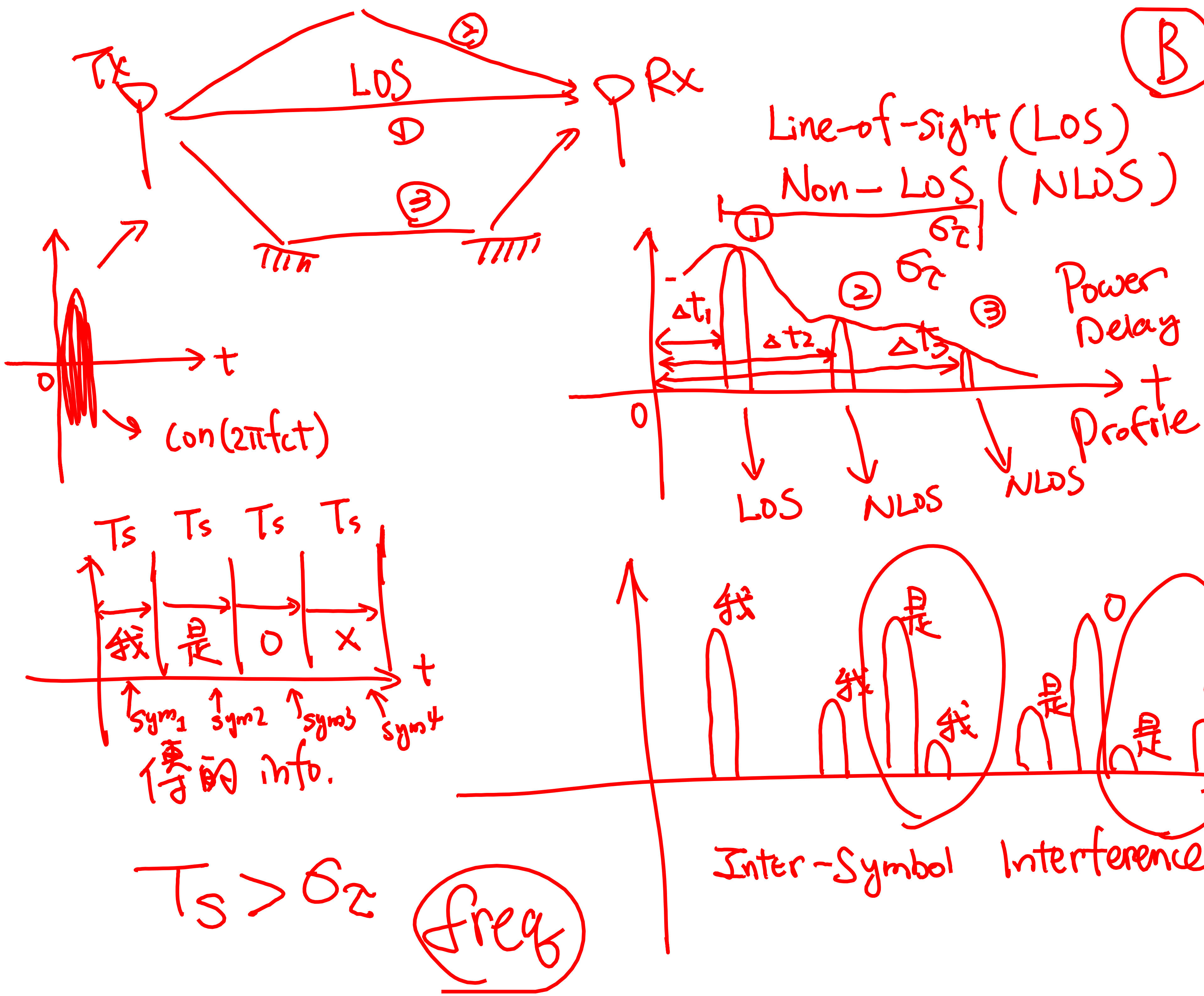
$$r(t) = r_1(t) + r_3(t) = \cos(\omega_c t)(1 + 0.6) = 1.6\cos(\omega_c t)$$

fading

"small-scale"



Multi-path —> inter symbol interference



Multiplexing - how to share the medium

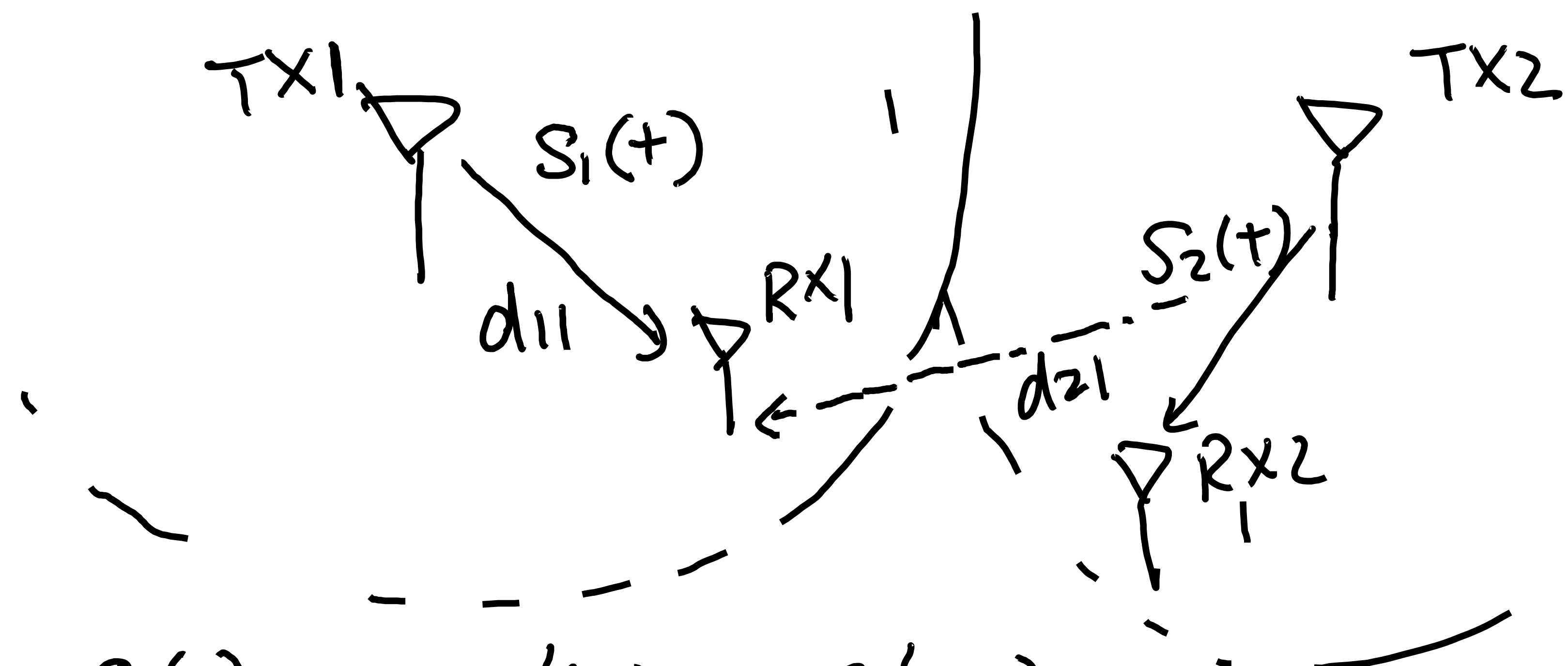
- Wireless channel is a broadcast channel
—> when you transmits, “everyone can hear”

- Duplexing: allows TX & RX to both happen
Multiplexing:
allows multiple sets of TX and RX to both happen

- Examples of multiplexing methods:
Spatial, frequency, and time multiplexing

Spatial Multiplexing

① Spatial Multiplexing (Spatial Reuse)



$d_{11} \ll d_{21}$

$L_{21} \propto d_{21}^{\gamma}$

$L_{11} \propto d_{11}^{\gamma}$

$$r_1(t) = s_1'(t) + s_2'(t)$$

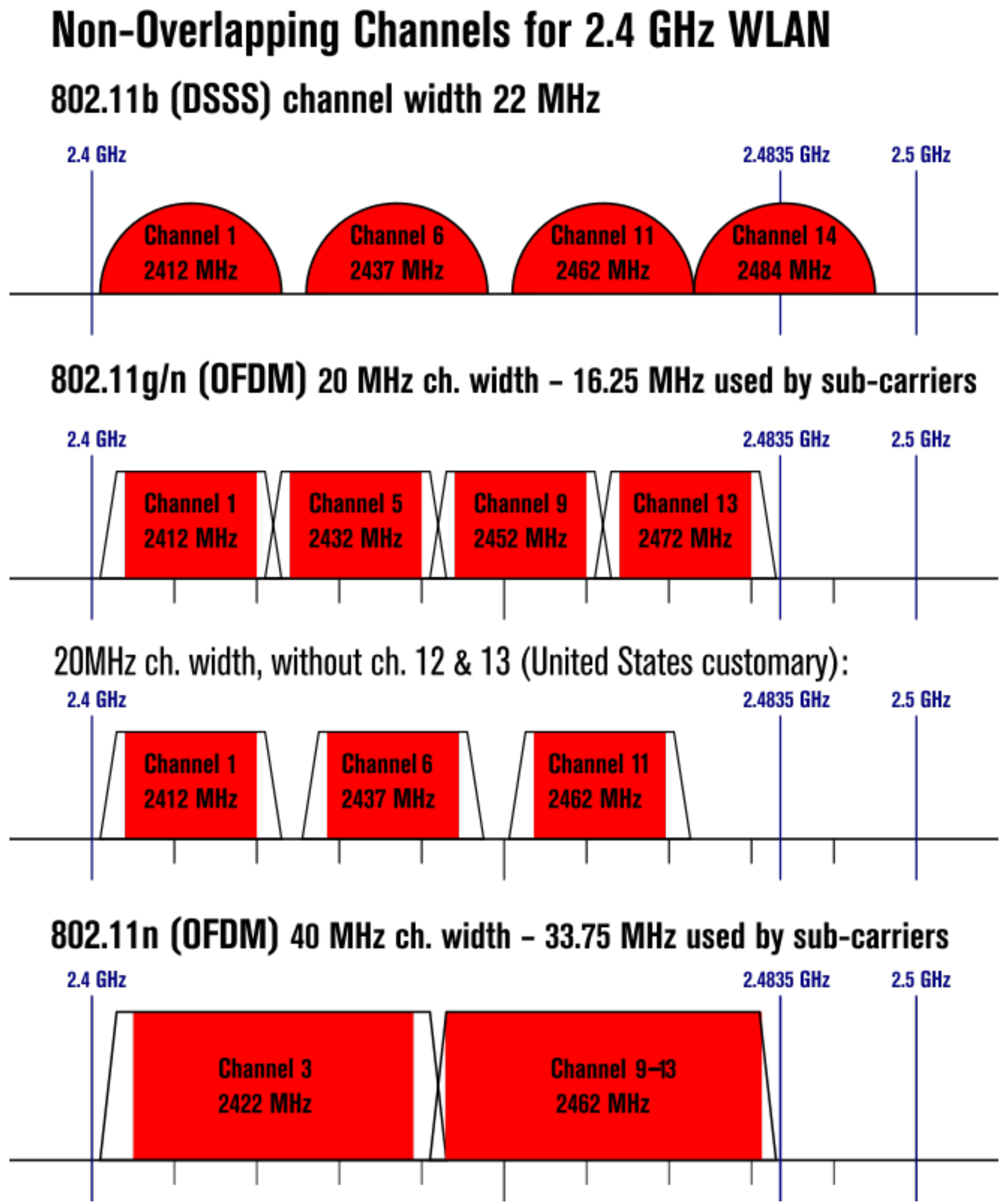
$$= \frac{a_1}{L_{11}} s_1(t+\phi_1) + \frac{a_2}{L_{21}} s_2(t+\phi_2)$$

intended received signal

interference → 0

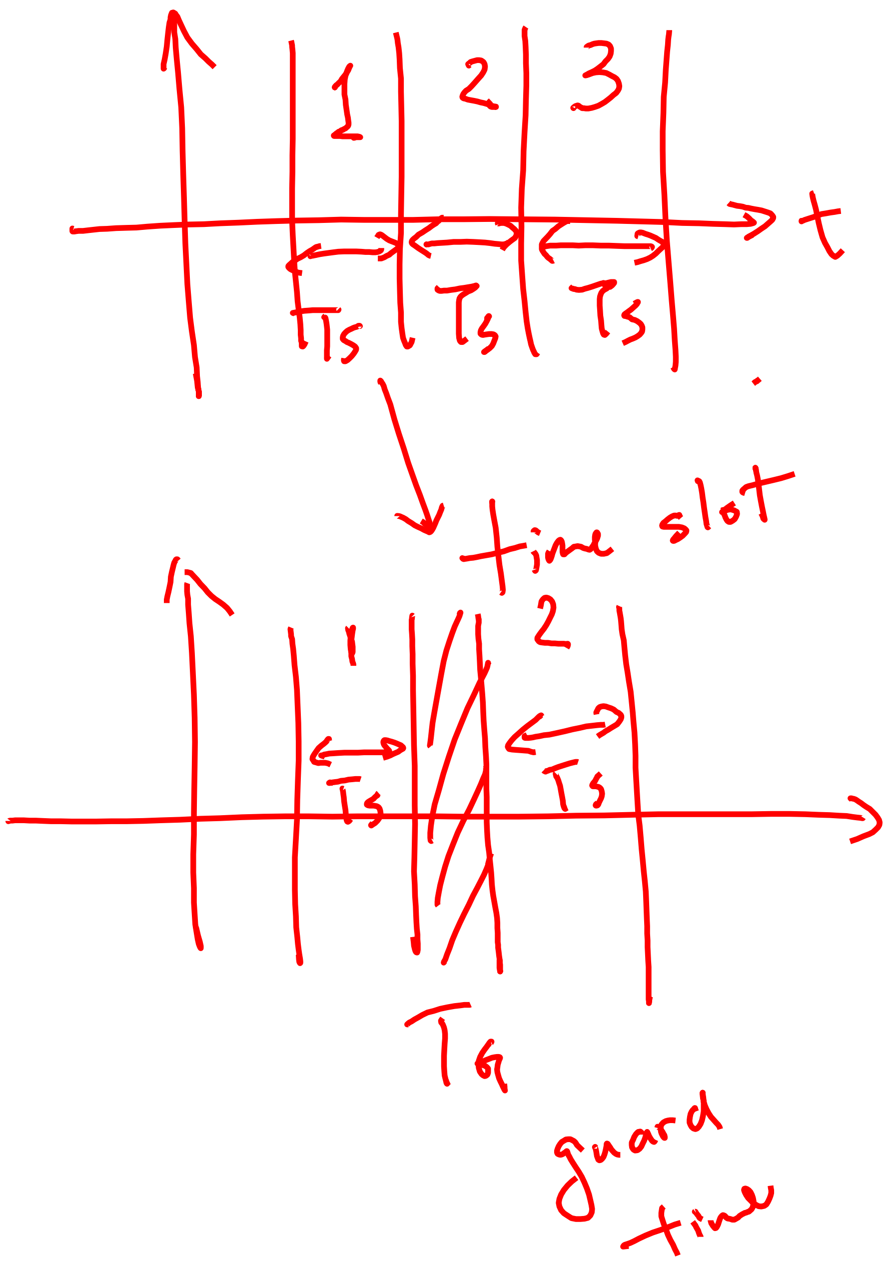
干擾

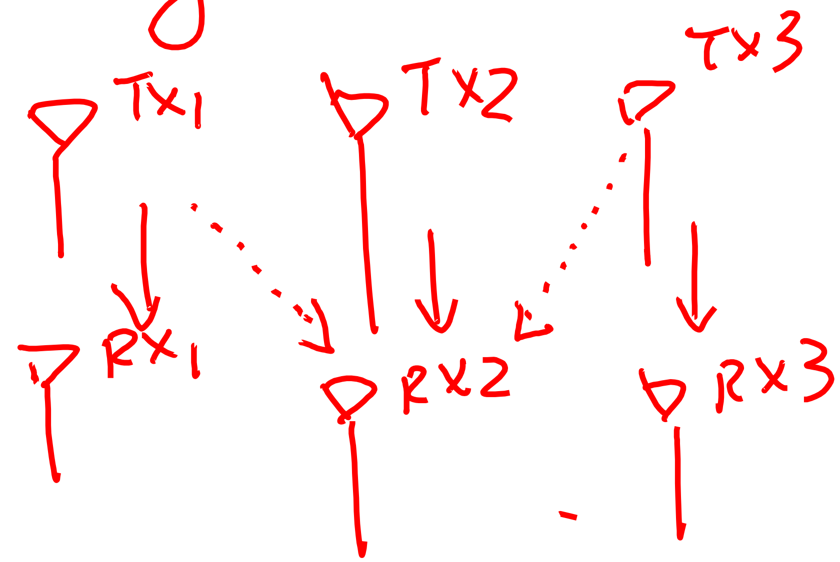
Frequency-Division Multiplexing



Time-Division Multiplexing

② Time-Division Multiplexing



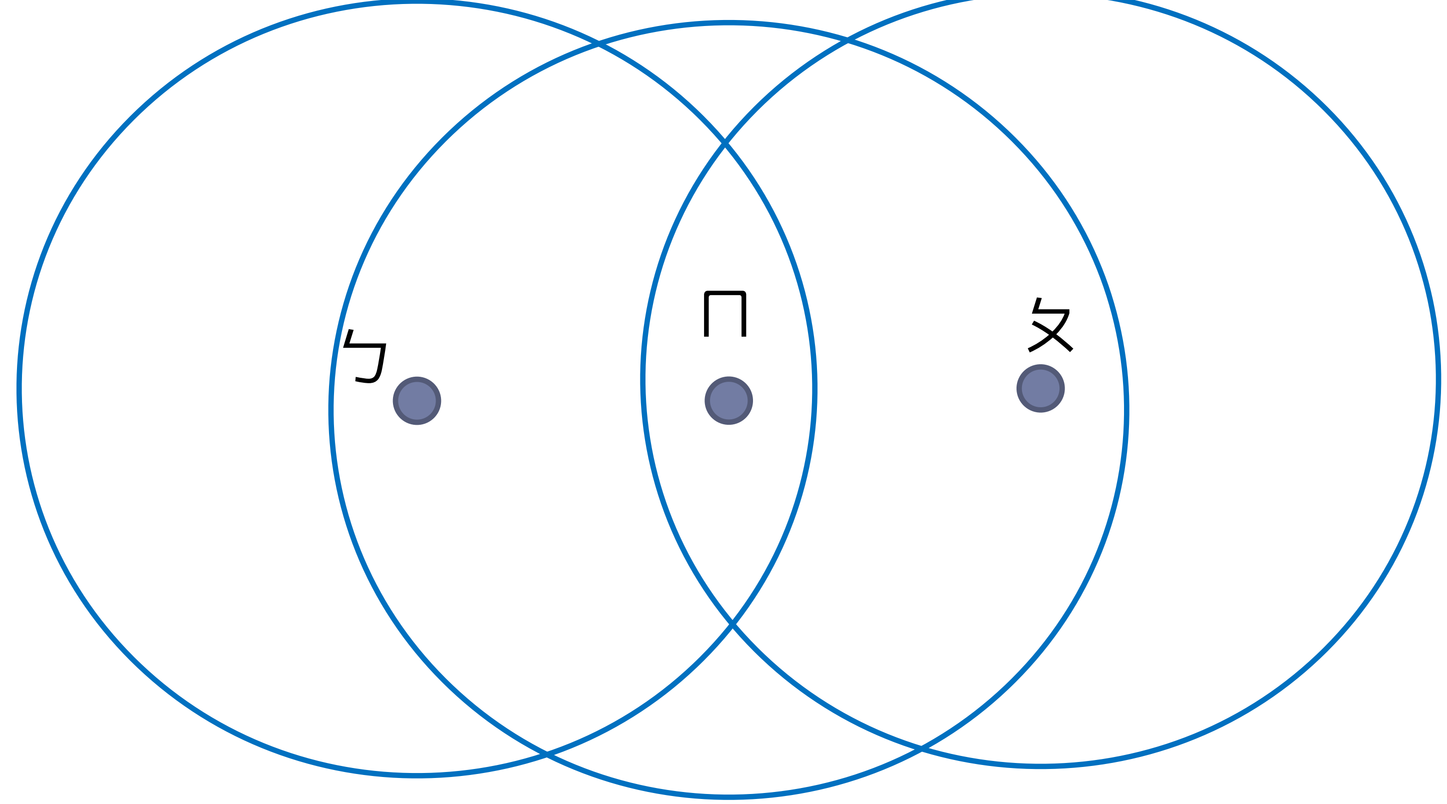


① time synchronization

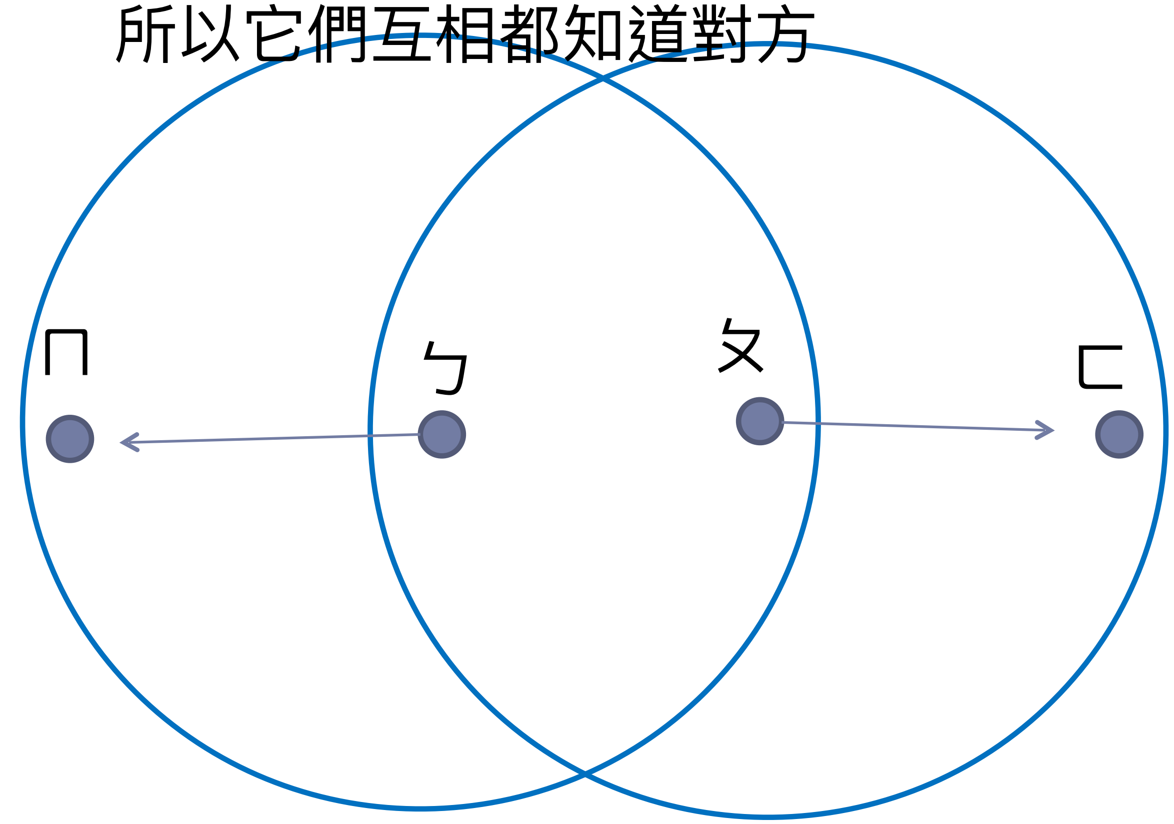
② guard time → overhead

Additional MAC Design for Collision Avoidance

- IEEE 802.11 (WiFi)
- Handshake四部曲
    - RTS (Request to send)
    - CTS (Clear to send)
    - Data
    - ACK (Acknowledgement)
- 使用 NAV (Network Allocation Vector)
    - 在CTS中標示需要保留通道的時間(虛擬CSMA)

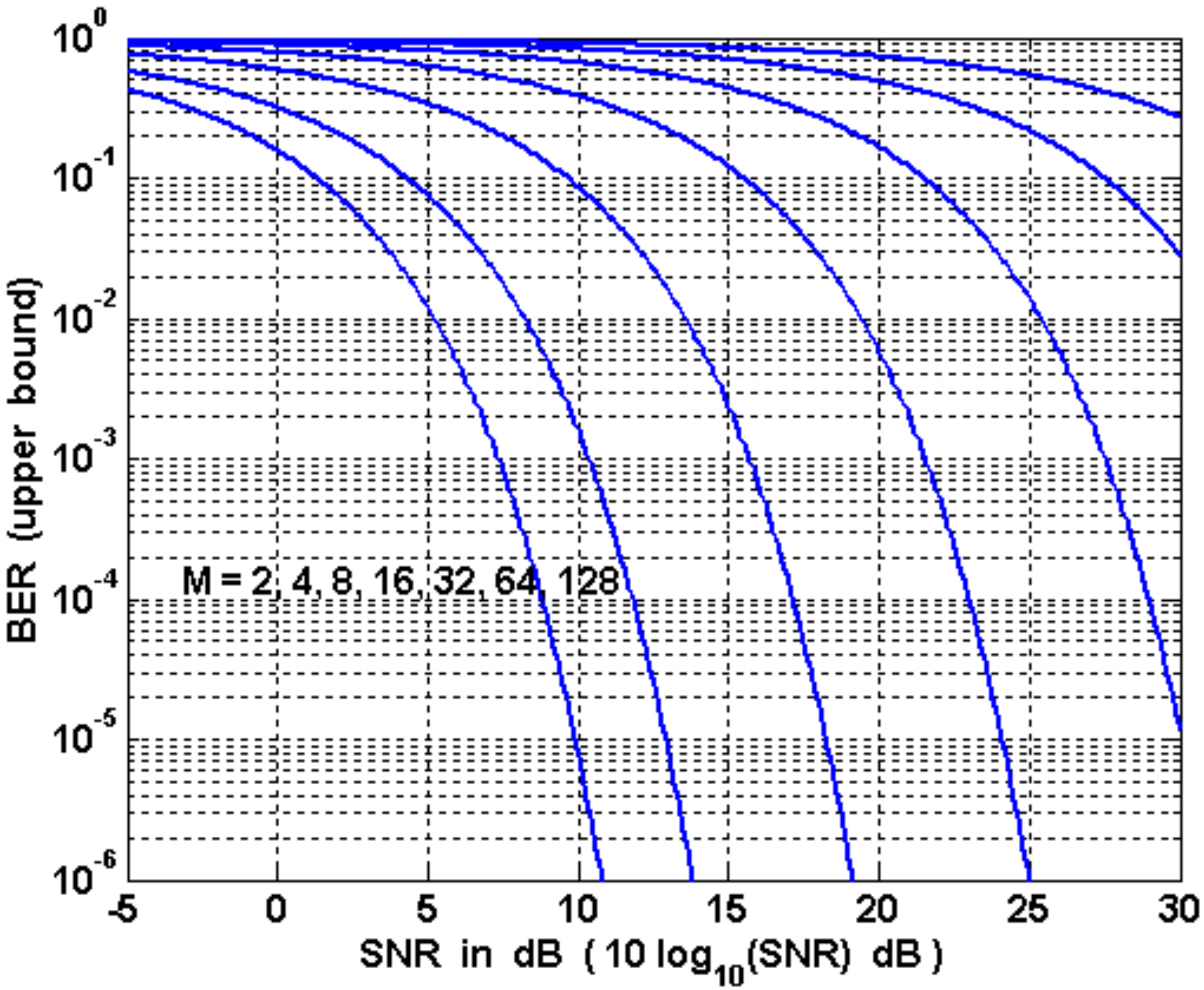


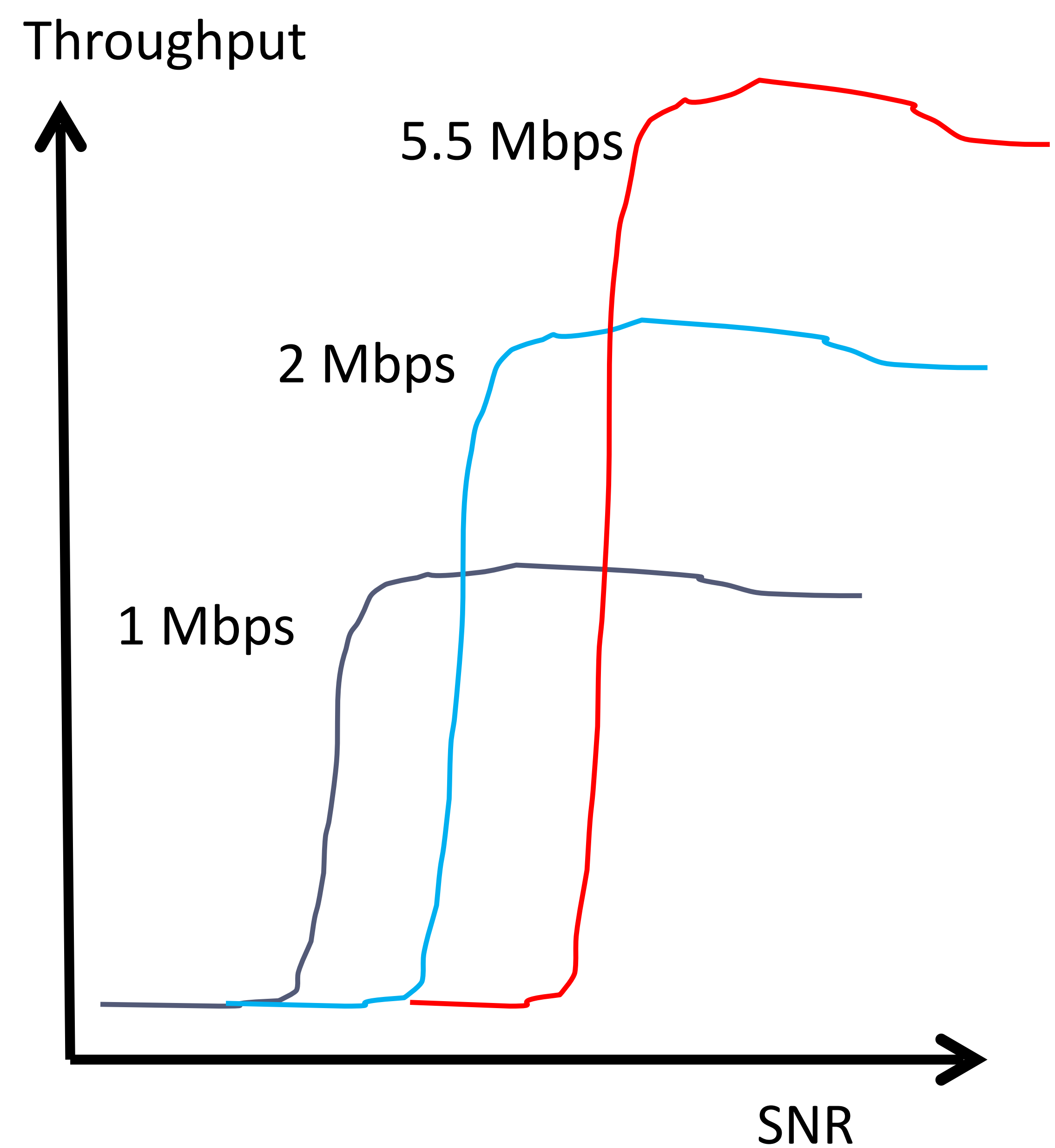
CTS 會被ㄅ和ㄆ接收到，
所以它們互相都知道對方



CTS of ㄇ→ㄅ 不會被 ㄆ接收到
CTS of ㄈ→ㄆ 不會被 ㄅ接收到
因此它們可以同時傳輸

Rate Adaptation





- 當SNR不足，但是傳輸速率(data rate)太高時會使一大部分的封包都錯誤
- 一般作法:
  - 當出現連續封包錯誤時，降低傳輸速率一級。
  - 當出現連續封包正確時，提升傳輸速率一級。
- 問題: 當封包出現連續錯誤時，並無法確定是因為SNR太低! (可能是碰撞!)
- 降速→相同大小封包傳更久→更容易碰撞!

What can / can’t we do (to improve WiFi systems)?

- Can’t:
  - Wireless channel (time variation, ISI)
  - Type of modulation (standard)
- Can:
  - Bandwidth (20/40/80/160 MHz)
  - Frequency (2.4 GHz, 5 GHz, channel assignment)
  - Data rate (e.g., 1 Mbps, 2 Mbps, 5.5 Mbps, etc.)
- Planning:
  - Transmission power
  - Location of the AP (distance, obstruction)
  - Traffic throttling

How do we add more system capacity?

- We can add more APs!
- But TX power (AP/client) needs to be scaled down.
- Otherwise:
  - Collision
  - Back-off (MAC)
  - Rate adaption algorithm selects a lower rate