Ch9: Channel Models

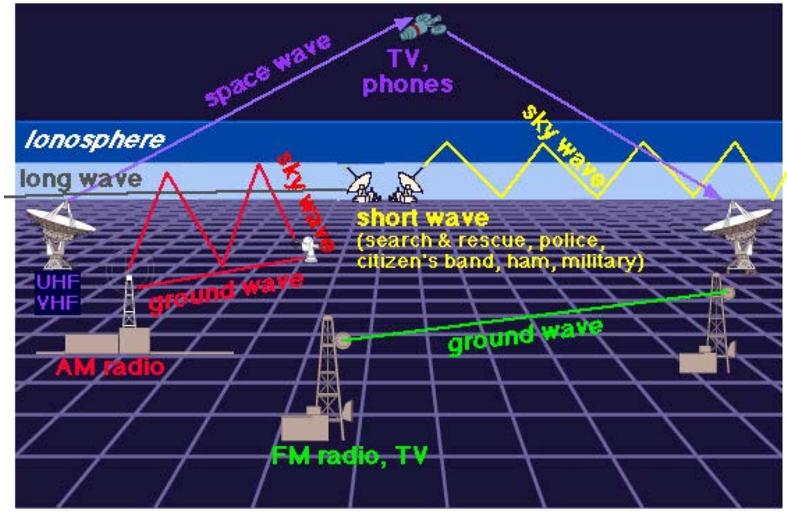
Information source and input transducer → Source Coding → Channel Coding → Modulator → Channel → Demodulator (Matched Filter) → Channel Decoding → Source Decoding → Information sink and output transducer

Ch9: Channel Model → Channel

- Questions to be answered:
  - Channel Effects: Different types of channel influences.
  - Multipath Channel: Wireless Communications.

Ch9: Channel Models

- **Channel Effects**
- Multipath Channels and OFDM



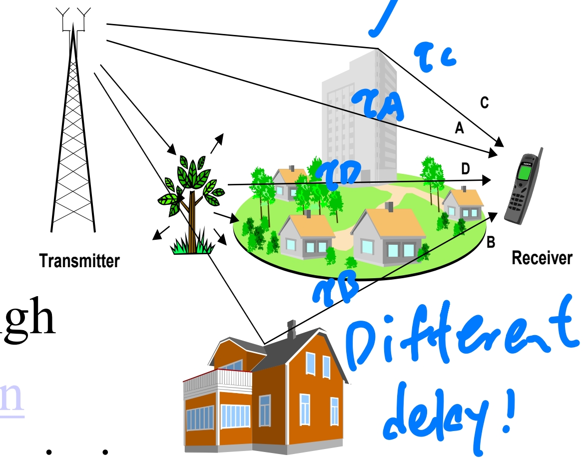
Wireless Propagation

- **A communications channel** - could be a telephone wire, free space and often presents distorted signals to the demodulator

Multipath

Explanation!

- **Wireless Propagation**
  - **Reflection**
    - When electronic wave are incident something with dimensions large compared to the wavelengh
  - **Diffraction** http://en.wikipedia.org/wiki/Diffraction
    - Occurs when there is an obstruction in the transmission path, and secondary waves are generated behind the obstruction body
  - **Scattering**
    - Arises when the incident wave length is in the order or lager than the blocking object with non-regular shape, the transmitting energy will be redirected in many directions



A: free space
B: reflection
C: diffraction
D: scattering

Channel - Transmission Media

不太consider这个

- **Channel Effects include**
  - **Noise** (e.g., additive white Gaussian noise or AWGN.)
  - **Attenuation** Signal power ↓
  - **Fading**: Signal amplitude can change in a random fashion in cellular and wireless communications systems.

    不同 frequency band，不同 gain!
  - **Frequency Selectivity:** Channel can have a bandwidth that is small compared to the signal bandwidth (e.g. in a telephone channel). Transmitted pulses will be changed in shape and smeared out in time causing Intersymbol interference (ISI).

    不同 time instance，不同 variation!
  - **Time Selectivity:** Signals experience different channel response at different time, which is usually caused by movements.

AWGN channel:

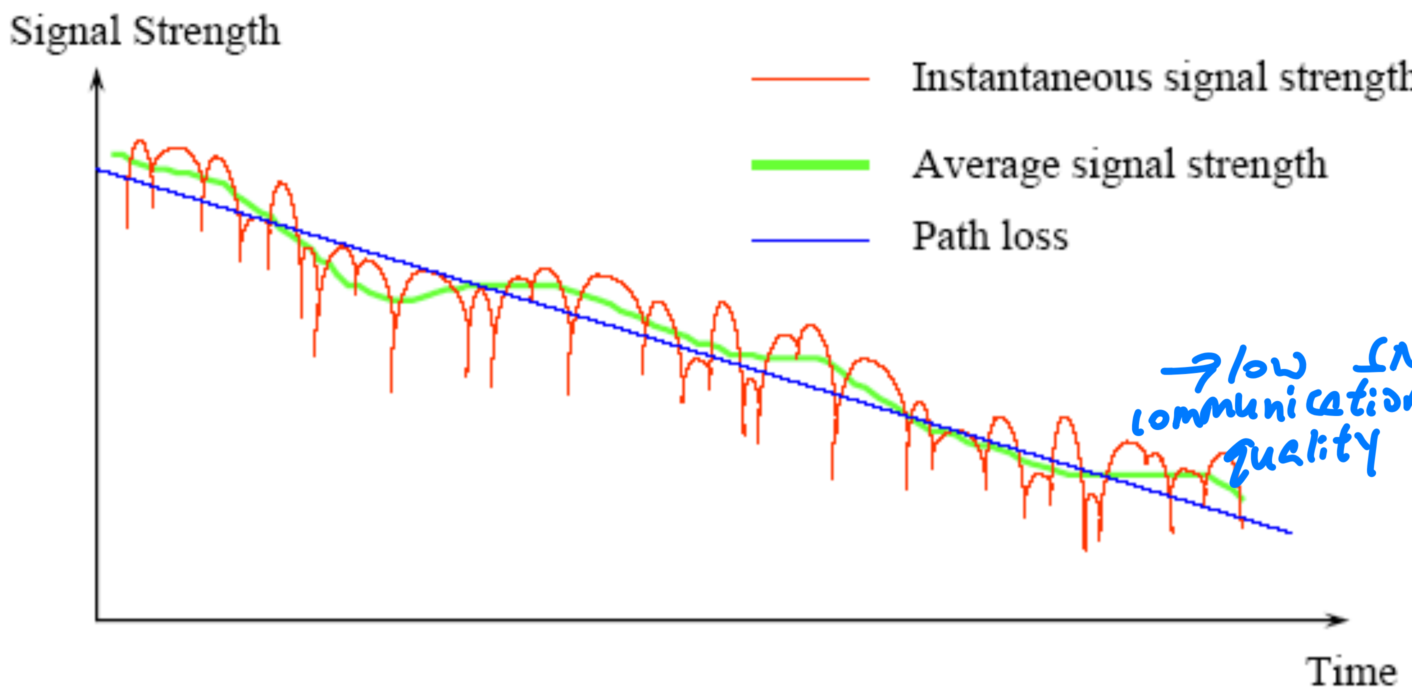
$$y(t) = x(t) + n(t)$$

$$Y = X + N$$

wireless part 也有改變

Channel Effects: Attenuation

Noise related to receiver



→ low SNR
communication quality low!

∝ distance

Signal strength will decrease in distance!

Receiver signal power [illegible]

Enable frequency reuse

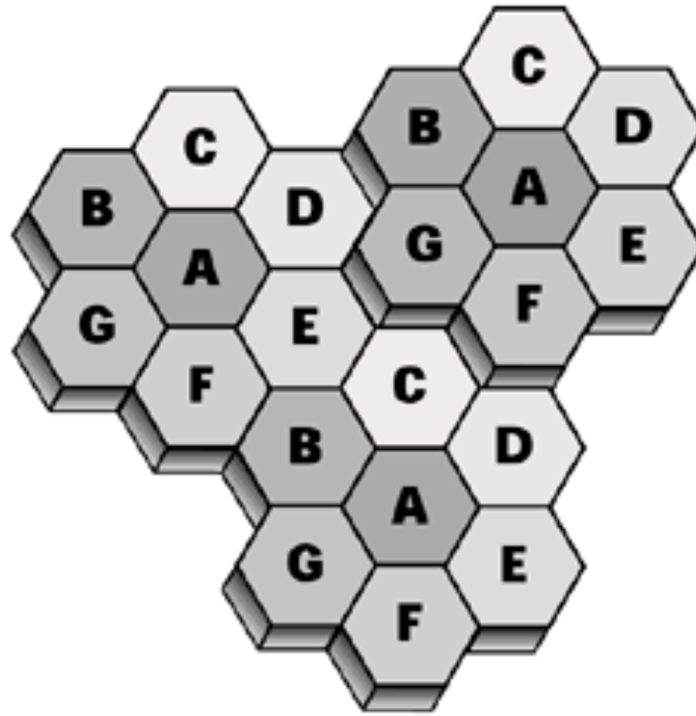
SNR ↓

Pathloss: Good or Bad?

higher power

cellular structure: ↓ spectrum
reuse same spectrum

cause interference!



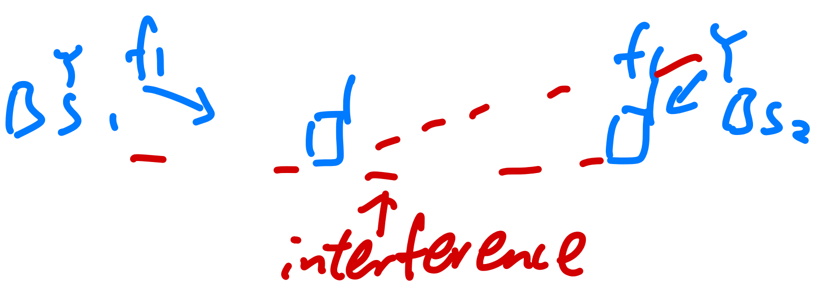
Frequency reuse factor=7

Path loss

$d \uparrow$ → Rx power ↓ → bad communication quality
SNR

Power control to compensate for that
↳ increase the transmittion power!

- For network perspective
we want frequency reuse : allow multiple users to use the same spectrum.
- Cause interference!!! :(



Depends on distance

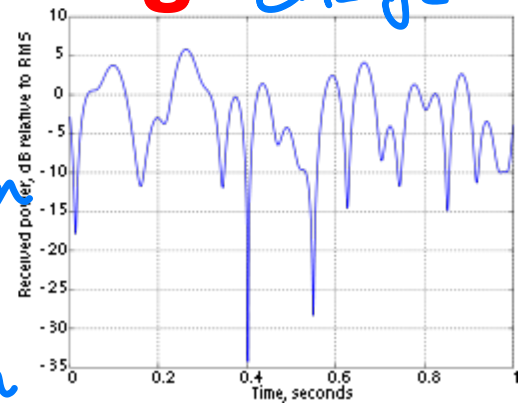
$$SNR = \frac{\text{signal power}}{\text{noise} + \text{interference}}$$

change the magnitude of signal!

Rayleigh Fading

change in time

- **Fading:** Signal amplitude can change in a random fashion.



If send $x \rightarrow h \cdot x \rightarrow \oplus \rightarrow y = hx+n$

multiplication phenomone

$|h| \sim$ Rayleigh distribution

- Rayleigh Fading: the received complex low-pass signal is modeled as a complex Gaussian random process
  - $g_I(t)$ and $g_Q(t)$ are independent zero-mean Gaussian RVs
  - The received complex envelope $\underline{\alpha(t) = |g(t)|}$ has a Rayleigh distribution

pdf

$$p_\alpha(x) = \frac{x}{\sigma^2} \exp\left\{-\frac{x^2}{2\sigma^2}\right\}$$

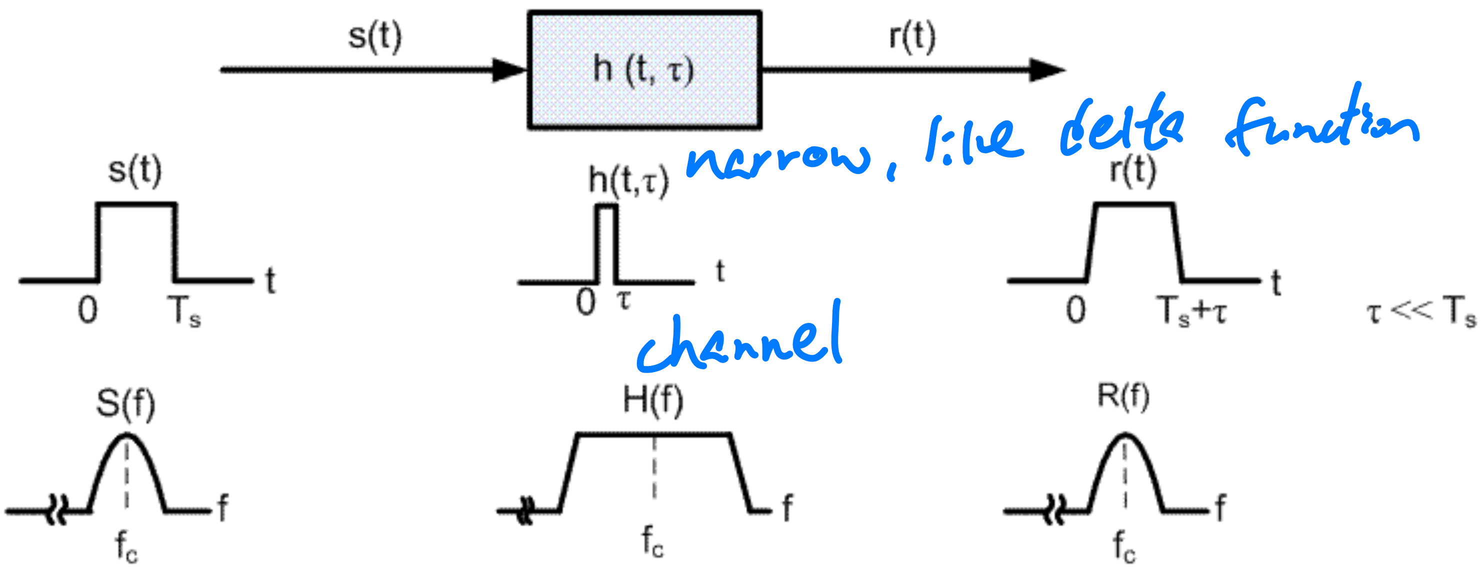
- The average power is

$$E[\alpha^2] = \Omega_p = 2\sigma^2$$

Good!

Flat Fading

channel 不会 affect input!



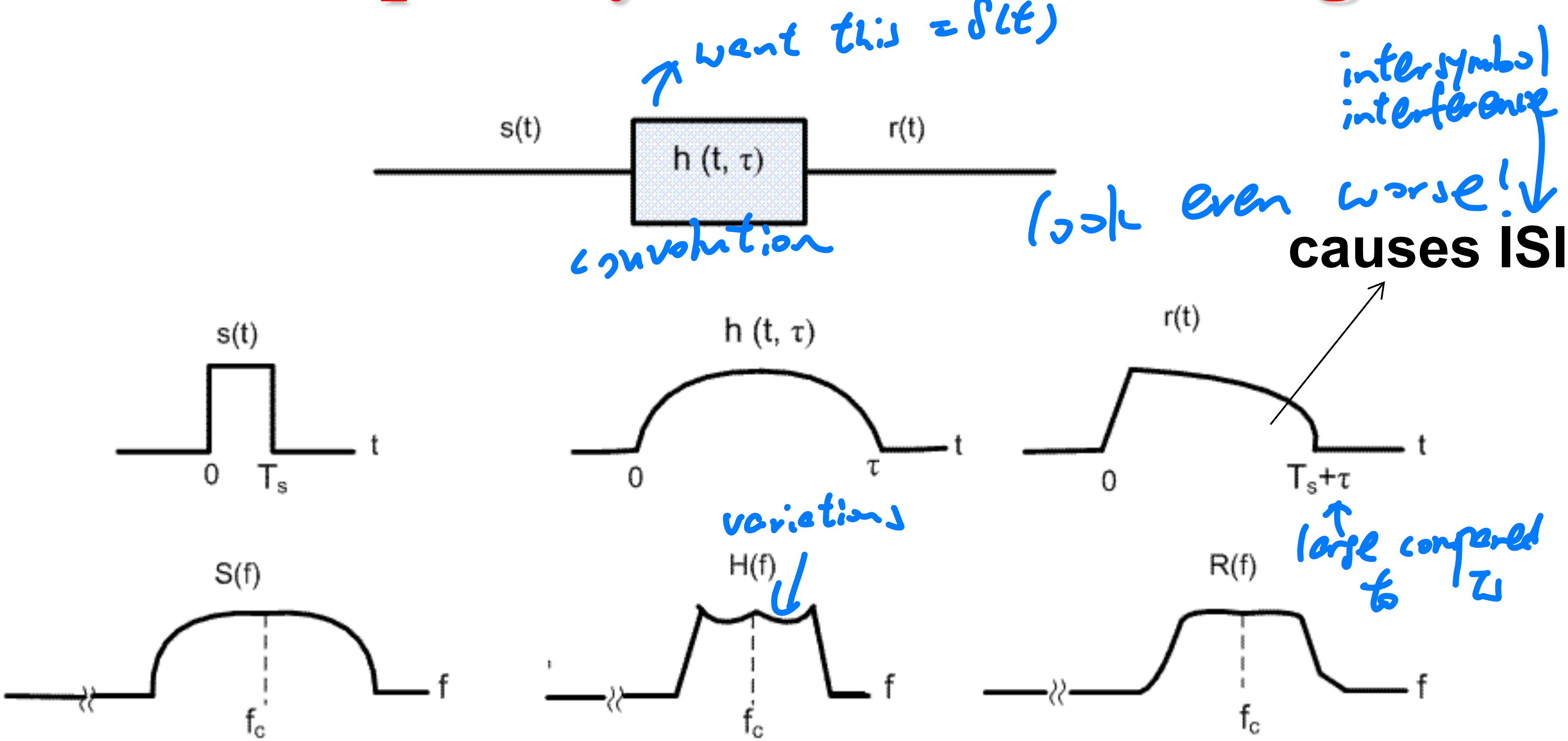
narrow, like delta function

channel

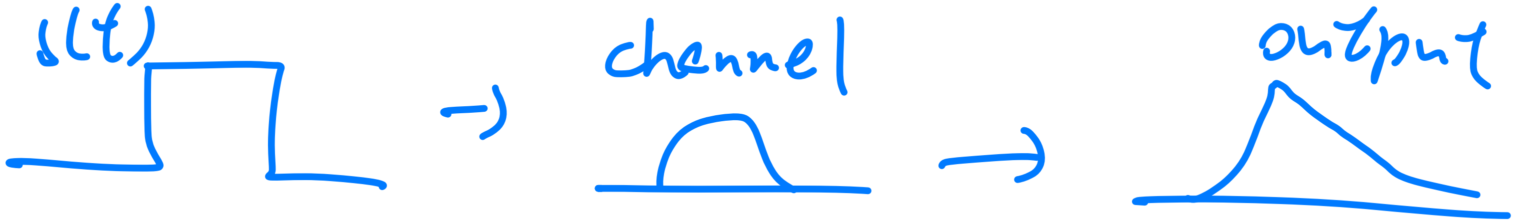
(a) Flat fading channel characteristics

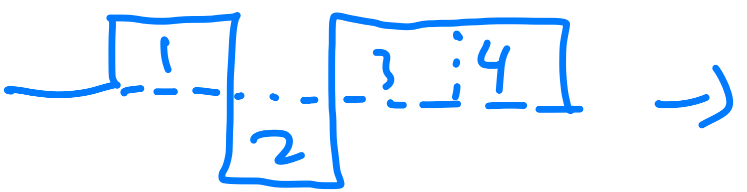
Similar to original one

Frequency Selective Fading

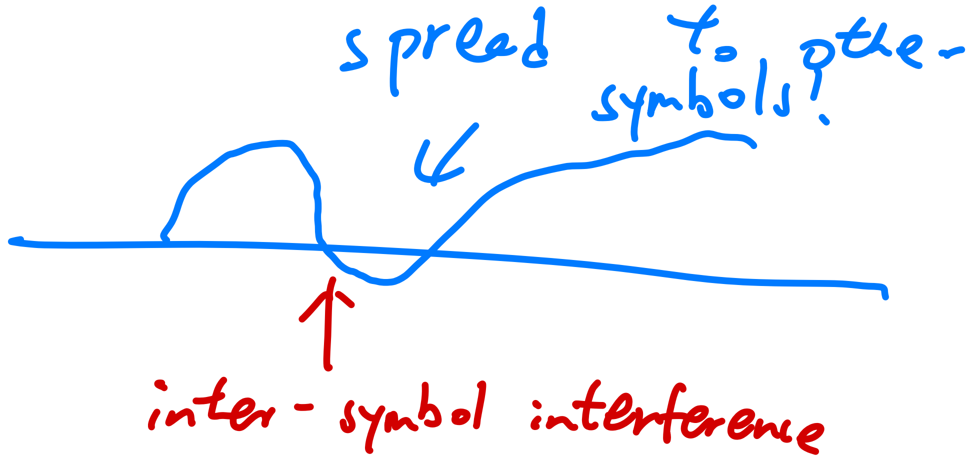


(b) Frequency selective fading channel characteristics



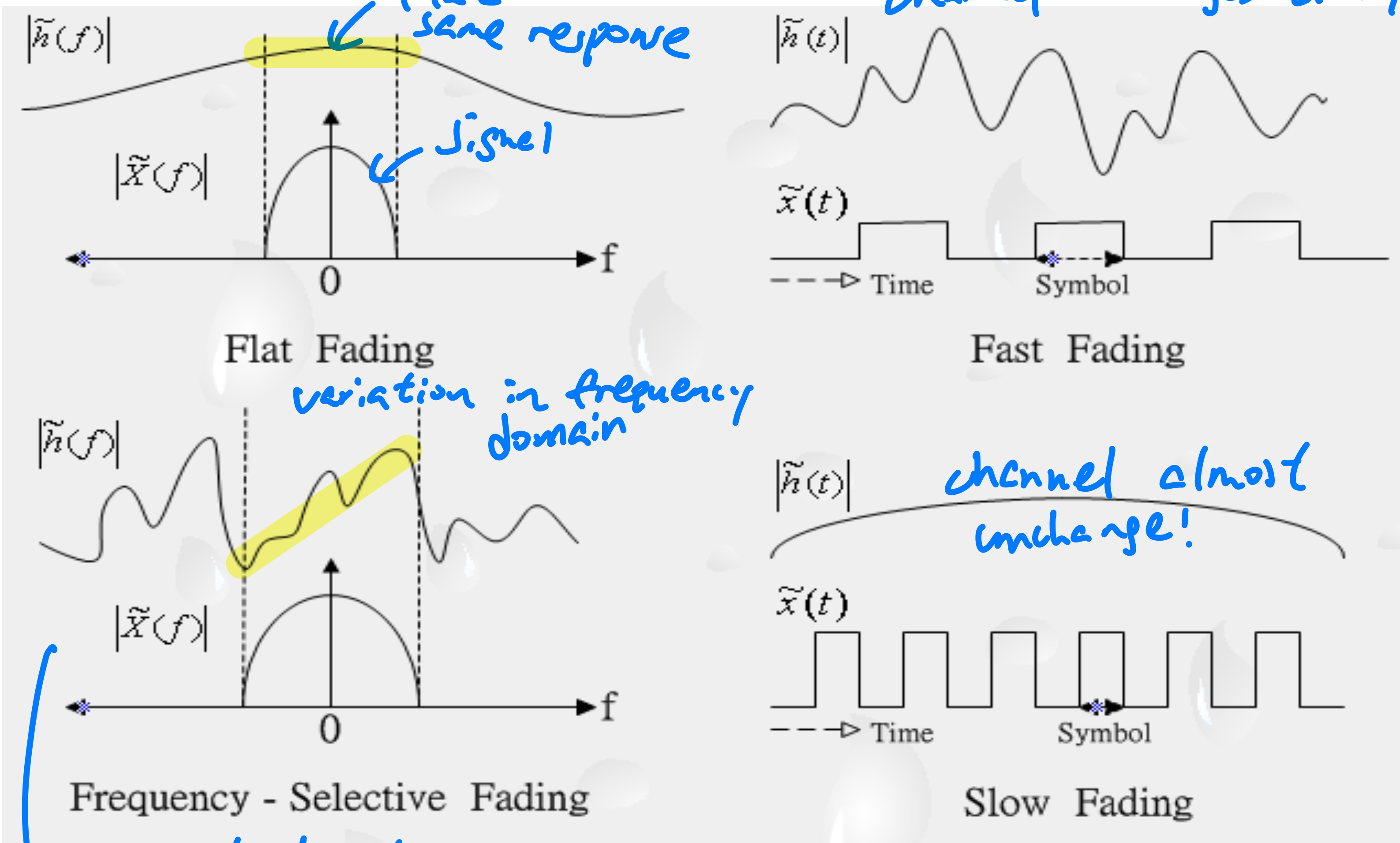


large bandwidth will cause this!



Fading Examples

channel changes slowly!



flat
same response

signal

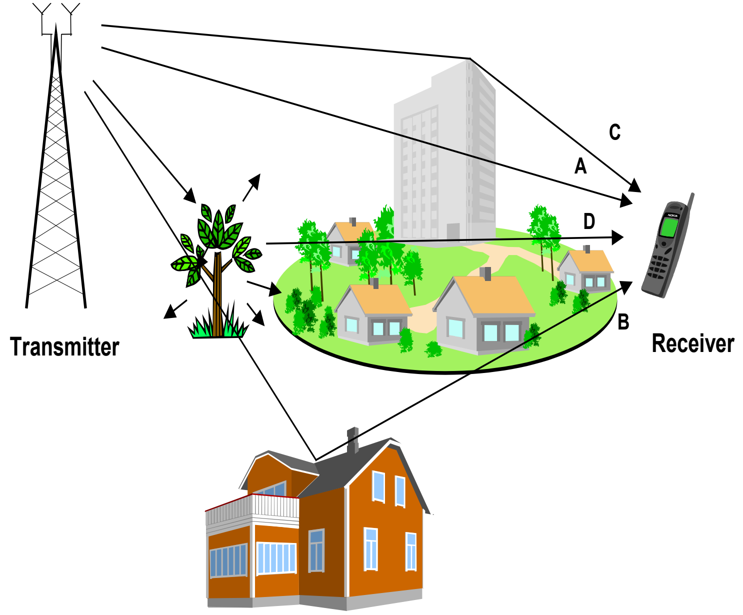
variation in frequency domain

channel almost unchange!

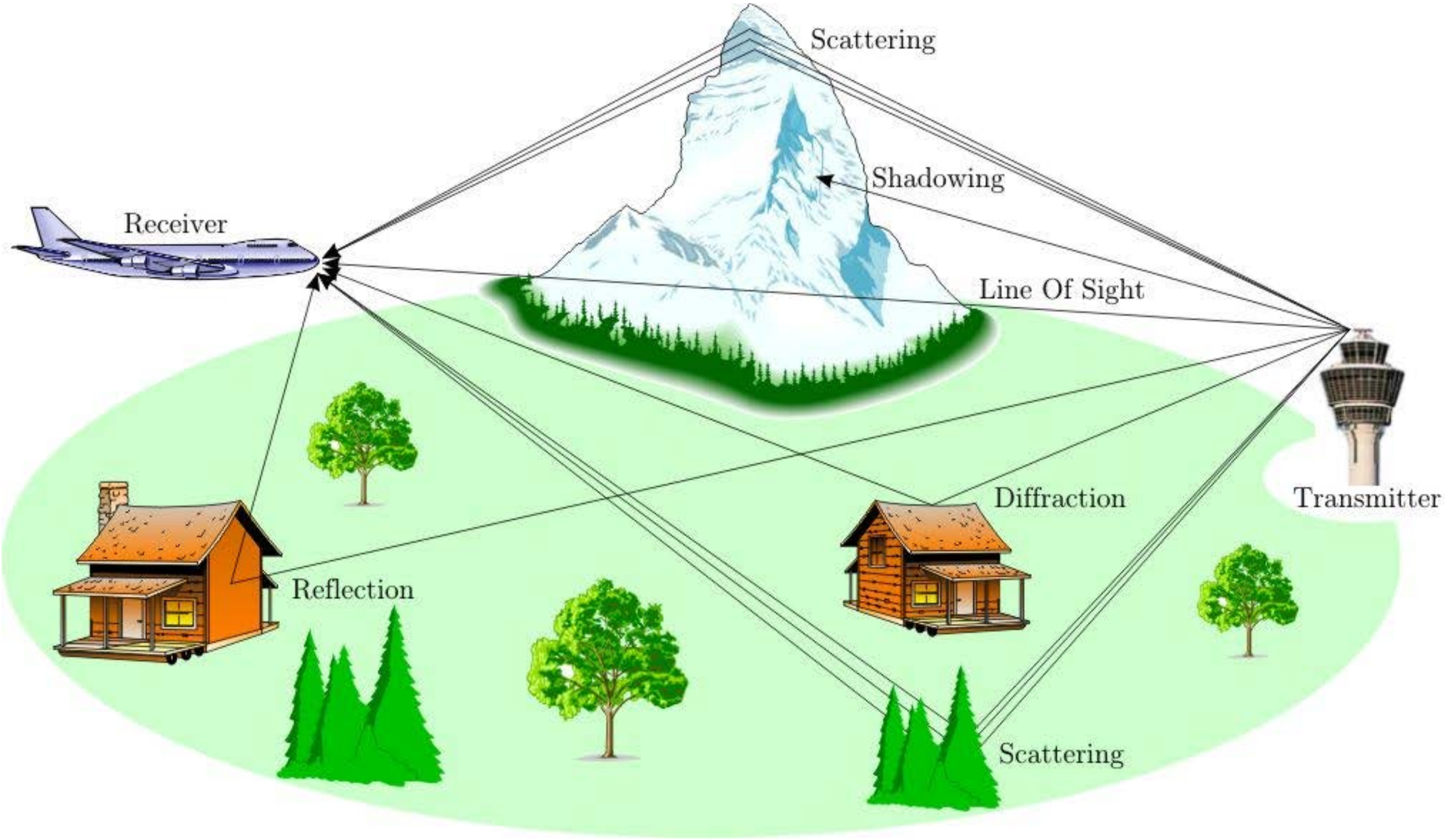
most difficult, cause ISI,
mainly focus about this next part!

Ch9: Channel Models

- Channel Effects
- **Multipath Channels and OFDM**



Multipath Channel



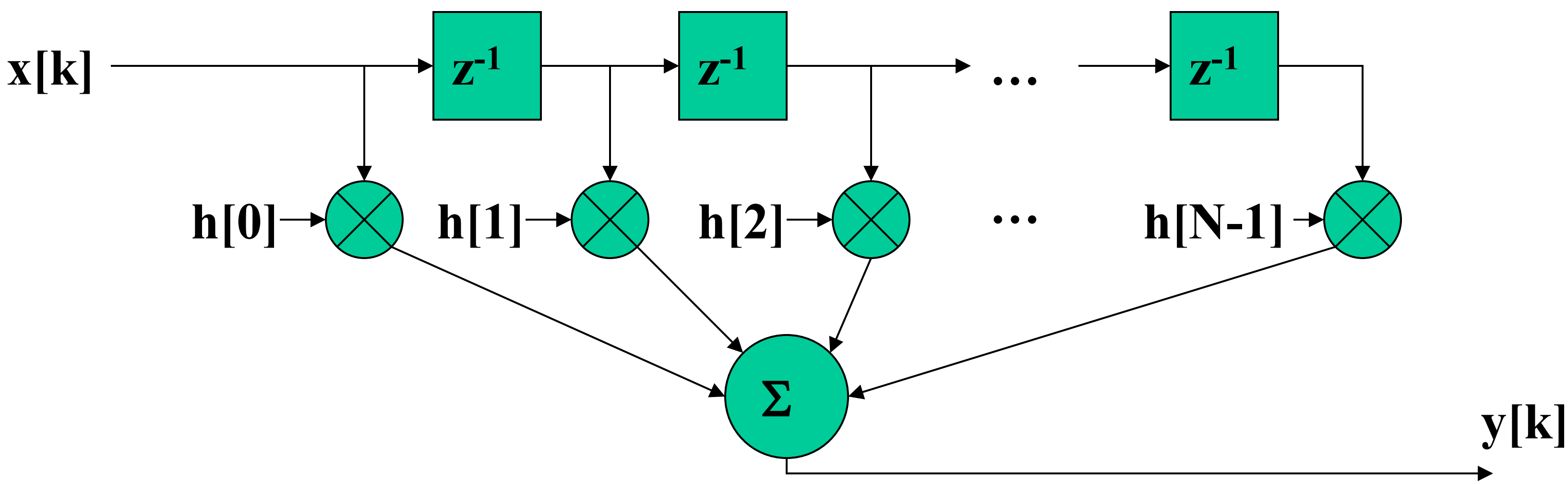
Model by this filter.

Finite Impulse Response (FIR)

- Assuming that $h[k]$ is causal and has finite duration for $k = 0, \ldots, N\text{-}1$

$$y[k] = \sum_{m=0}^{N-1} h[m]\,x[k-m]$$

- Block diagram of an implementation for the finite impulse response filter



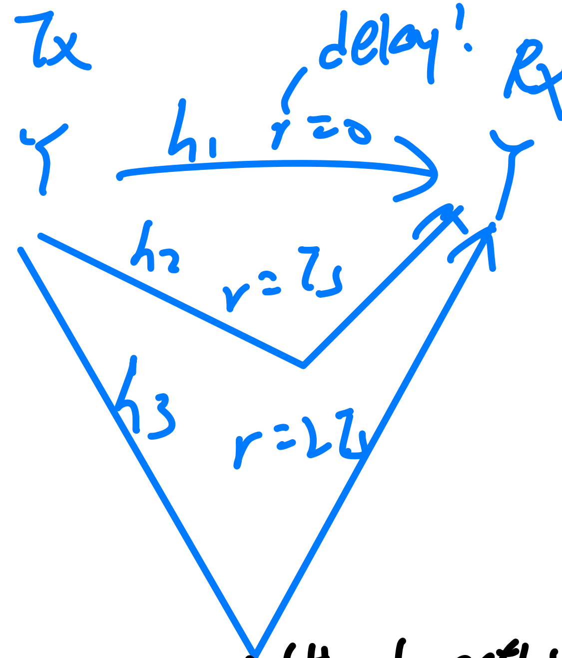
Large bandwidth → freq-selective fading

	T_1	T_2	T_3
Transmit	x_1	x_2	x_3

$y_1 = h_1 x_1$

$y_2 = h_1 x_2 + h_2 \underbrace{x_1}_{\text{delayed}}$

? $y_3 = h_1 x_3 + \underbrace{h_2 x_2 + h_3 x_1}_{\text{ISI}}$



$p = 3$ (# of paths)

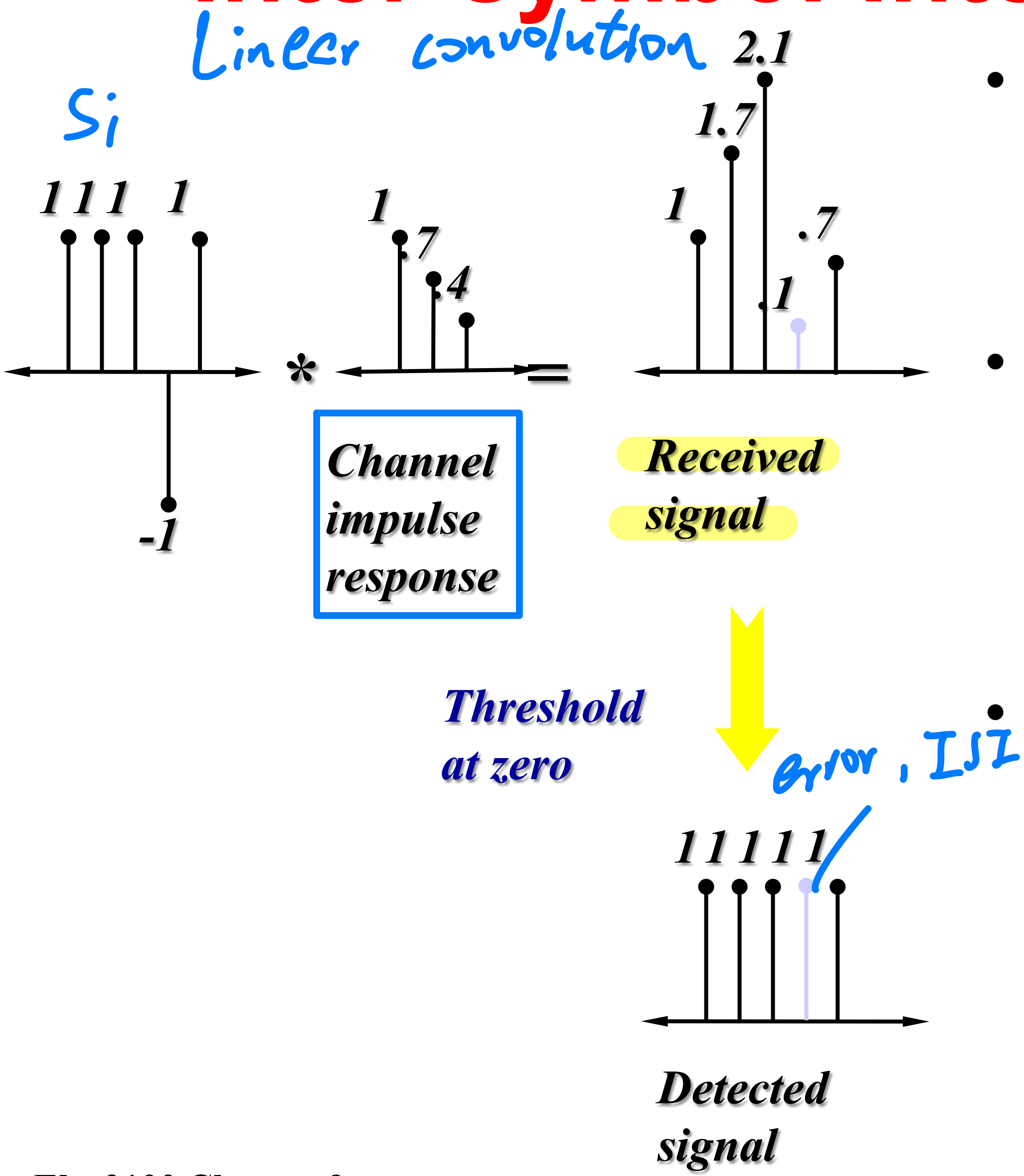
x_1 will have 3 copies!

Same as FIR!

$$y_k = \sum_{i=1}^{P} h_i x_{k-i} \quad \text{(FIR)}, \quad P = \text{number of paths}$$

Get rid of this!

Inter-symbol Interference (ISI)



- Ideal channel
  - Impulse response is an impulse
  - Frequency response is flat
- Non-ideal channel causes ISI
  - Channel memory
  - Magnitude and phase variation
- Received symbol is weighted sum of neighboring symbols
  - Weights are determined by channel impulse response

Difficulties

$$x[n] \rightarrow \boxed{h[n]} \rightarrow y[n]$$

$$h[n],\ y[n] \rightarrow x[n] = ?$$

What we know from DFT.

we have $x[n] \textcircled{N} h[n] = y[n]$

$$\text{DFT} \Rightarrow X[k]H[k] = Y[k]$$

$$X[k] = \frac{Y[k]}{H[k]}$$ Easy detection!

z-transform is more general!

★ key problem

How to convert linear convolution to circular convolution?

Convolution Review

- Discrete-time convolution

$$y[k] = \sum_{m=-\infty}^{\infty} h[m]\, x[k-m]$$

- For every k, we compute a new summation

$$x[k] \rightarrow \boxed{h[k]} \rightarrow y[k]$$

Represented by its impulse response

- Continuous-time convolution

$$y(t) = \int_{-\infty}^{\infty} h(\tau)\, x(t-\tau)\, d\tau$$

- For every value of t, we compute a new integral

$$x(t) \rightarrow \boxed{h(t)} \rightarrow y(t)$$

Represented by its impulse response

Linear vs. Circular Convolution

n:	0	1	2	3	$\langle 4\rangle_4$	$\langle 5\rangle_4$	$\langle 6\rangle_4$
$g[n]$:	$g[0]$	$g[1]$	$g[2]$	$g[3]$			
$h[n]$	$h[0]$	$h[1]$	$h[2]$	$h[3]$			
	$g[0]h[0]$	$g[1]h[0]$	$g[2]h[0]$	$g[3]h[0]$			
		$g[0]h[1]$	$g[1]h[1]$	$g[2]h[1]$	$\boxed{g[3]h[1]}$		
			$g[0]h[2]$	$g[1]h[2]$	$\boxed{g[2]h[2]}$	$\boxed{g[3]h[2]}$	
				$g[0]h[3]$	$\boxed{g[1]h[3]}$	$\boxed{g[2]h[3]}$	$\boxed{g[3]h[3]}$

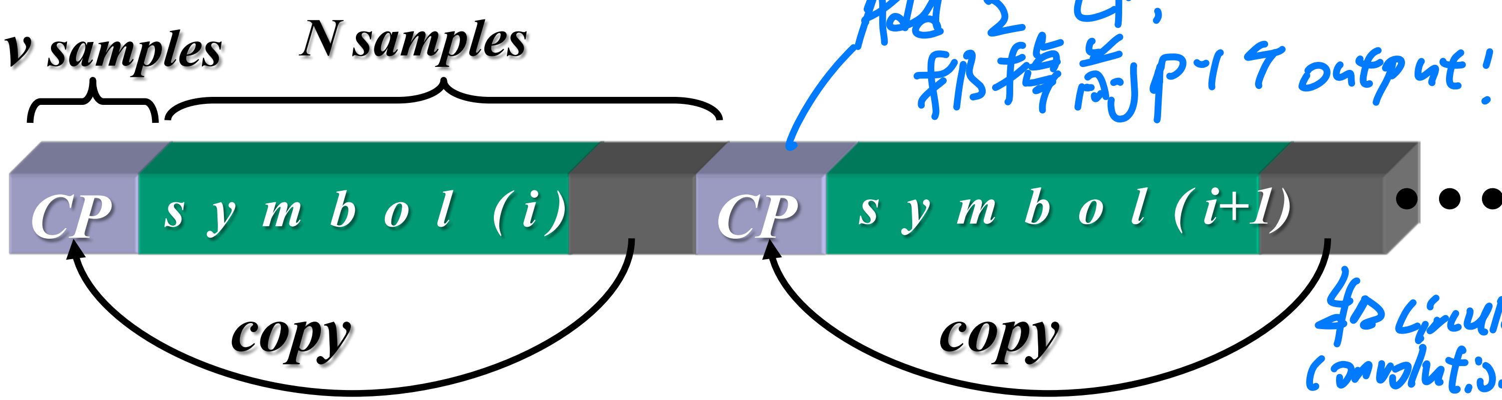
The partial products generated in the 2nd, 3rd, and 4th rows are circularly shifted to the left as indicated above

Cyclic Prefix Helps in Fighting ISI

- Provide guard time between successive symbols
  - No ISI if channel length is shorter than n +1 samples

- Choose guard time samples to be a copy of the end of the symbol – cyclic prefix
  - Cyclic prefix converts linear convolution into circular convolution
  - Need circular convolution so that

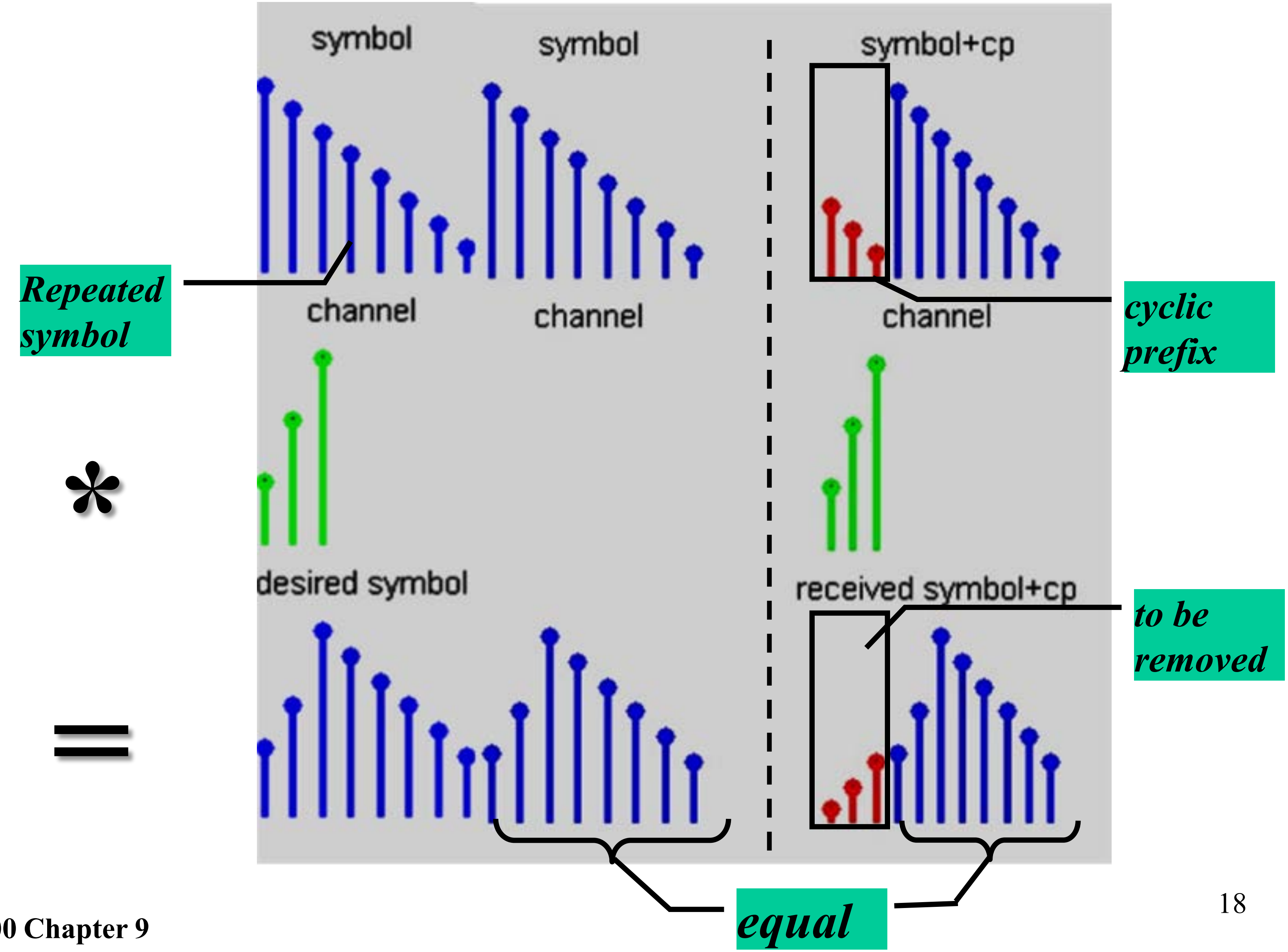
    symbol ⊗ channel ⇔ **FFT(symbol) x FFT(channel)**
  - Then division by the FFT(channel) can undo channel distortion



Add 2 CP, 扔掉前 p-1 个 output!

和 circular convolution 一样!

Cyclic Prefix Helps in Fighting ISI



Circular Convolution

- The N-point circular convolution can be written in matrix form as

$$\begin{bmatrix} y_C[0] \\ y_C[1] \\ y_C[2] \\ \vdots \\ y_C[N-1] \end{bmatrix} = \begin{bmatrix} h[0] & h[N-1] & h[N-2] & \cdots & h[1] \\ h[1] & h[0] & h[N-1] & \cdots & h[2] \\ h[2] & h[1] & h[0] & \cdots & h[3] \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h[N-1] & h[N-2] & h[N-3] & \cdots & h[0] \end{bmatrix} \begin{bmatrix} g[0] \\ g[1] \\ g[2] \\ \vdots \\ g[N-1] \end{bmatrix}$$

- Note: The elements of each diagonal of the $N \times N$ matrix are equal
- Such a matrix is called a **circulant matrix**

Circular Convolution & DFT/IDFT

- Circular convolution: $y[n] = x[n] \circledast h[n] = h[n] \circledast x[n].$

$$x[n] \circledast h[n] = h[n] \circledast x[n] \triangleq \sum_{k=0}^{L-1} h[k]x[n-k]_L$$

- ***Circular convolution allows DFT!***

$$\mathrm{DFT}\{y[n]\} = \mathrm{DFT}\{h[n] \circledast x[n]\}$$

$$Y[m] = H[m]X[m].$$

$$\mathrm{DFT}\{x[n]\} = X[m] \triangleq \frac{1}{\sqrt{L}} \sum_{n=0}^{L-1} x[n]e^{-j\frac{2\pi nm}{L}}$$

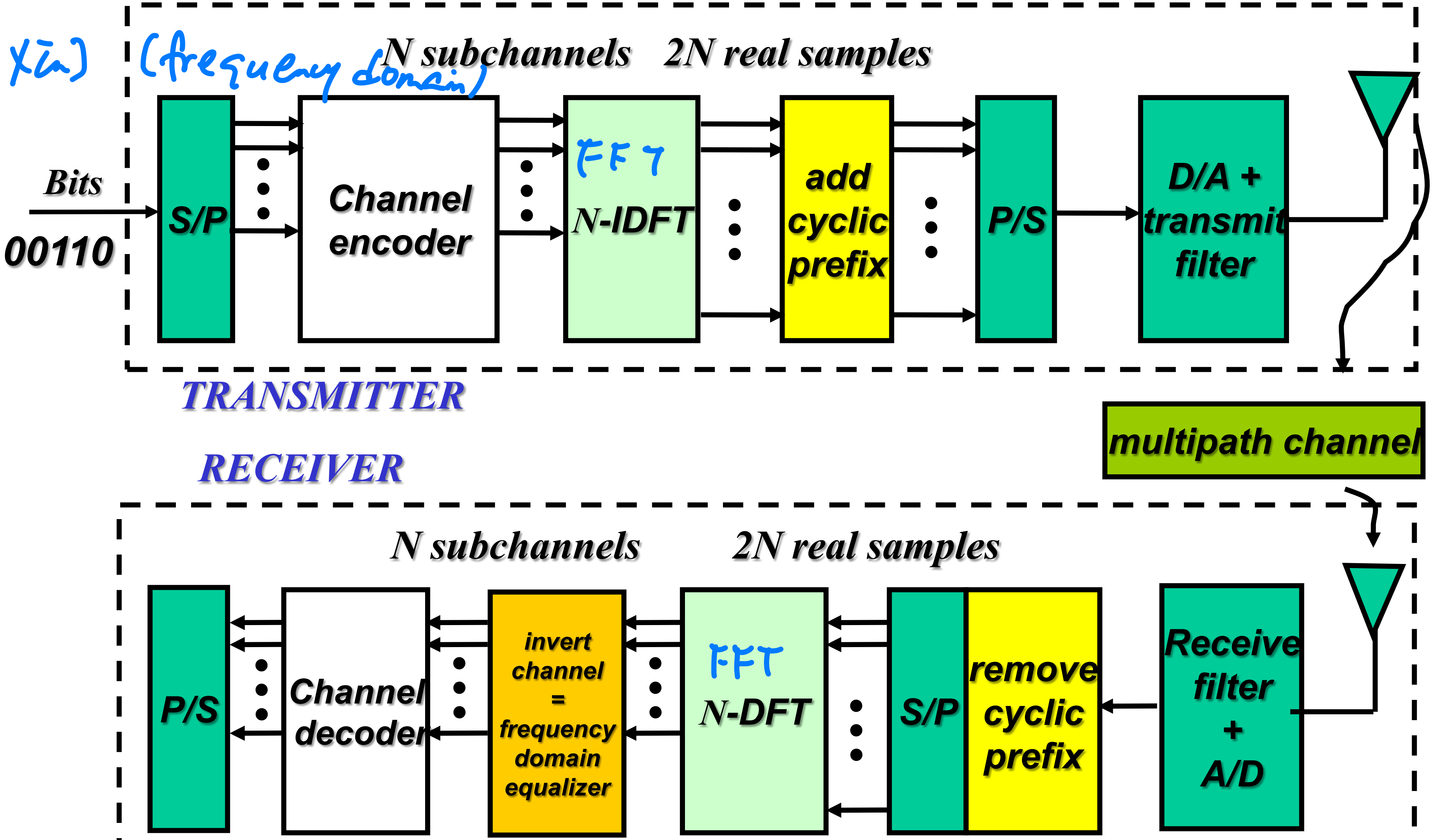
$$\mathrm{IDFT}\{X[m]\} = x[n] \triangleq \frac{1}{\sqrt{L}} \sum_{m=0}^{L-1} X[m]e^{j\frac{2\pi nm}{L}}$$

- ***Detection of X (knowing H):***

$$\hat{X}[m] = \frac{Y[m]}{H[m]}$$

(Note: ISI free! Just a scaling by H)

An OFDM Modem



OFDM Applications