$x(t) \longrightarrow \boxed{h(t)} \longrightarrow y(t) = x(t) * h(t)$, $h(t)$ wireless channel

$h(t) = \sum_{i=0}^{L-1} a_i\, \delta(t-\tau_i) \longrightarrow$ due to scattering

$y(t) = Re\left\{ \sum_{i=0}^{L-1} s_b(t-\tau_i)\, a_i e^{j2\pi f_c \tau_i} \cdot e^{j2\pi f_c t} \right\}$

complex base band representation of $y(t)$

Narrow band assumption: $f_m < \frac{1}{\tau_i} \Rightarrow s_b(t-\tau_i) \approx s_b(t)$

$\Rightarrow y_b(t) = s_b(t) \cdot \sum_{i=0}^{L-1} a_i\, e^{-j2\pi f_c \tau_i}$ → complex fading coefficient (h)

fading: variation of power w.r.t time

$h = X + jY = a\, e^{j\phi}$

$X, Y \sim N(0, 1/2)$; $f_A(a) = 2a\, e^{-a^2}$; $\phi \sim unif(-\pi, \pi)$

- To get knowledge of 'h' it must be measured atleast once every coherence time
- measuring/estimating h is called channel estimation
- Estimation is done using pilot symbol transmission

$T_c <$ channel estimation time ← fast fading

$T_c >$ channel estimation time ← slow fading

generally $\sigma_\tau << T_c$

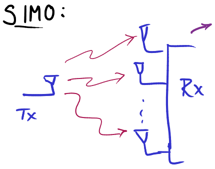
$T_c \uparrow$		
	flat fading, slow fading	Freq. selective fading, slow fading
	flat fading, fast fading	Freq. selective fading, fast fading
		$\rightarrow \sigma_\tau$

	wireline	wireless
SNR:	$\frac{P^2}{\sigma_n^2}$	$\frac{P^2 a^2}{\sigma_n^2}$; a - random variable
	$BER = Q(\sqrt{SNR}) \approx e^{-SNR}$	$avg.BER = \frac{1}{2}\left(1 - \sqrt{\frac{SNR}{SNR+2}}\right) \approx \frac{1}{2\,SNR}$

Deep fade → Noise power > signal power

$\mathbb{P}(\text{deep fade}) \approx \frac{1}{SNR}$

SIMO:



h_i − fading coefficient of link i

$\bar{y} = \bar{h} x + \bar{n}_{L\times 1}$; $E[|n_i|^2] = \sigma_n^2$

Signal detection: linear combination of y_i's (Beam forming)

$\hat{x} = w^H \bar{y}$; $w^* = \frac{\bar{h}}{\|\bar{h}\|} \longrightarrow$ Maximal Ratio Combiner (MRC) (or) Spacial Matched filter

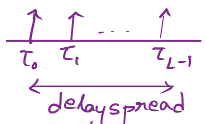
$SNR = \frac{\|h\|^2 P}{\sigma_n^2}$

avg. BER $\approx \frac{1}{2^L} \cdot \frac{1}{(SNR)^L} \cdot {}^{2L-1}C_L \;\propto\; \frac{1}{(SNR)^L}$

$\mathbb{P}(\text{deep fade}) \propto \frac{1}{(SNR)^L}$

Diversity order $= -\lim_{SNR\to\infty} \frac{\log(BER)}{\log(SNR)}$ → L SIMO System; → ∞ for wireline

$|h(\tau)|^2 = \sum_{i=0}^{L-1} |a_i|^2 \delta(\tau - \tau_i)$



max delay spread $= \tau_{L-1} - \tau_0$

RMS delay spread (σ_τ) — weighted power

$$\sigma_\tau = \sqrt{\frac{\sum_{i=0}^{L-1} |a_i|^2 (\tau - \bar{\tau}_i)^2}{\sum_i |a_i|^2}} \; ; \quad \bar{\tau} = \frac{\sum |a_i|^2 \tau_i}{\sum_i |a_i|^2}$$

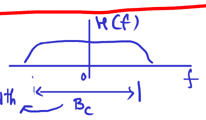
↳ Total power

- avg. Power $= \mathbb{E}[|h(\tau)|^2] = \bar{\phi}(\tau)$

$$f(\tau) = \frac{\bar{\phi}(\tau)}{\int_0^\infty \bar{\phi}(\tau)\, d\tau} \; ; \quad \bar{\tau} = \int_0^\infty \tau f(\tau)\, d\tau \; ; \quad \sigma_\tau^2 = \int_0^\infty (\tau - \bar{\tau})^2 f(\tau)\, d\tau$$

Delay spread ≈ 1-3 μs outdoor
≈ 10-50 ns indoor

$H(f) = \mathcal{F}(h(t)) \longrightarrow$



coherence bandwidth

$B_c \approx \frac{1}{2\sigma_\tau}$

B_s − symbol Bandwidth

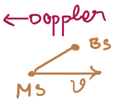
$B_s > B_c \Rightarrow$ frequency selective distortion

⇕

$\sigma_\tau >> T_{symbol} \Rightarrow$ Inter symbol Interference (ISI)

$(2B_c << B_s)$

Change in frequency due to motion ← doppler effect



$h_b(t) = \sum_{i=0}^{L-1} a_i\, e^{-j2\pi f_c \tau_i}\, e^{j2\pi f_d t}$

↳ time varying channel; time varying phase; $\tau_i(t) = \tau_i - \frac{v\cos\theta}{c} t$

$f_d = f_c \frac{v\cos\theta}{c}$

mobility → doppler → Time selective channel.

Coherence Time $T_c = \frac{1}{4 f_d}$ (approx time channel is constant)

Doppler spread $B_d = 2 f_d$; $T_c \approx$ ms