Wireless Communications seminar 02

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Contents

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- Review of Large-scale fading
    - Pathloss
    - Shadowing
    - Cell Planning

- Small-scale fading (multi-path channel fading)
    - Time-varying impulse response
    - Coherence Bandwidth & Power Delay Profile
    - Coherence Time & Doppler spread spectrum

REVIEW (LARGE-SCALE FADING)

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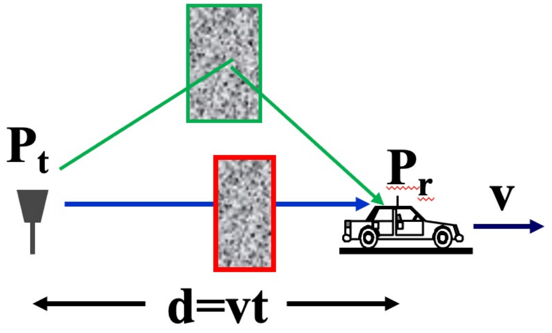
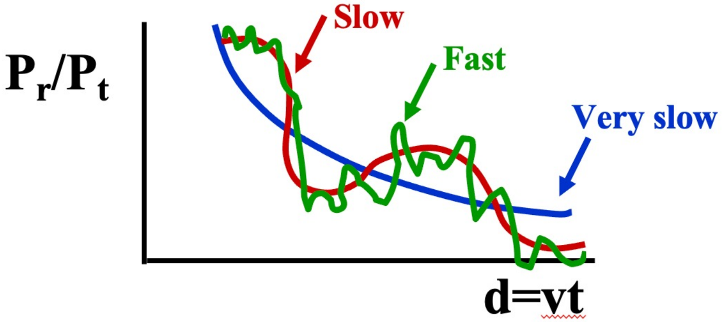
- Path Loss
  - Signal power decrease by distance
- Shadowing
  - Attenuation by obstacles
- Multipath Fading
  - Reflection, diffraction, scattering





"Path loss" + "Shadowing" + "Multipath"

Review (Large-scale Fading)

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- Pathloss + Shadowing
- Shadowing: Log-normal random variable

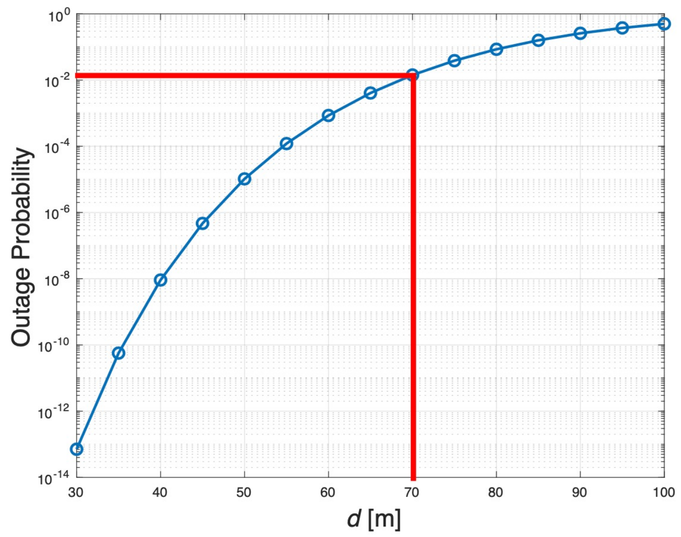
$$\frac{P_r}{P_t}dB = 10\log_{10} K - 10\gamma\log_{10}\left(\frac{d}{d_0}\right) - \Psi_{dB}, \qquad \Psi_{dB} \sim \mathcal{N}\left(\mu_\Psi, \sigma_\Psi^2\right)$$

- Outage probability: $p_{out}(P_{min}, d) = p(P_r(d) < P_{min})$
- For Log-normal shadowing model:

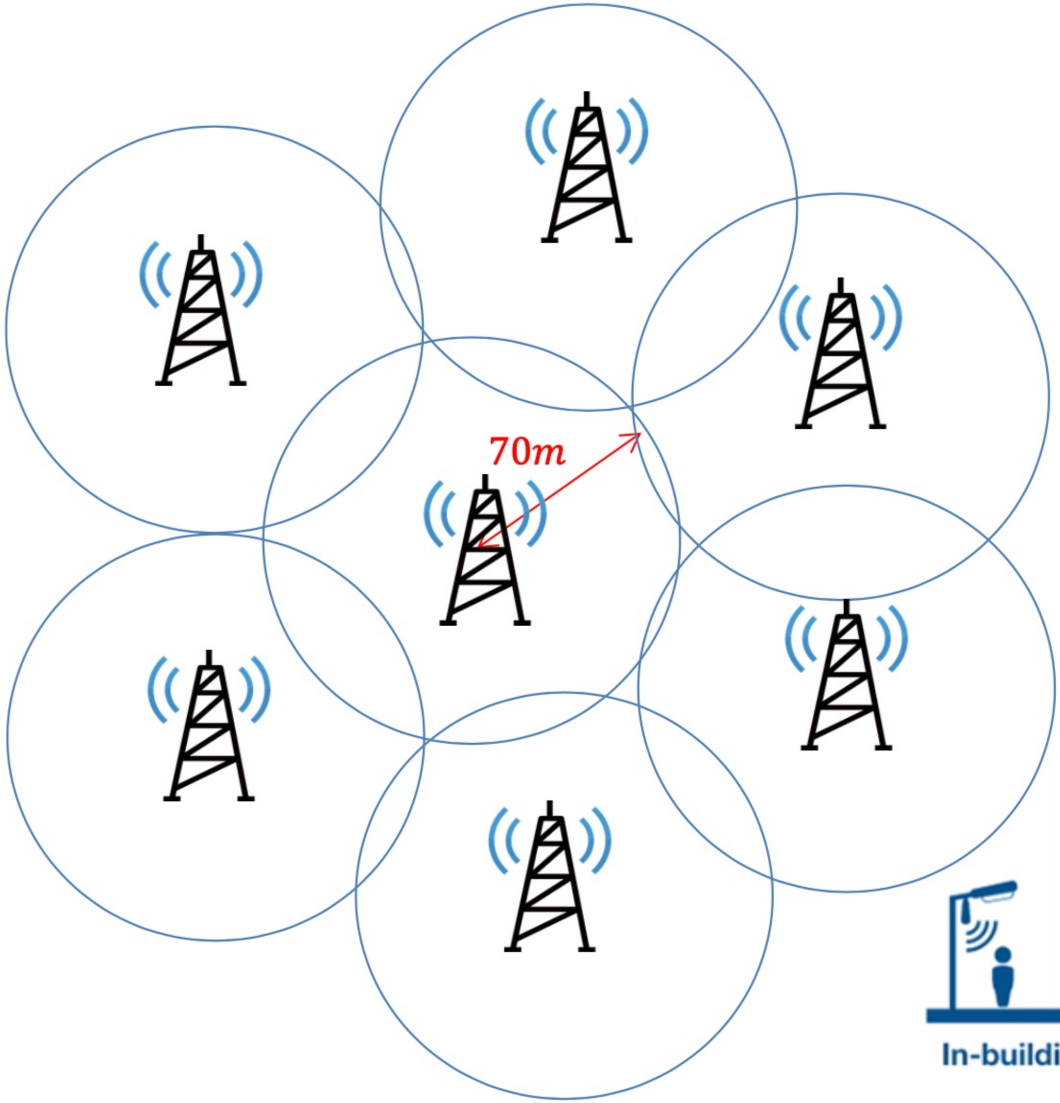
$$p(P_r(d) \leq P_{min}) = 1 - Q\left(\frac{P_{min} - (P_t + K_{dB} - 10\gamma\log_{10}(d/d_0))}{\sigma_{\psi_{dB}}}\right)$$

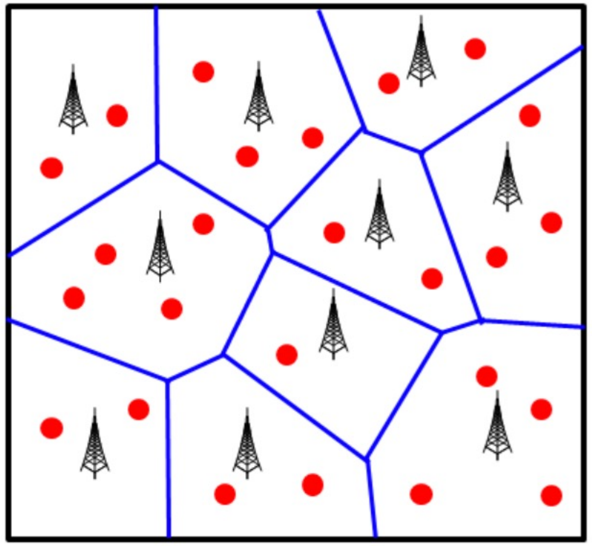
Review (Large-Scale Fading)

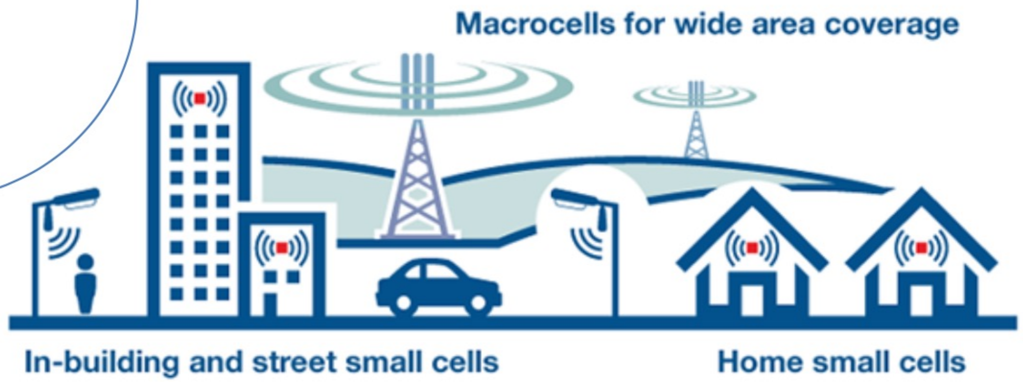
- Cell Planning : Choosing Cell Size
- Ex)
  - Consider wireless system
  - Transmit power at BS: 100dBm
  - Path-loss model: $P_r(d)\mathrm{dBm} = P_t\mathrm{dBm} \; - 40\log_{10} d - \varphi_{dB},\; \varphi_{dB} \sim \mathcal{N}(0, 8^2)$
  - Required Received power: 20dBm
  - Required Outage probability: $p_{out} < 0.01$



Review (Large-Scale Fading)

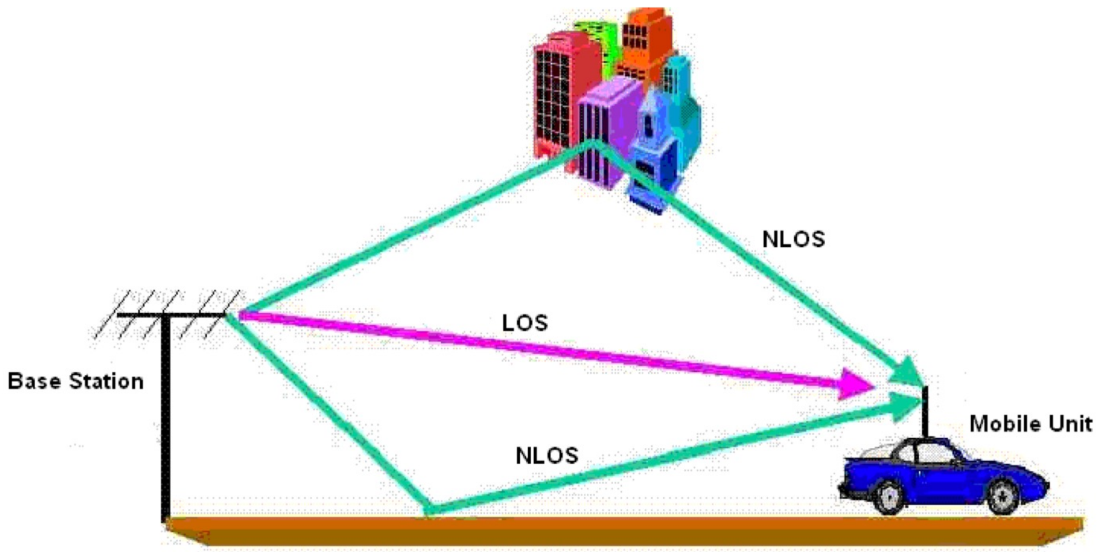


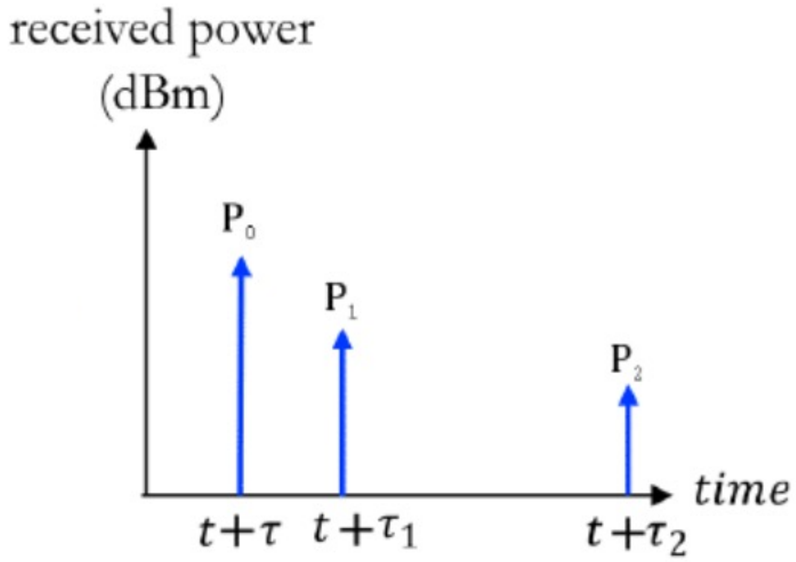




MULTIPATH MODEL

- Multipath Fading
  - Constructive and destructive effects of different multipath components introduced by the channel
- Time-Varying Channel impulse response





MULTIPATH MODEL

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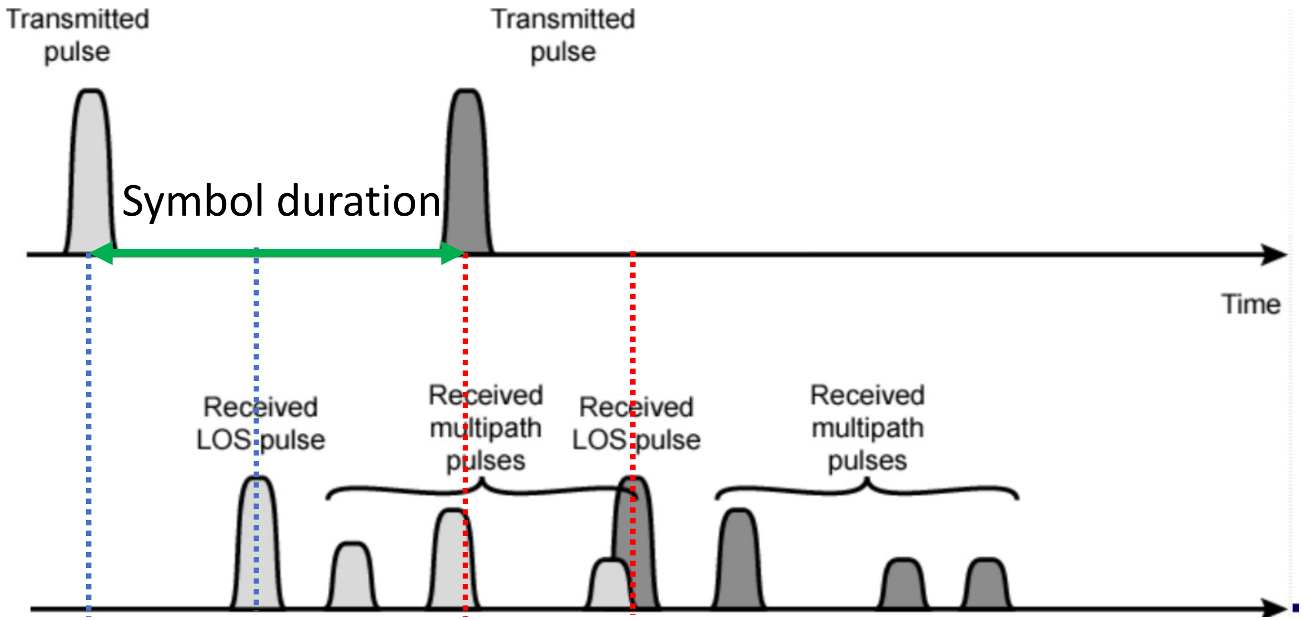
- Multipath Fading
  - Constructive and destructive effects of different multipath components introduced by the channel
- **Time-Varying Channel impulse response**
  - Impulse response → A Train of impulse responses



STATISTICAL MULTIPATH MODEL

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- Random number of multipath components
- Random Components change with time
  - The baseband signal : $\tilde{s}(t)$
  - Amplitude : $\alpha_i(t)$
  - Angle of arrival : $\theta_i(t)$
  - Doppler shift : $f_{D_i}(t) = \frac{v}{c} cos\theta_i(t)$
  - Phase shift : $\phi_{D_i}(t) = \int_t f_{D_i}(t)dt$
  - Path delay : $\tau_i(t) = \frac{x_i(t)}{c}$, $x_i(t)$: path length
- The Received Signal

$$r(t) = Re\left\{\sum_{i=0}^{N(t)-1} \underbrace{\alpha_i(t)}_{\text{Pathloss, Shadowing}} \tilde{s}(t - \underbrace{\tau_i(t)}_{\text{delay}}) e^{j(2\pi f_c(t-\tau_i(t)) + \underbrace{\phi_{D_i(t)}}_{\text{Doppler}})}\right\}$$

TIME-VARYING IMPULSE RESPONSE

- Received signal in multipath

$$r(t) = Re\left\{\sum_{i=0}^{N(t)-1} \alpha_i(t)\tilde{s}\big(t-\tau_i(t)\big)e^{j\left(2\pi f_c(t-\tau_i(t))+\phi_{D_i}(t)\right)}\right\}$$

$$\phi_i(t) = -2\pi f_c\tau_i(t) + \phi_{Di}(t)$$

$$= Re\left\{e^{j2\pi f_c t}\sum_{i=0}^{N(t)-1} \boxed{\tilde{s}\big(t-\tau_i(t)\big)}\alpha_i(t)e^{j\phi_i(t)}\right\},$$

Sifting property

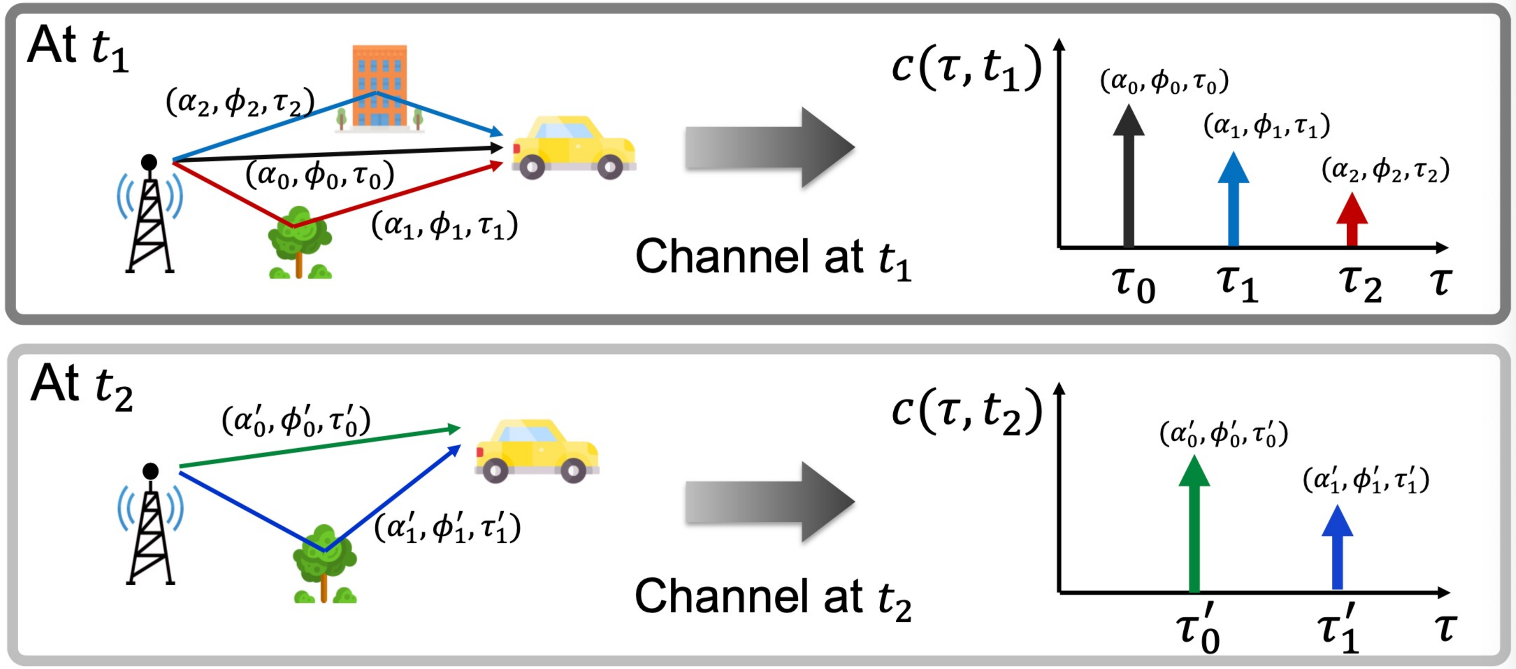
$$= Re\left\{e^{j2\pi f_c t}\sum_{i=0}^{N(t)-1} \boxed{\int_{\infty}^{\infty}\delta\big(\tau-\tau_i(t)\big)\tilde{s}(t-\tau)}d\tau\,\alpha_i(t)e^{j\phi_i(t)}\right\}$$

$$= Re\left\{e^{j2\pi f_c t}\left(\int_{-\infty}^{\infty} c(\tau,t)\tilde{s}(t-\tau)d\tau\right)\right\}$$

Time-varying Impulse Response

- Multipath is modeled by time-varying channel impulse response

$$c(\tau,t)=\sum_{i=0}^{N(t)-1}\delta\big(\tau-\tau_i(t)\big)\alpha_i(t)e^{j\phi_i(t)}$$



WIDEBAND MODEL

- Assume that the delay spread is significantly larger than the signal bandwidth (i.e., $T_D = \max_i|\tau_i - \tau_0| \gg B_s^{-1}$
  - Each of the multipath can be resolved
  - Multipath delay spread should be considered

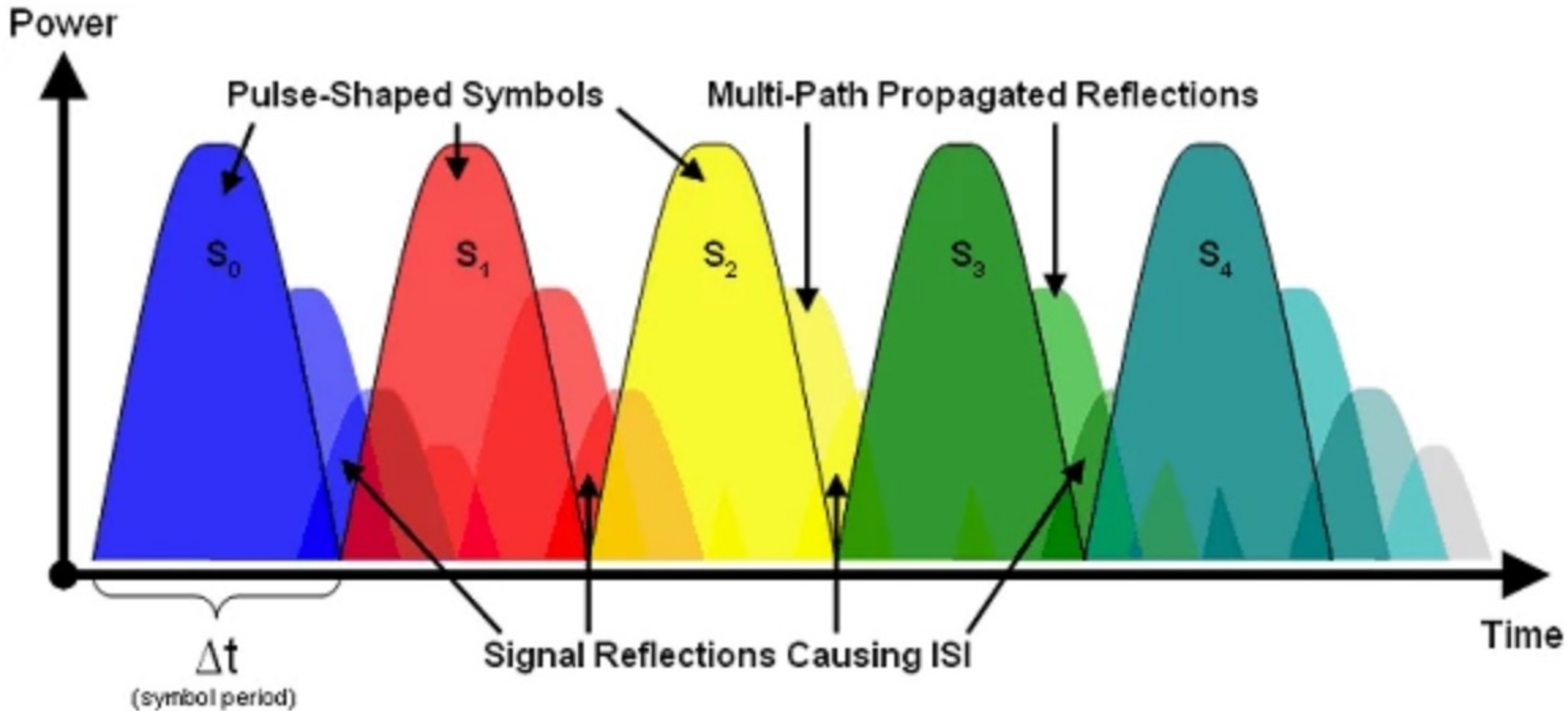
- Use $c(\tau, t)$ for characterizing channel

$$c(\tau, t) = \sum_{i=0}^{N(t)-1} \delta\big(\tau - \tau_i(t)\big)\alpha_i(t)e^{j\phi_i(t)}$$

  - Since $c(\tau, t)$ is random, we should charactize it statistically

Wideband Model

- An Intuition for ISI in wideband



WIDEBAND MODEL

- Key Assumptions on $c(\tau, t)$
  - Zero-mean complex Gaussian process
  - Phase of each multipath component is uniformly distributed
  - Wide Sense Stationary (WSS)
  - Uncorrelated scattering (US) : channel responses are uncorrelated between two different time delays

- Autocorrelation function ($A_c(\tau, \Delta t)$)
  - Characteristics of wideband channel are derived from the function

$$A_c(\tau_1, \tau_2; t, t + \Delta t) = \mathbb{E}[c^*(\tau_1, t)c(\tau_2, t + \Delta t)]$$

$$= A_c(\tau; \Delta_t)$$

∵ Wide Sense Stationary

WIDEBAND MODEL

- Wideband Channel Characteristics
  - Power delay profile
  - Coherence bandwidth
  - Doppler spread
  - Coherence time

Coherence Bandwidth

- Power delay profile

$$A_c(\tau) \triangleq A_c(\tau, 0) = \mathbb{E}[c^*(\tau_1, t)c(\tau_2, t)]$$

  - Average power associated with a given multipath delay
- Delay spread
  - The delay associated with a given multipath component is weighted by its relative power
  - **Average** delay μ_{T_D}

$$\mu_{T_D} = \frac{\int_0^\infty \tau A_c(\tau)d\tau}{\int_0^\infty A_c(\tau)d\tau}$$

  - **rms delay** spread σ_{T_D}

$$\sigma_{T_D} = \sqrt{\frac{\int_0^\infty \left(\tau - \mu_{T_D}\right)^2 A_c(\tau)d\tau}{\int_0^{(\infty)} A_c(\tau)d\tau}}$$

COHERENCE BANDWIDTH

- Delay spread of the channel is rougly by the time delay T where $A_c(\tau) \approx 0$ for $\tau \geq T$
  - $T_s \ll \textbf{rms}$ delay spread σ_{T_m} $\left(T_s < \frac{1}{10}\sigma_{T_m}\right)$

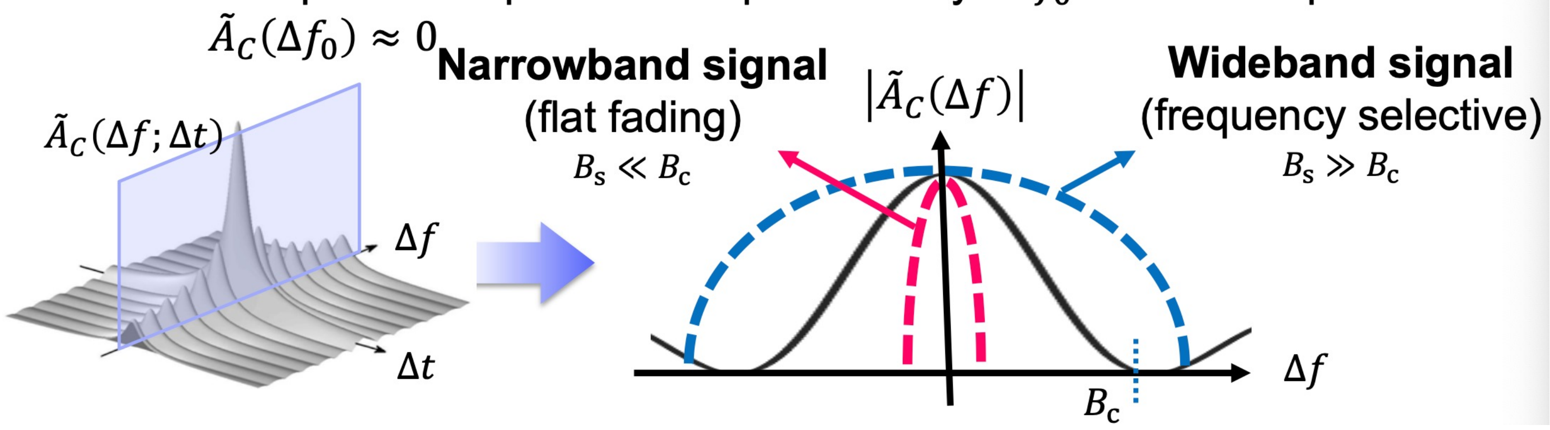
The system experiences significant ISI

  - T_s not small enough with respect to the **rms** delay spread σ_{T_m} $\left(T_s > \frac{1}{10}\sigma_{T_m}\right)$

The ISI can be negligible

Coherence Bandwidth

- **Define** $\boldsymbol{\tilde{A}(\Delta f; \Delta t) = \int_{\infty}^{\infty} A_c(\tau; \Delta t) e^{-j2\pi\Delta f\tau} d\tau}$
- $\tilde{A}(\Delta f) \triangleq \tilde{A}_c(\Delta f; 0)$: The autocorrelation of time-varying multipath channel in frequency domain
- The Coherence Bandwidth $B_c \approx \frac{1}{\sigma_{T_D}}$
  - Frequency B_c where $\tilde{A}(\Delta f) \approx 0$ for all $\Delta f > B_c$
  - Multipath components separated by Δf_0 are independent if $\tilde{A}_c(\Delta f_0) \approx 0$



Coherence Time

- **Define** $\boldsymbol{\tilde{A}_c(\Delta f;\Delta t) = \int_{\infty}^{\infty} A_c(\tau;\Delta t)e^{-j2\pi\Delta f\tau}d\tau}$
- Coherence time T_c
  - Time variation of the channel (**by Doppler shift**)
  - $\tilde{A}_c(\Delta t) \triangleq \tilde{A}_c(\Delta f = 0;\Delta t)$
  - $\tilde{A}_c(\Delta t) = 0$ $\rightarrow$ uncorrelated and independent
  - T_c: Range of Δt values over which $\tilde{A}_c(\Delta t)$ is approximately nonzero
- Doppler spread $B_D \approx \frac{1}{T_c}$
  - Doppler power spectrum: $S_c(\rho) = \mathcal{F}_{\Delta t}\left[\tilde{A}_c(\Delta t)\right] = \int_{-\infty}^{\infty} A_c(\Delta t)e^{-j2\pi\rho\Delta t}d\Delta t$

    $\rightarrow$ gives a Power Spectral Density of the received signal as a function of Doppler ρ
  - B_D : Maximum ρ value for which $|S_c(\rho)|$ is greater than zero

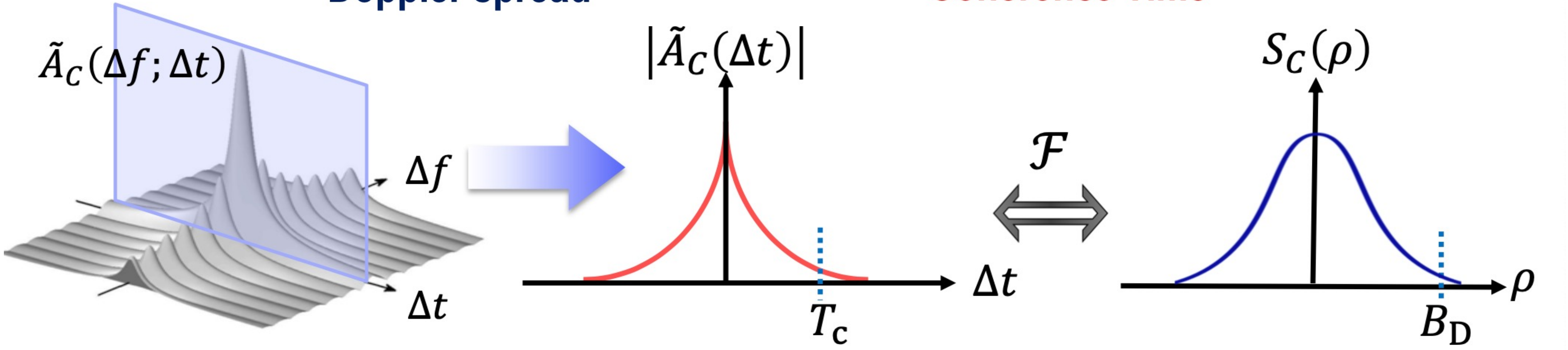
COHERENCE TIME

- Coherence time and Doppler Spread
  - By Fourier Transform

$$\tilde{A}_c(\Delta t) \xrightarrow{\mathcal{F}ourier\ Transform} S_c(\rho)$$

$$\boxed{\boxed{B_{\mathrm{D}}} \approx \boxed{1/T_{\mathrm{c}}}}$$

Doppler spread **Coherence Time^{-1}**



SUMMARY

- Coherence Bandwidth and Power delay profile

$$B_c \approx \frac{1}{\sigma_{T_D}}$$

- Coherence Time and Doppler spread

$$T_c \approx \frac{1}{B_D}$$

- And they all come from $c(\tau, t)$: the time-varying channel impulse response

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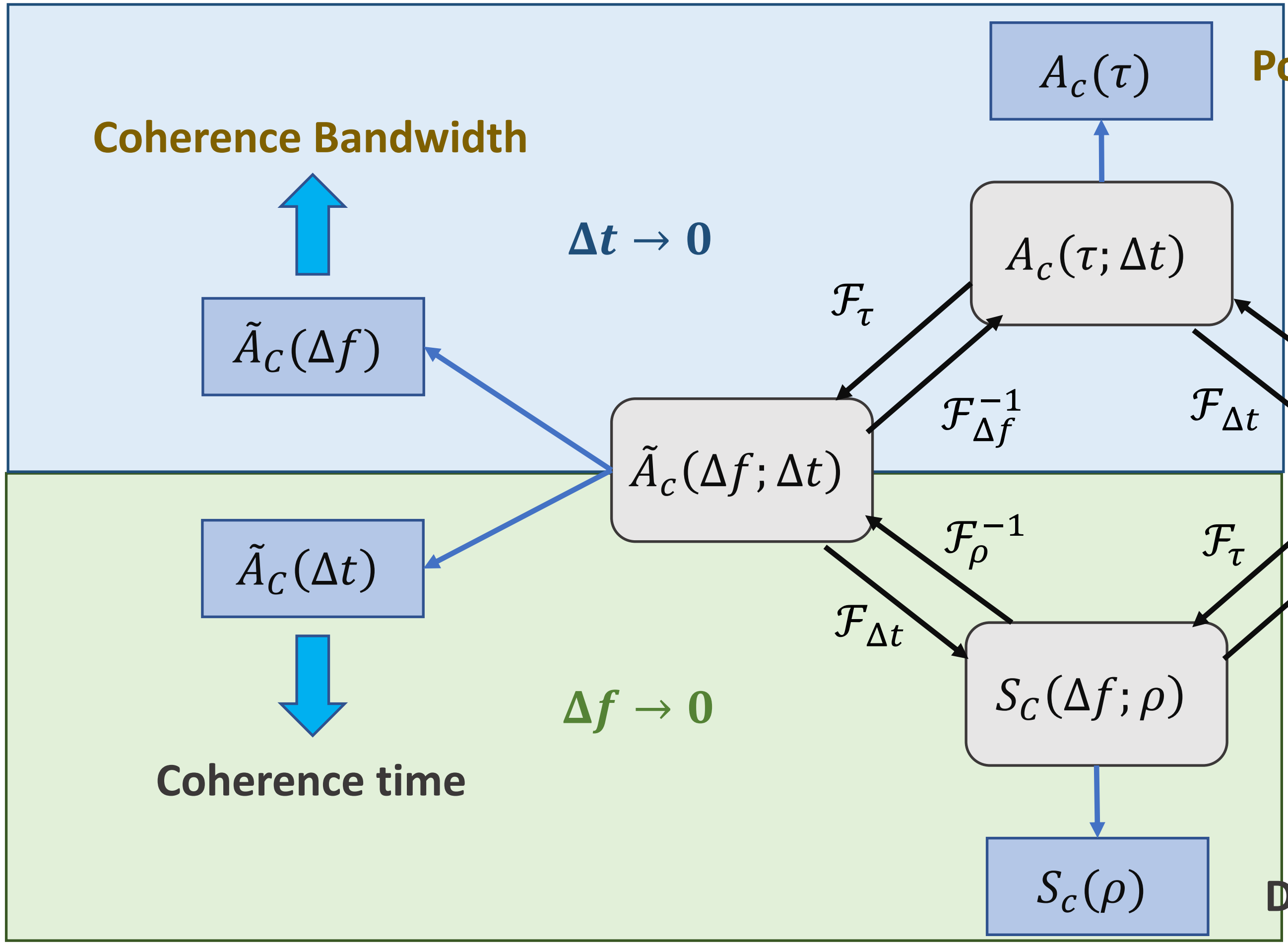
SUMMARY

- The Relationships of the Characteristics



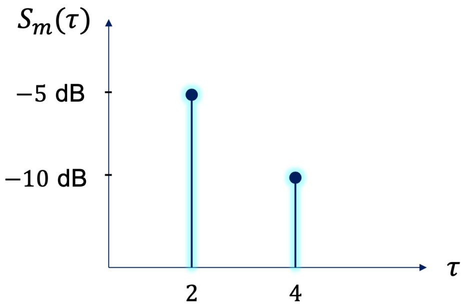
Autocorrelation function

$\mathcal{F}_\rho^{-1}$

$S_c(\tau;\rho)$

$\mathcal{F}_{\Delta f}^{-1}$

Scattering function



Power Delay Profile → **Delay Spread**

$$\sigma_\tau = \sqrt{\overline{\tau^2} - \bar{\tau}^2}$$

$$\bar{\tau} = \frac{\int_0^\infty S_m(\tau)\tau d\tau}{\int_0^\infty S_m(\tau)d\tau} \quad \text{and} \quad \overline{\tau^2} = \frac{\int_0^\infty S_m(\tau)\tau^2 d\tau}{\int_0^\infty S_m(\tau)d\tau}$$

Doppler Power Spectrum → **Doppler Spread**

SUMMARY

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Coherence BW becomes a smaller than signal BW "multipath"

Coherence Time becomes a smaller than symbol duration

"mobility"

Slow fading Frequency-flat fading	Slow fading Frequency-selective fading
Fast fading Frequency-flat fading	Fast fading Frequency-selective fading

Discrete-Time Baseband Model

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- Frequency Flat / Slow Fading Channel (at time domain)

$$y[n] = hs[n] + v[n]$$

- Frequency Flat / Fast Fading Channel (at time domain)

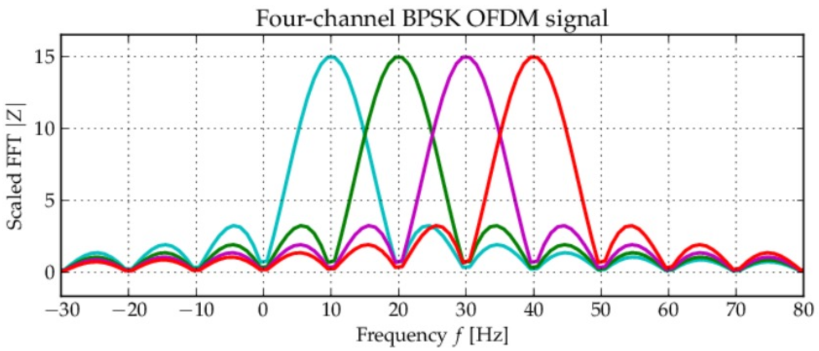
$$y[n] = h[n]s[n] + v[n]$$

Channel tracking via Wiener/Kalman filters

- Frequency Selective / Slow Fading Channel

$$y[n] = \sum_{l=0}^{L} h[l]s[n-l] + v[n]$$

OFDM modulation



- Frequency Selective / Fast Fading Channel

$$y[n] = \sum_{l=1}^{(L)} h[n,l]s[n-l] + v[n]$$

V2V Communications

References

- ECE 432 Mobile Communications_Lecture2_Ajou_university lecture notes by S.N. Hong & W.J Shin
- Goldsmith, Andrea. *Wireless communications*. Cambridge university press, 2005.

QnA

Thank you