

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

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

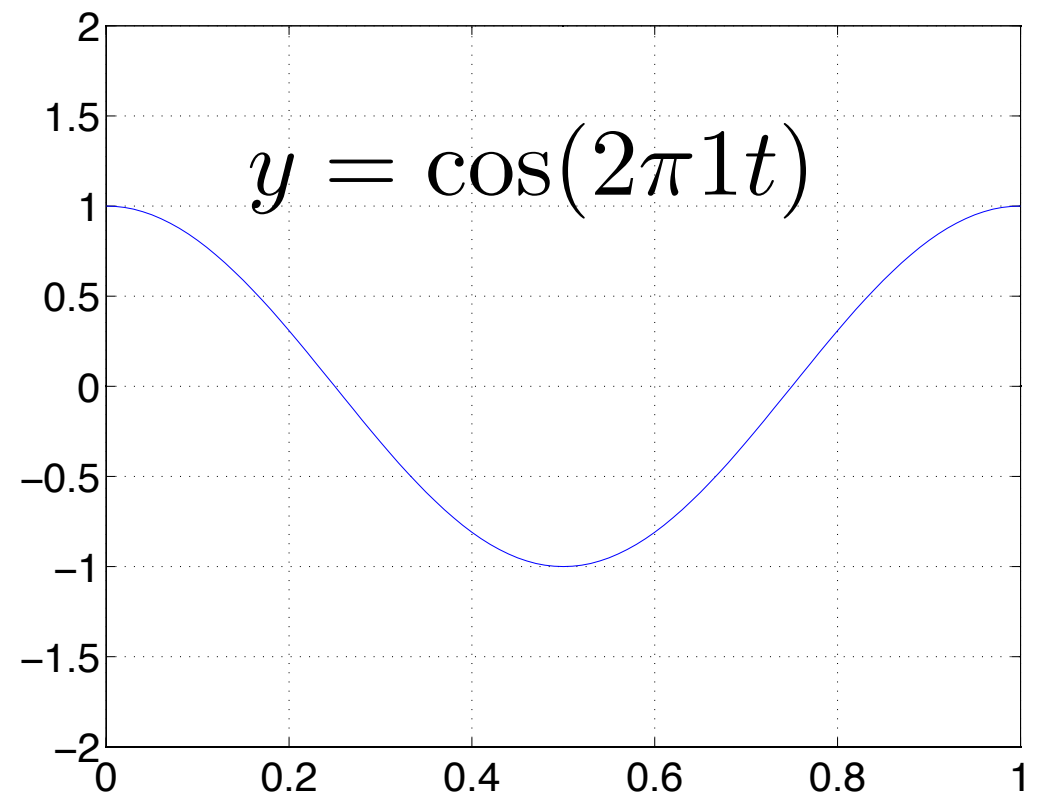
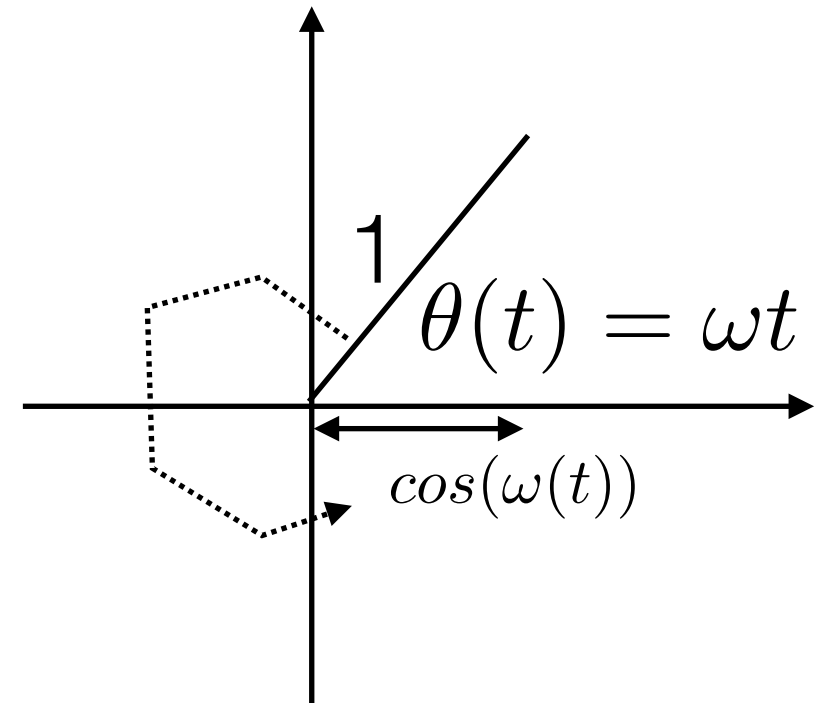
ω : angular frequency
(每單位時間轉多少弧度)

$$\omega = 2\pi f$$

f : frequency (Hz)
(每單位時間轉多少2 pi, 圈)

How about

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

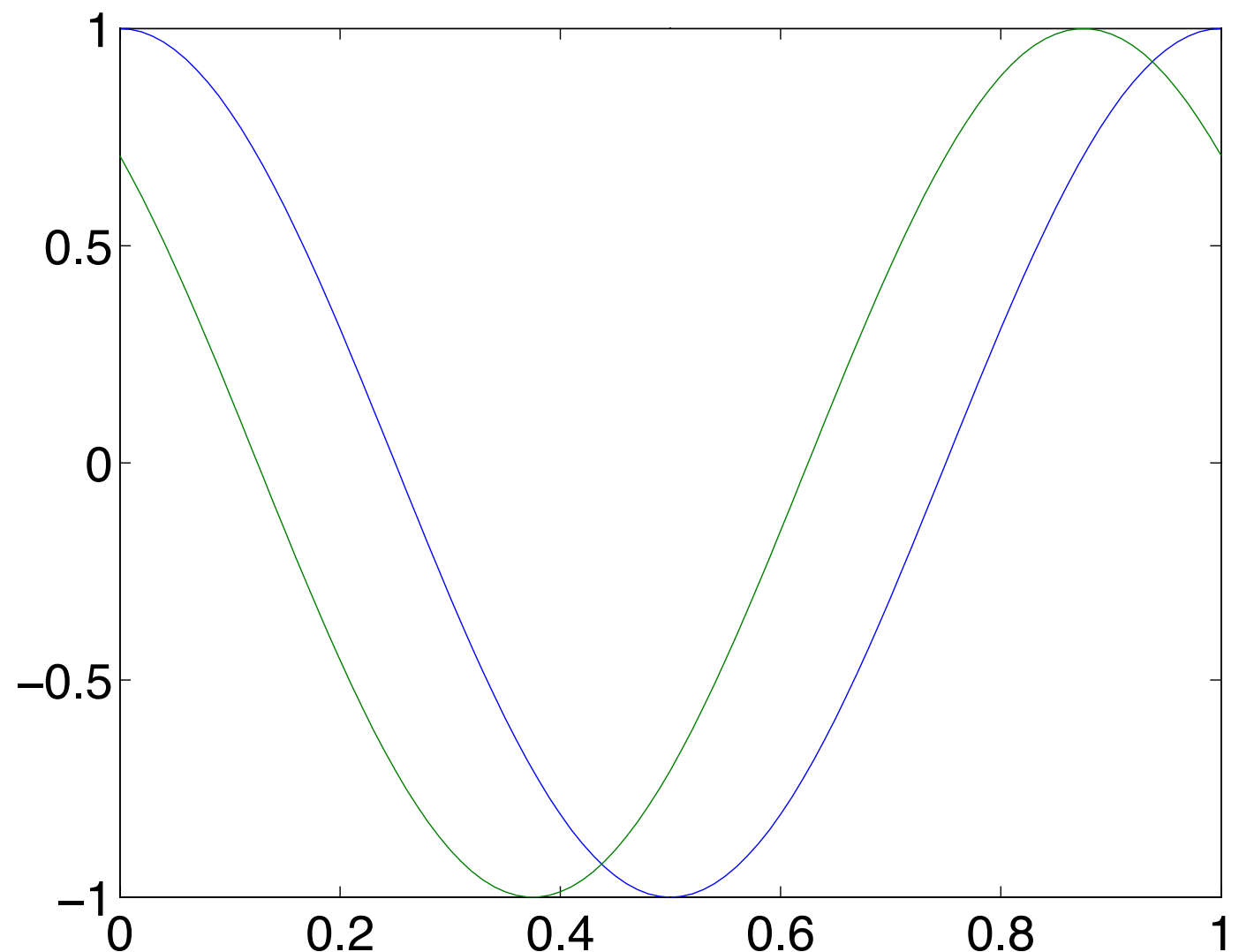


Sinusoidal Wave - Initial Phase

Initial phase created “shifted” waveform

$$y = \cos(2\pi ft + \phi)$$

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



Modulation -

How to represent information?

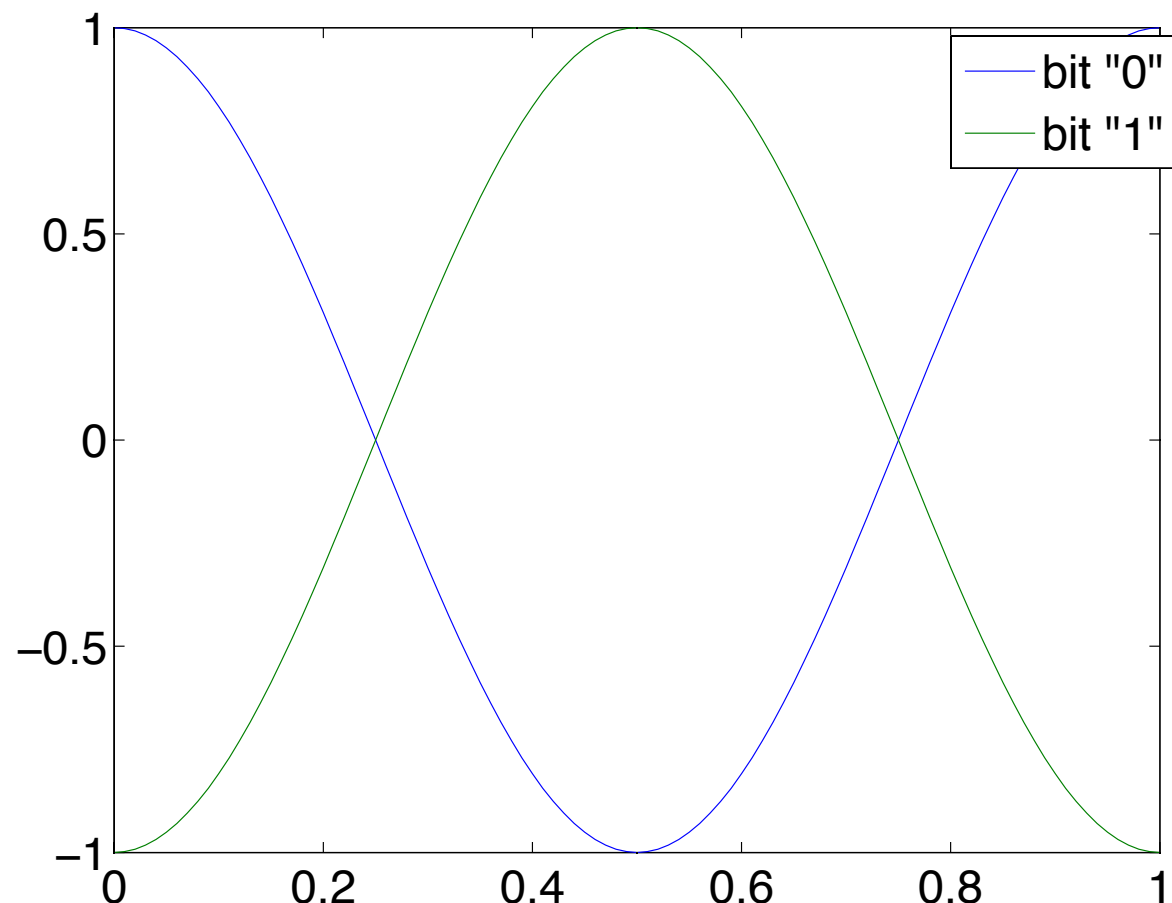
- Symbol: map to a number of bits
- Example: When one symbol map to:
 - 1 bit, then there are 2 kinds of symbol, mapping to “0” and “1”
 - 2 bits, then there are 4 kinds of symbol, mapping to “00”, “01”, “10”, and “11”
- Each symbol corresponds to a particular waveform

Phase Shift Keying (PSK)

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

$$s(t) = \cos(2\pi f_c t + 0) \quad \text{bit "0"}$$

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



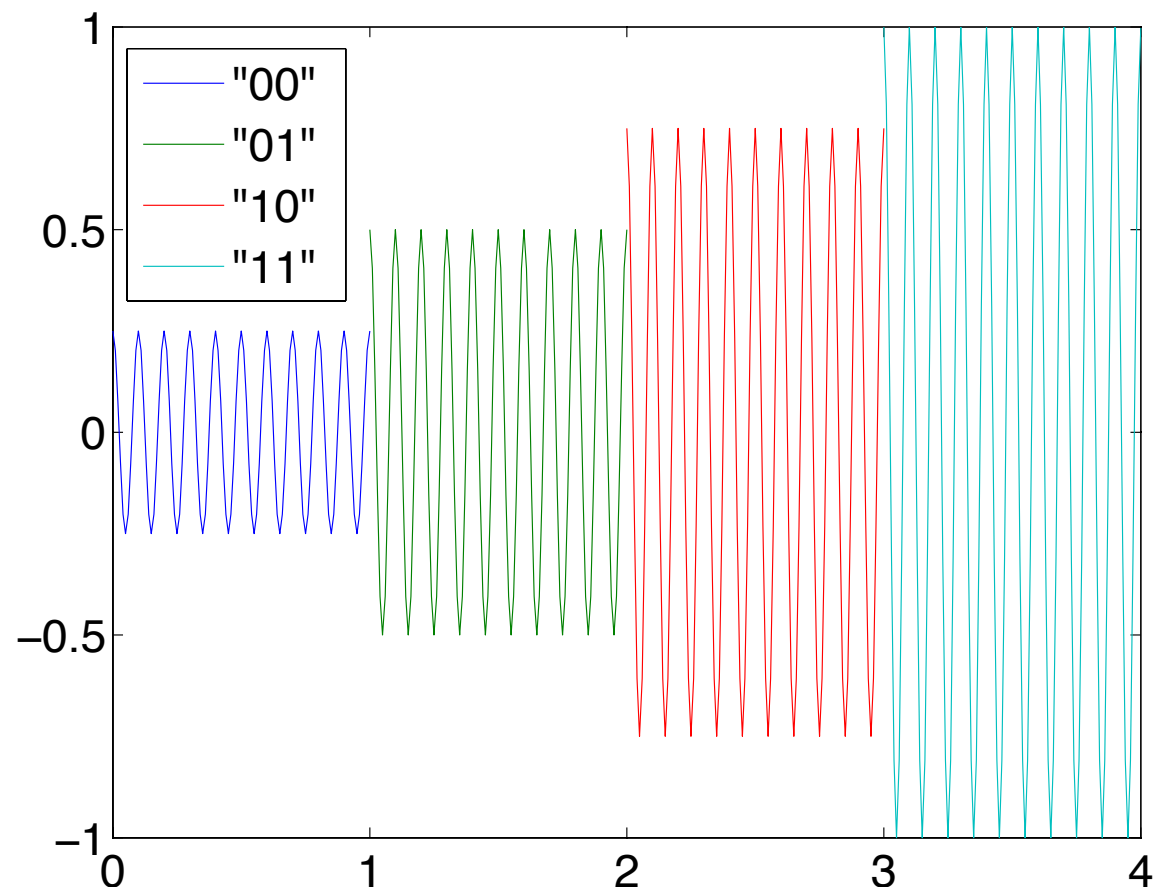
$$s(t) = \cos(2\pi f_c t + \phi_i)$$

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

Amplitude Shift Keying (ASK)

4-Amplitude Shift Keying (4-ASK)

$$s(t) = a_i \cos(2\pi ft) \quad a_i = \left\{ \frac{1}{4}, \frac{2}{4}, \frac{3}{4}, 1 \right\}$$



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

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

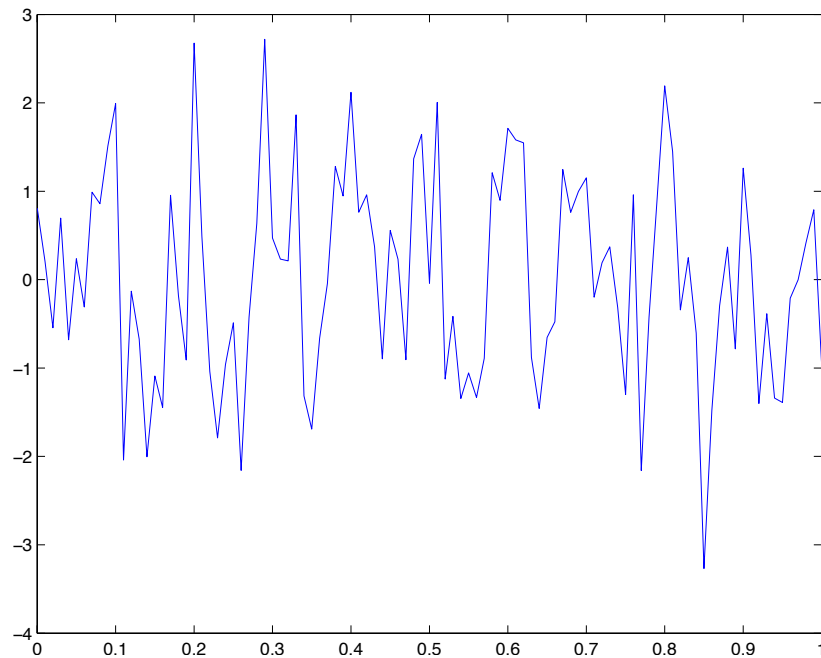
signal power

noise variance (power)

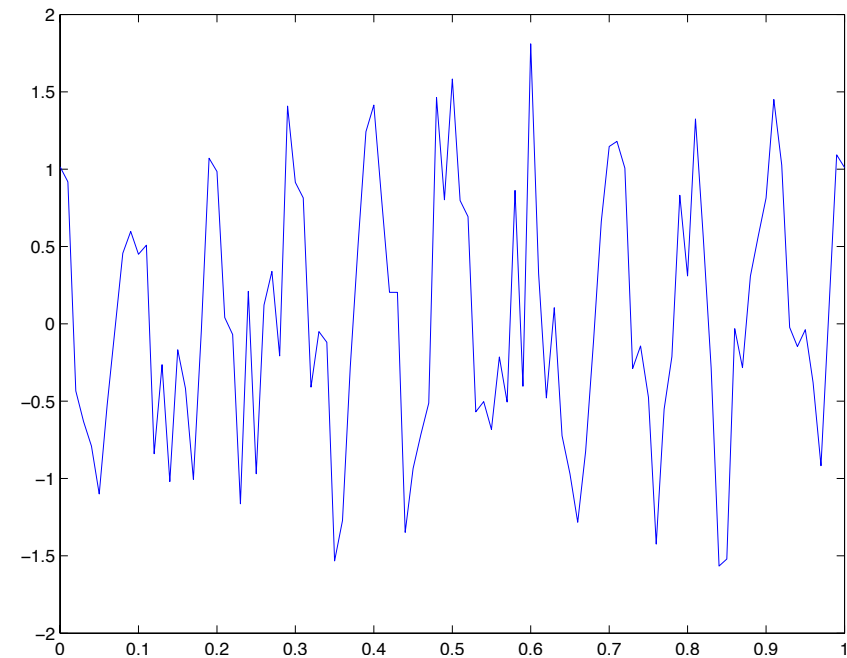
SNR versus Error Rate

Low SNR \longrightarrow hard to decode
 \longrightarrow higher error rate

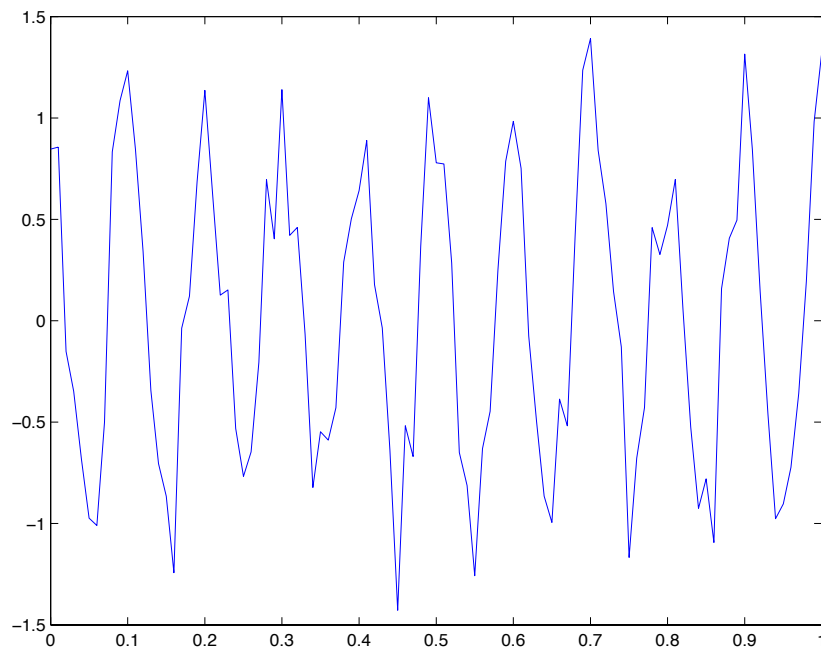
SNR=0 dB



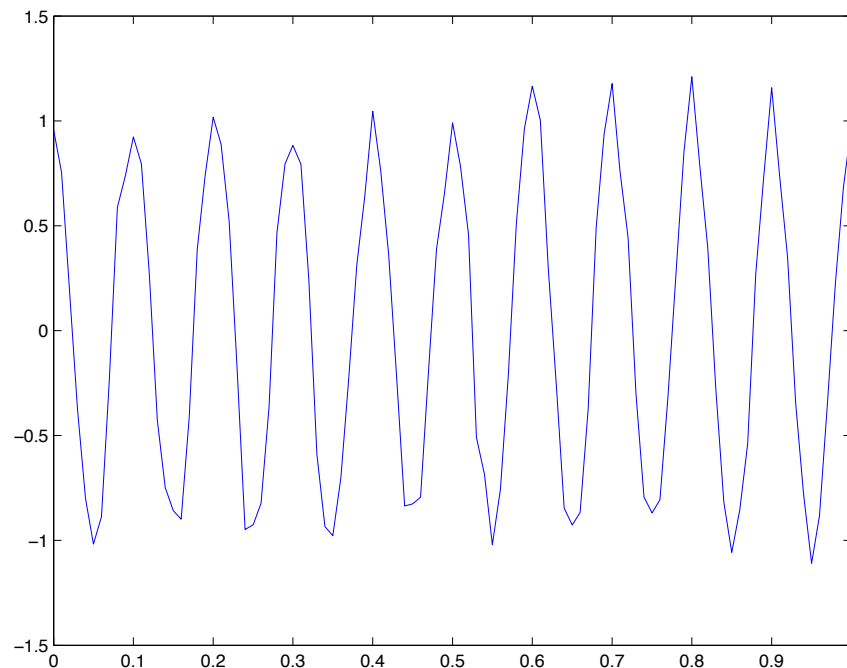
SNR=6 dB



SNR=12 dB



SNR=20 dB

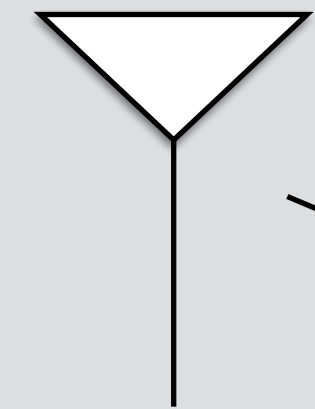


Path Loss

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

- 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

$$\text{EIRP} = P_t G_t$$

Power spatial density (W/m²)

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

d



RX Antenna

$\cdot A_e$

Antenna gain G

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

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

Friis formula & path loss exponent

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

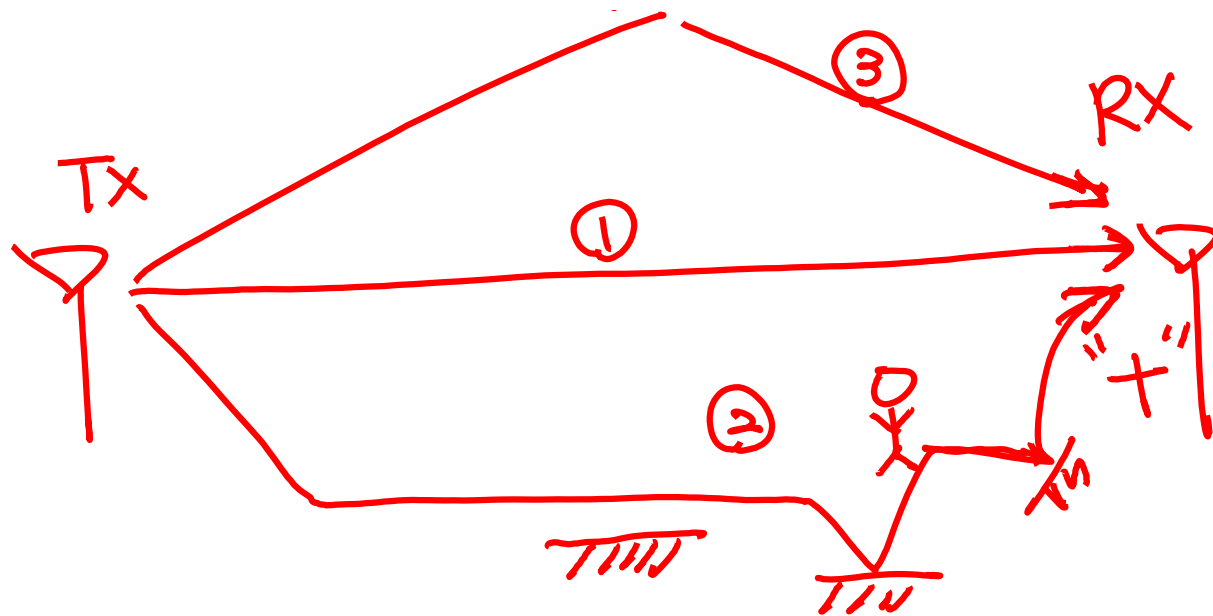
- **Higher frequency** signal experiences larger path loss (with the same antenna gain)

- 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



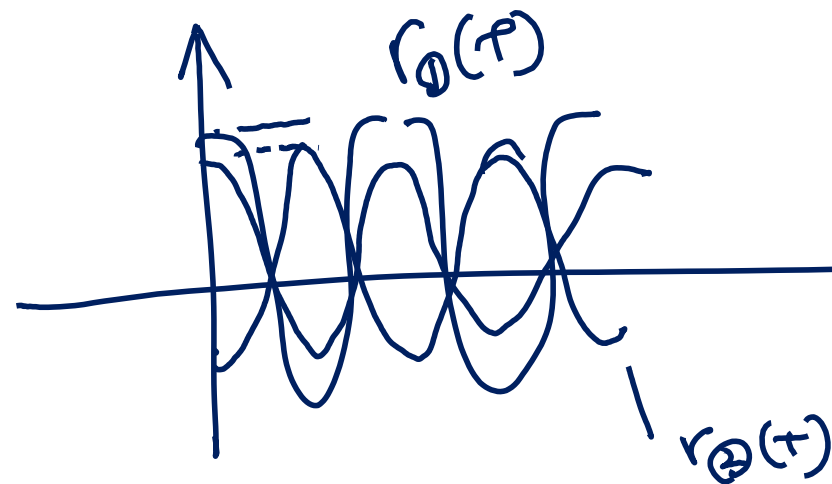
$$r_i(t) = \frac{a(t)}{\rho} \cos(\omega_c(t - \Delta t) + \phi)$$

$i = \begin{matrix} \textcircled{1} \\ \textcircled{2} \\ \textcircled{3} \end{matrix}$

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

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

Multi-path —> power fluctuation (fading)



$$r_0(t) = \cos(\omega_c t)$$

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

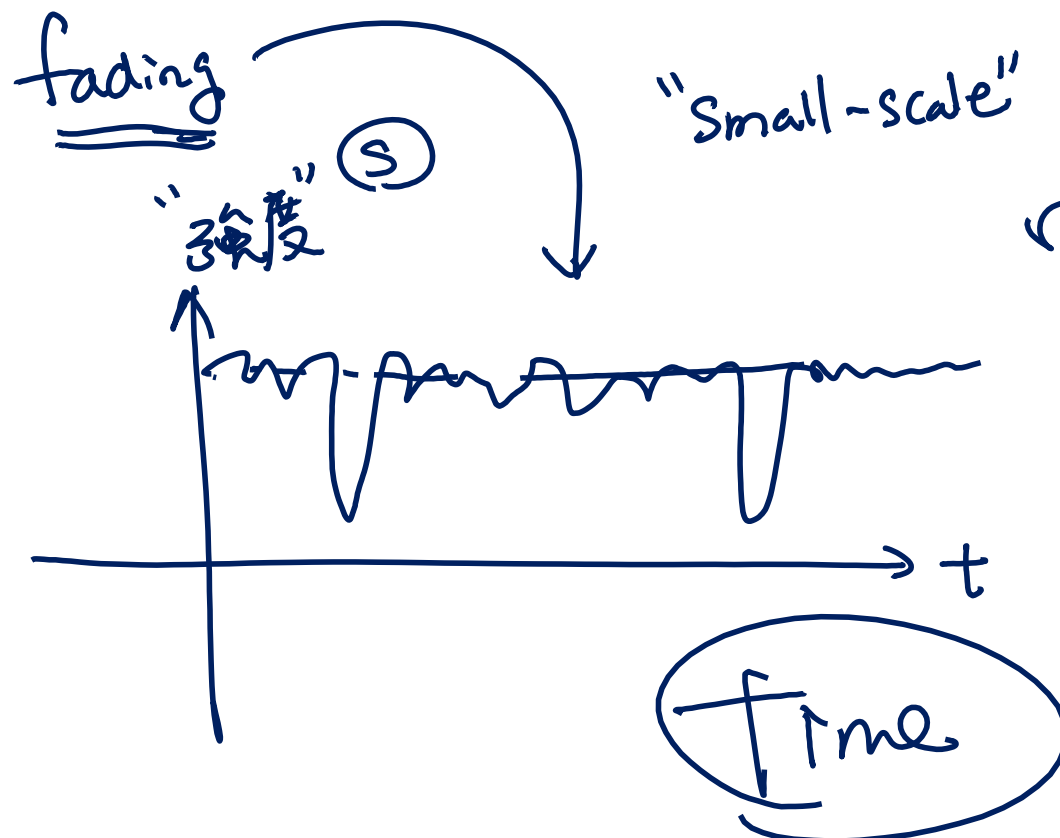
$$\begin{aligned} r(t) &= r_0(t) + r_2(t) \\ &= \cos(\omega_c t)(1 - 0.8) \end{aligned}$$

$$= \textcircled{0.2} \cos(\omega_c t)$$

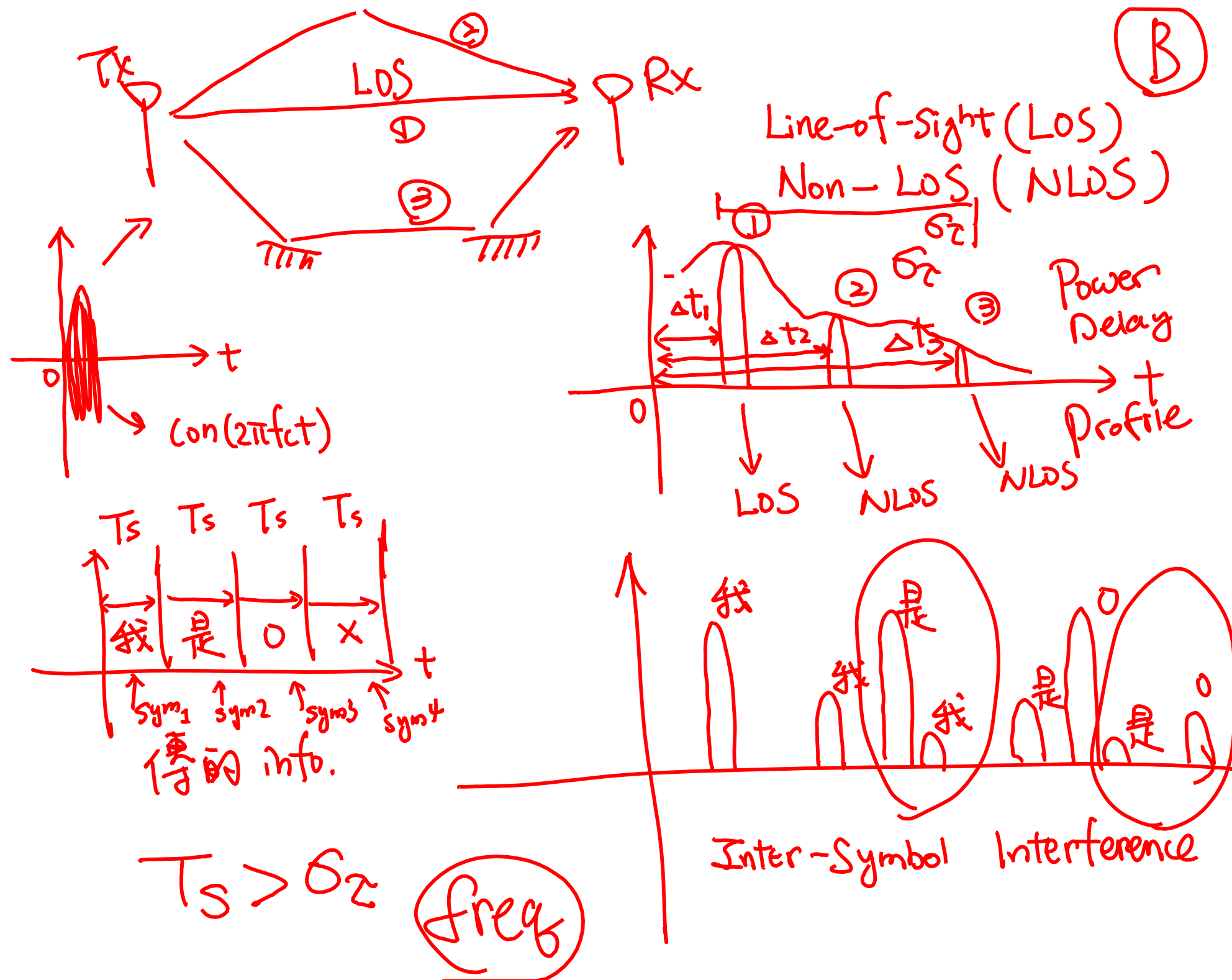
$$r(t) = r_0(t) + r_3(t)$$

$$= \cos(\omega_c t)(1 + \textcircled{0.6})$$

$$= 1.6 \cos(\omega_c t)$$



Multi-path \rightarrow inter symbol interference

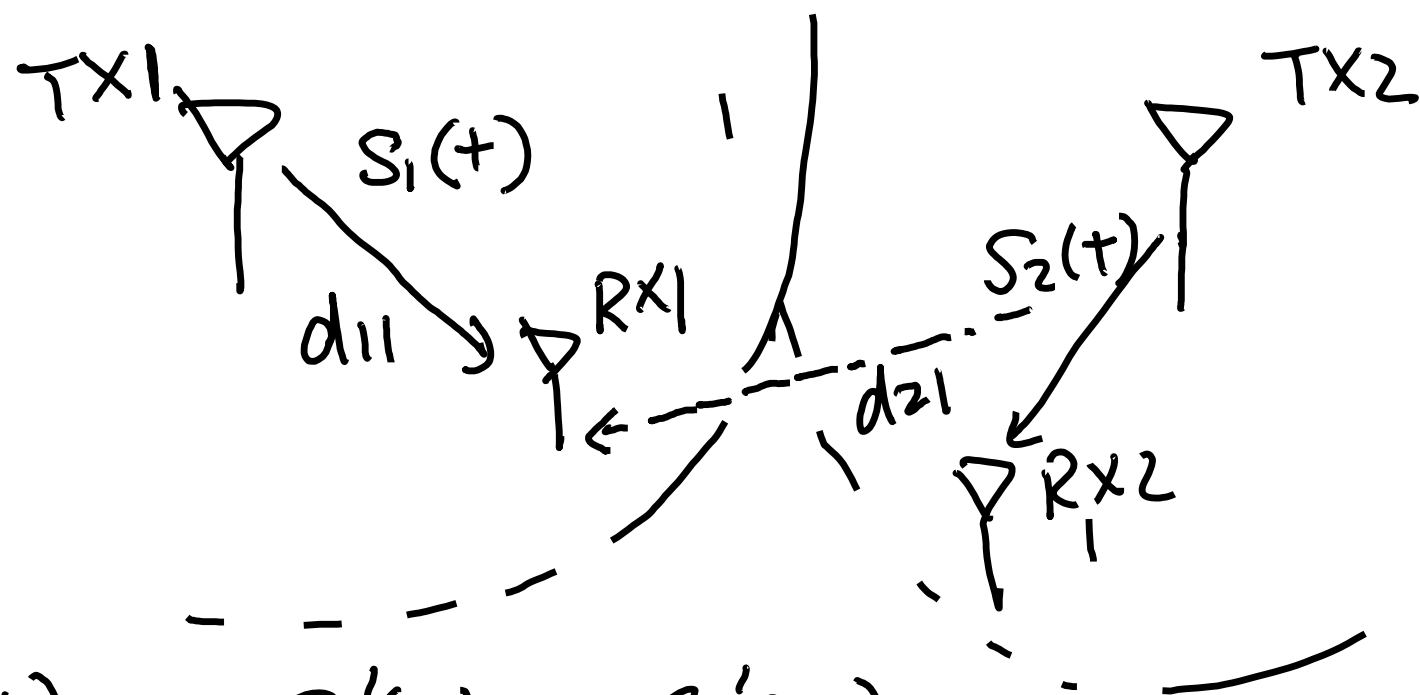


Multiplexing - how to share the medium

- 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)



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

$$L_{21} \propto d_{21}^{-\alpha}$$

$$L_{11} \propto d_{11}^{-\alpha}$$

$$r_1(t) = S_1'(t) + S_2'(t)$$

$$= \left[\frac{a_1}{L_{11}} S_1(t + \phi_1) \right] + \left[\frac{a_2}{L_{21}} S_2(t + \phi_2) \right]$$

intended received signal

interference

干扰

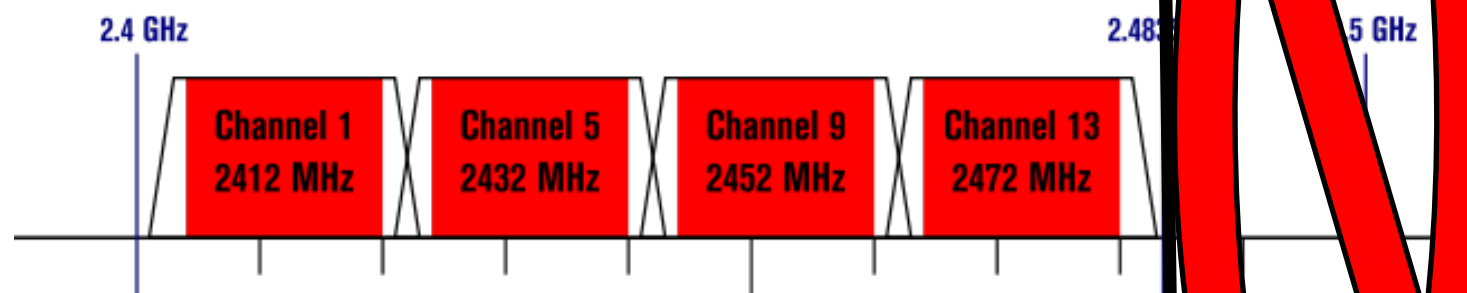
Frequency-Division Multiplexing

Non-Overlapping Channels for 2.4 GHz WLAN

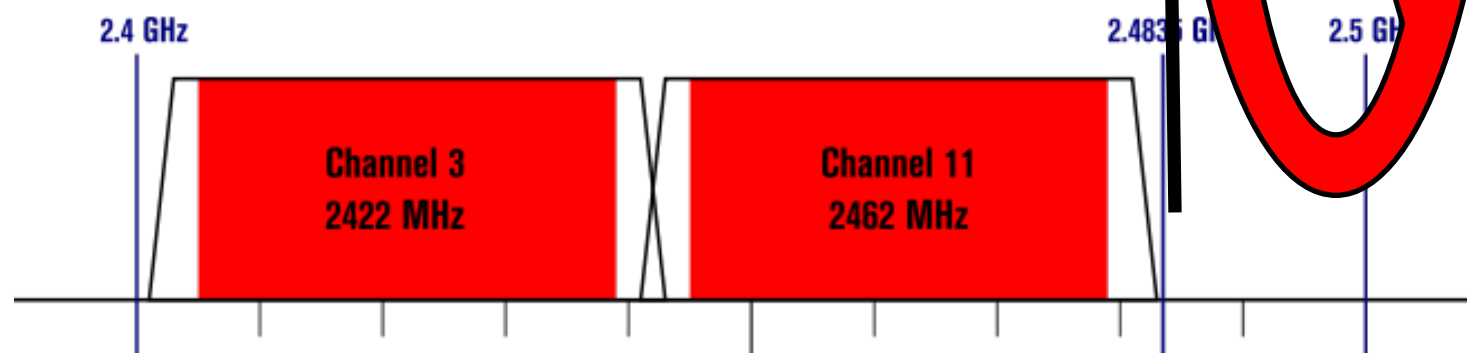
802.11b (DSSS) channel width 22 MHz



802.11g/n (OFDM) 20 MHz ch. width - 16.25 MHz used by data carrier



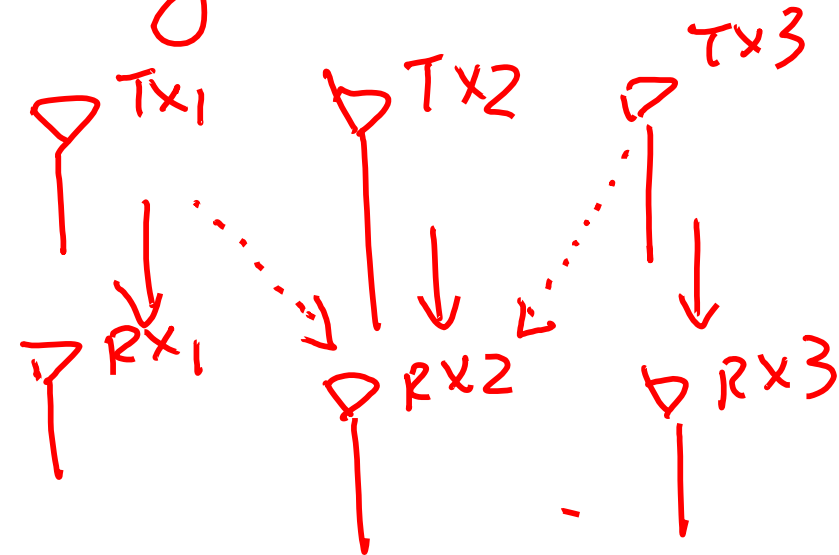
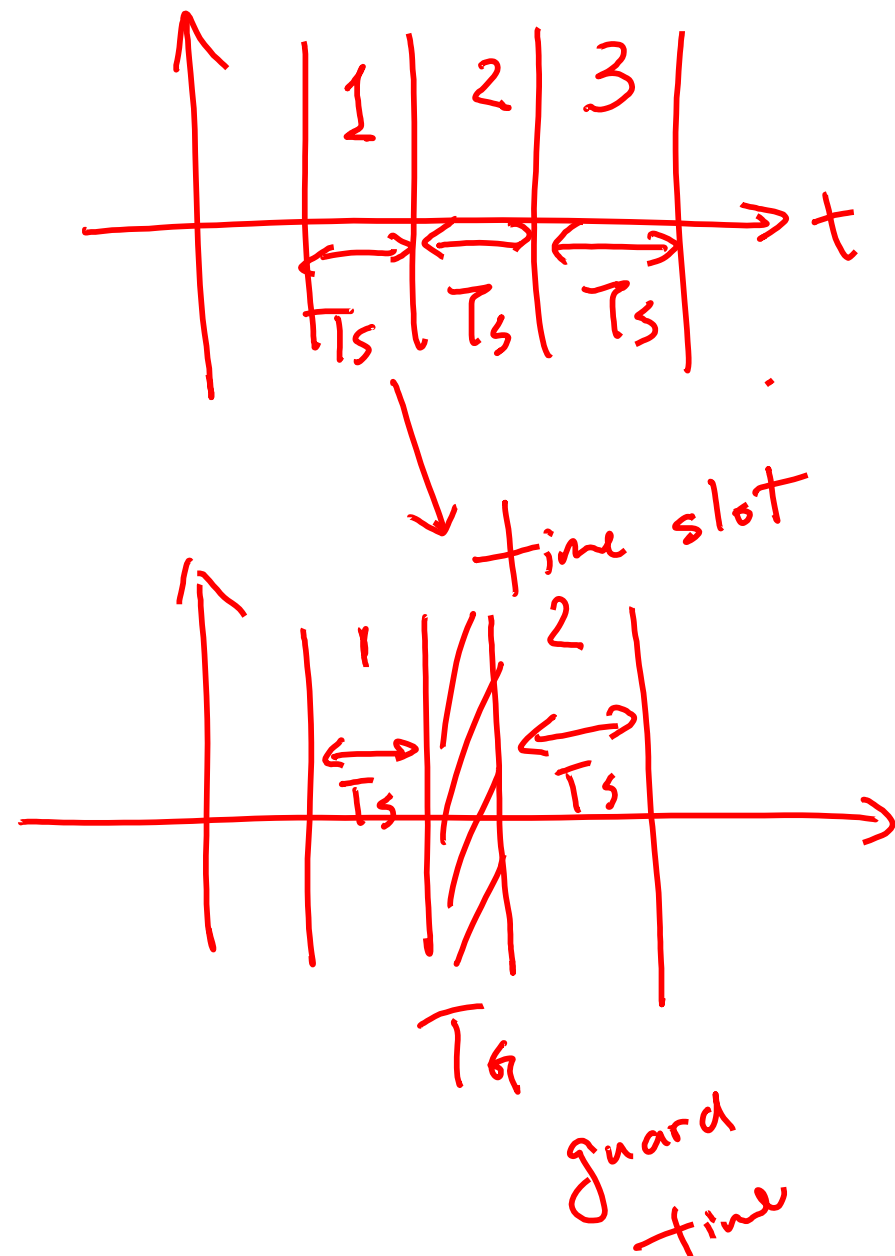
802.11n (OFDM) 40 MHz ch. width - 33.75 MHz used by data carrier



Taiwan (following U.S. regulations) can only use up to channel 11 (2462 MHz)

Time-Division Multiplexing

② Time-Division Multiplexing

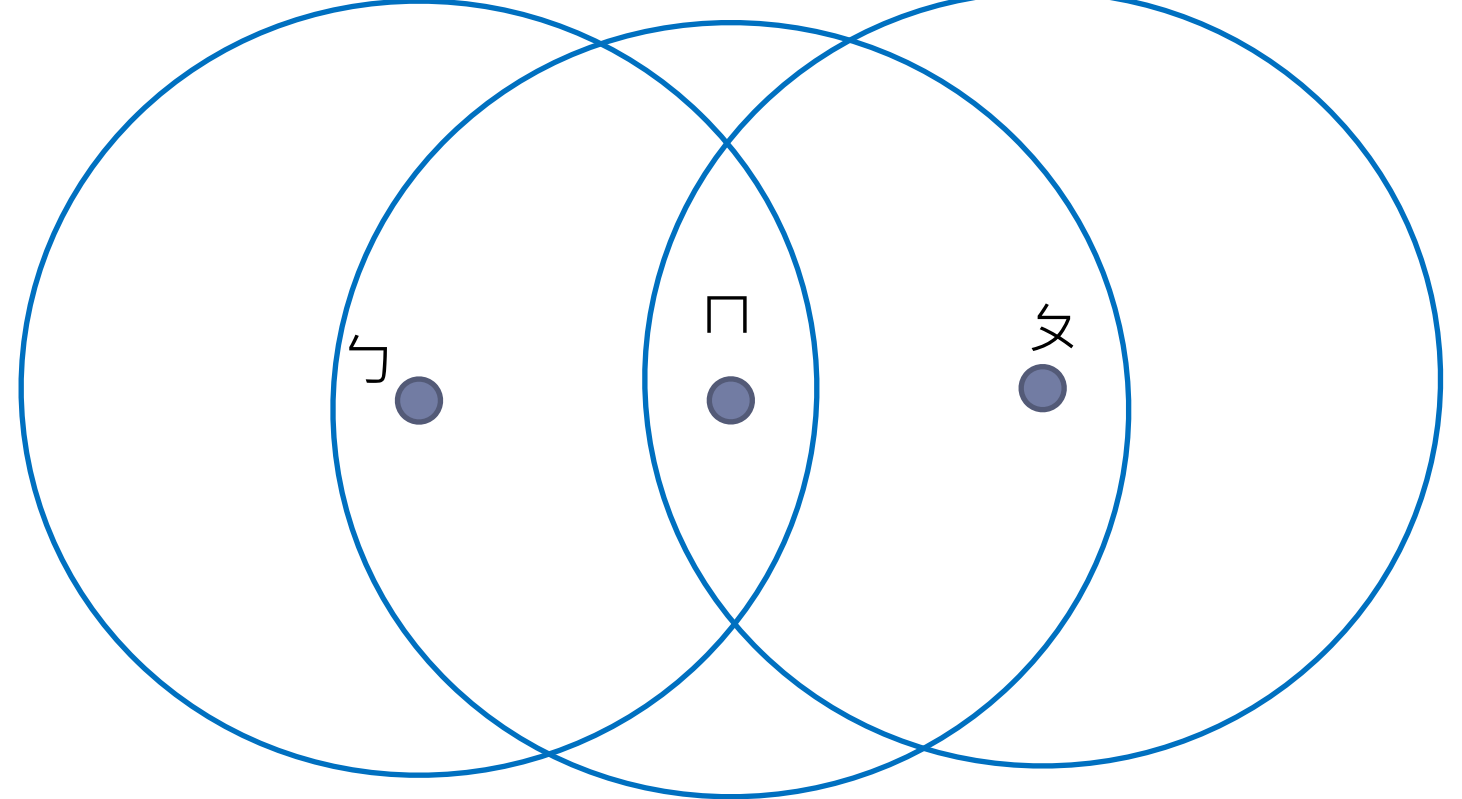


① time synchronization

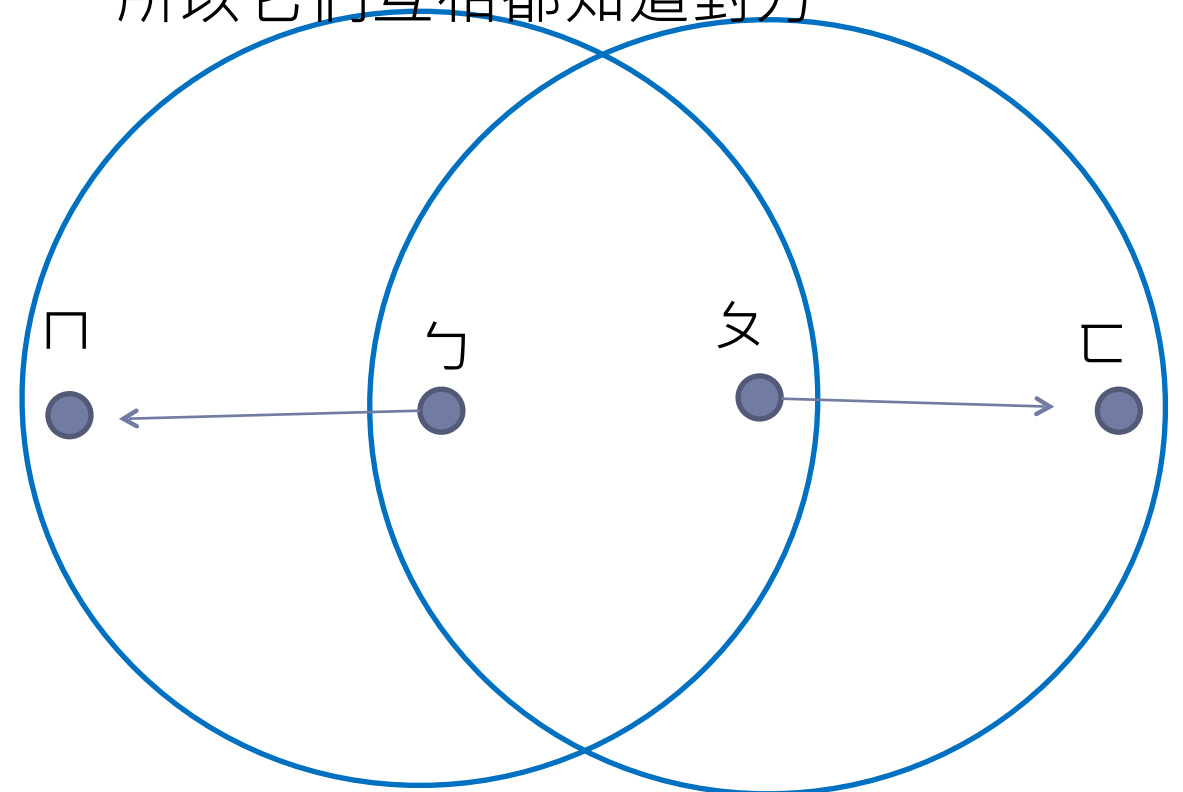
③ guard time \rightarrow overhead

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)

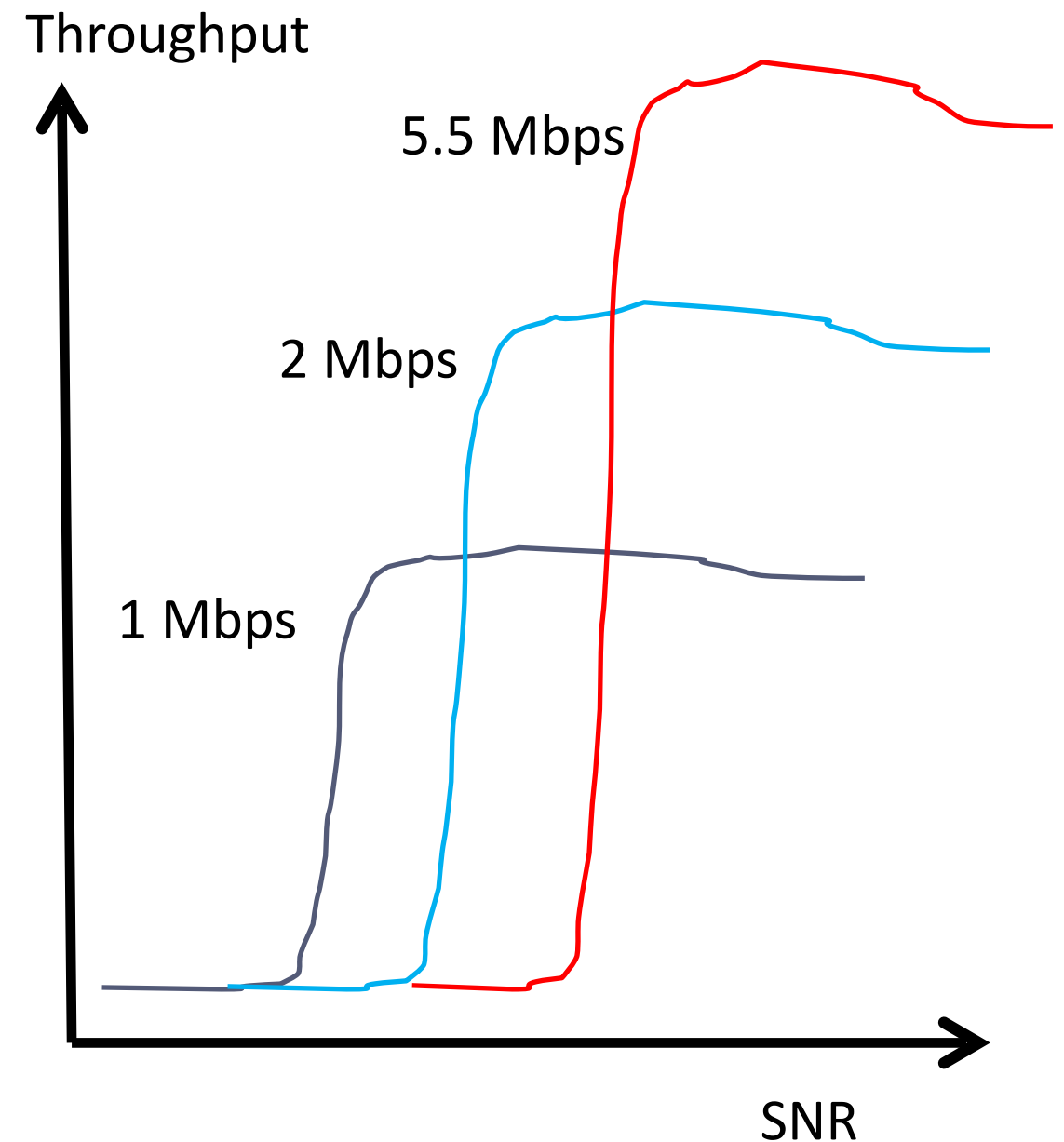
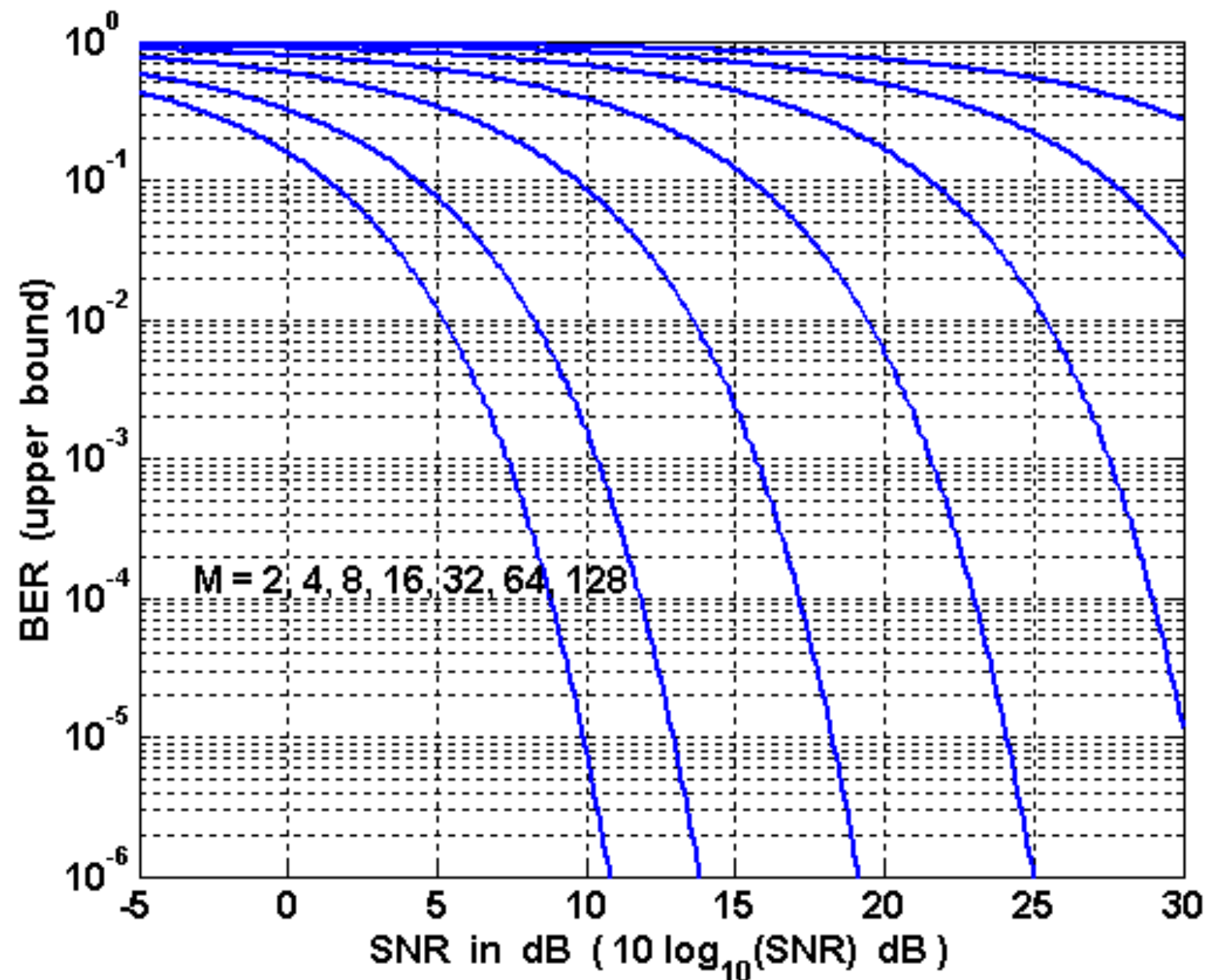


CTS 會被 ㄣ 和 ㄣ 接收到，
所以它們互相都知道對方



RTS of ㄣ → ㄣ 不會被 ㄣ 接收到
RTS of ㄣ → ㄣ 不會被 ㄣ 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 \rightarrow 相同大小封包傳更久 \rightarrow 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 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 needs to be scaled down.
- Otherwise:
 - Collision
 - Back-off (MAC)
 - Rate adaption algorithm selects a lower rate