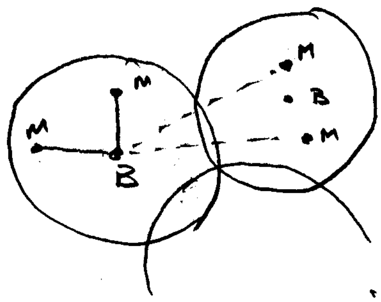
3. PROPAGATION, FADING AND DIVERSITY

- This chapter outlines the features of the propagation environment that affect MUD
  - scattering and fading
  - what fading does to BER
  - diversity: why you need it, and how to get it
  - MUD by spatial processing
  - imperfect channel state information.
- It's all classical, so highlights plus references.

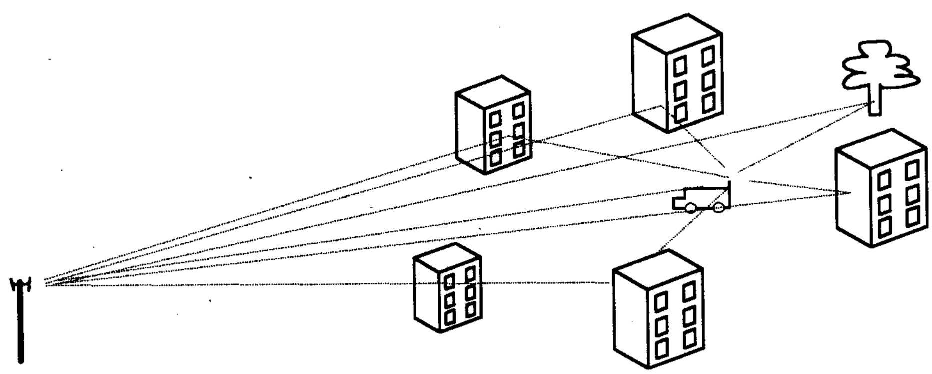
3.1 Scattering Channels

- In the mobile environment, received signal strength depends on distance and obstructions (path loss and shadowing), both with a coarse spatial scale



It also has a spatial microstructure caused by the scattering environment around the mobile.

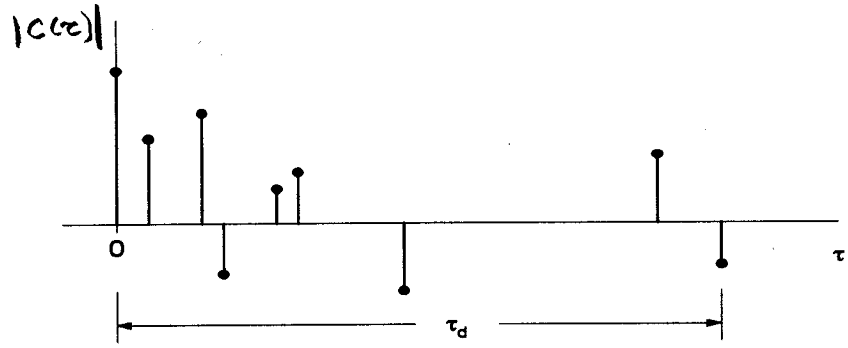
- We can infer most of what we need in this course from the sketch below



[Cave00]

- It's a linear time-dispersive (frequency selective) filter with Channel Impulse Response

$$c(\tau) = \sum_{\ell=0}^{L-1} c_\ell \, \delta(\tau - \tau_\ell)$$

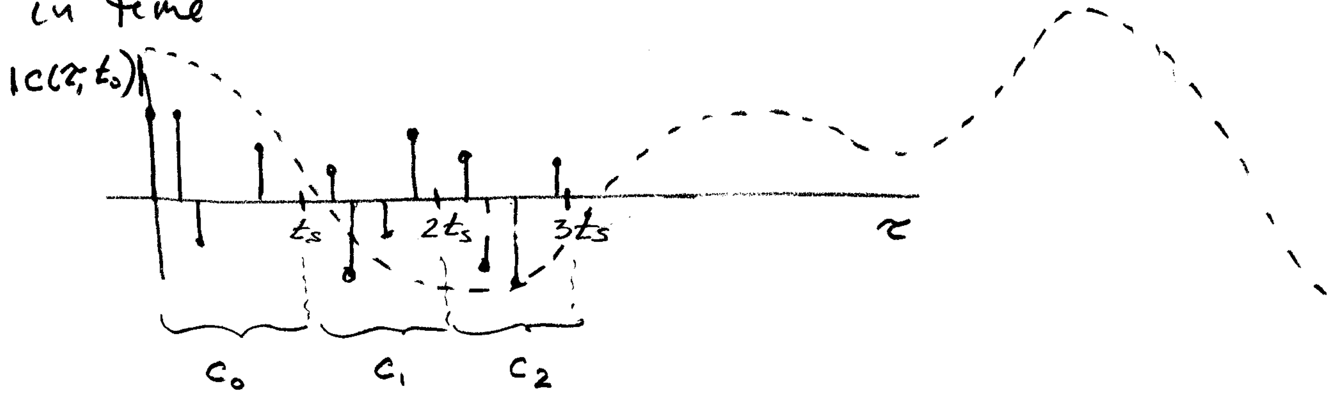


- If mobile moves, phases of components vary in amounts depending on angle of ray w.r.t. direction of travel; it's a linear time variant filter

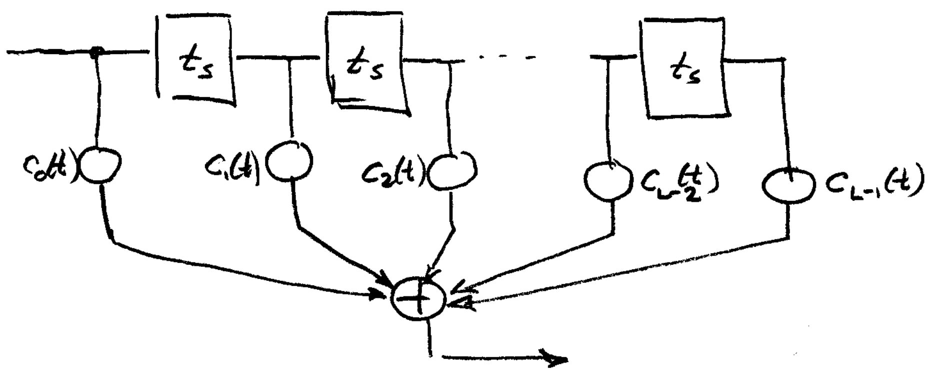
$$c(\tau, t) = \sum_{\ell=0}^{L-1} c_\ell(t) \, \delta(\tau - \tau_\ell)$$

- CIRs of different mobiles are uncorrelated, even if mobiles are only a few wavelengths apart.

- Signal bandwidth determines its temporal resolution. Usually aggregate all components into resolution bins for a model equispaced in time



$$c(\tau, t) = \sum_{l=0}^{L-1} c_l(t)\, \delta(\tau - l t_s)$$

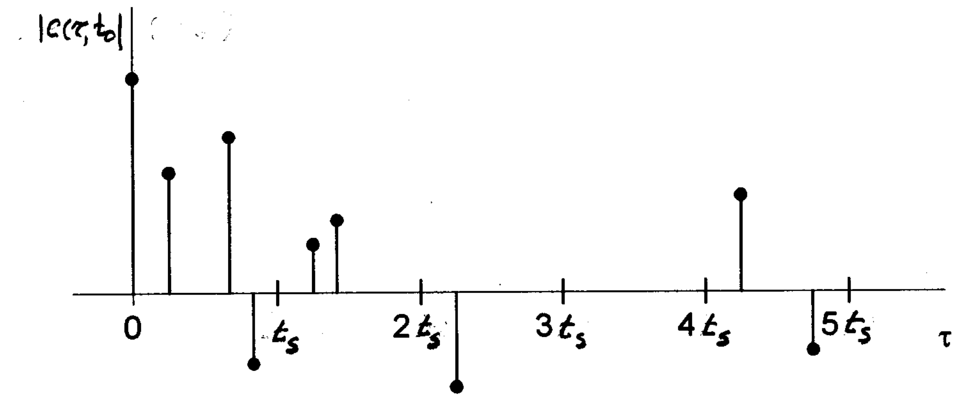


the TDL model

- The behaviour of the aggregated coefficients depends on number of components. Extremes:
  - lots of components; invoke central limit theorem, claim $c_l(t)$ is complex Gaussian

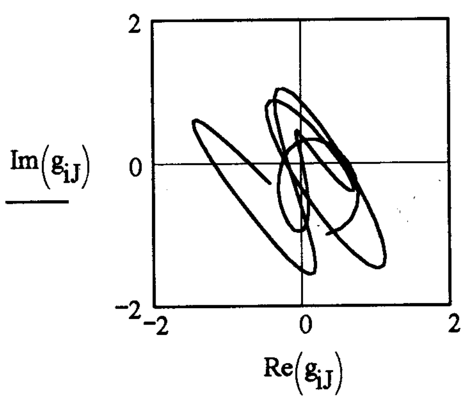
or
  - one component; it just rotates.

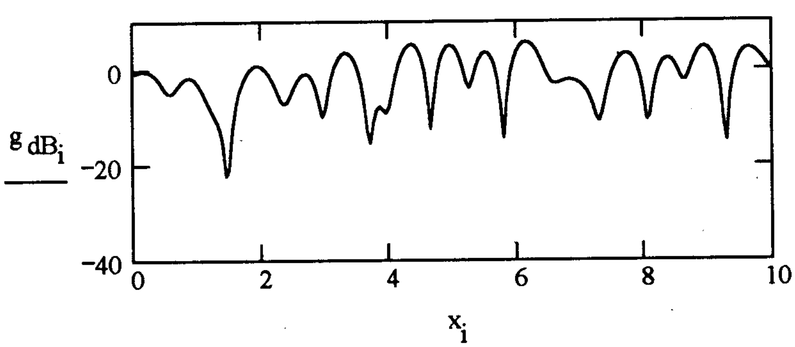
- Commonly, the situation is ambiguous, especially with W-CDMA (4 Mchip/s, $f_s = 8$ MHz)

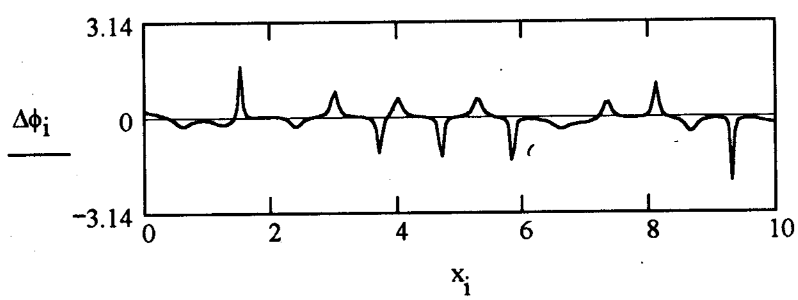


We'll be conservative and assume Gaussian

- The trajectory of a coefficient is instructive:







- If coefficients are Gaussian, then

$$p_c(c) = \frac{1}{2\pi\sigma_c^2}\exp\left(-\frac{1}{2}\frac{|c-\bar{c}|^2}{\sigma_c^2}\right), \qquad \sigma_c^2 = \tfrac{1}{2}E\left[|c-\bar{c}|^2\right]$$

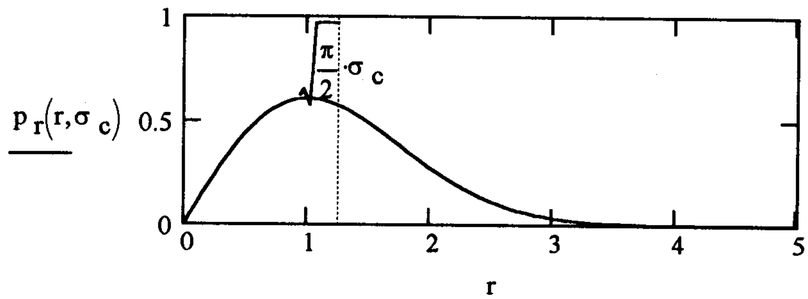
- In polars, $c = re^{j\theta}$. If mean $\bar{c}=0$, then

$$p_{r,\theta}(r,\theta) = \frac{r}{2\pi\sigma_c^2}e^{-r^2/2\sigma_c^2}; \quad r \geq 0, \ -\pi \leq \theta \leq \pi$$

so r, θ are independent, θ uniform, and

$$p_r(r) = \frac{r}{\sigma_c^2}e^{-r^2/2\sigma_c^2}, \quad r \geq 0 \quad \text{Rayleigh}$$

Received amplitude of the component has a Rayleigh pdf.

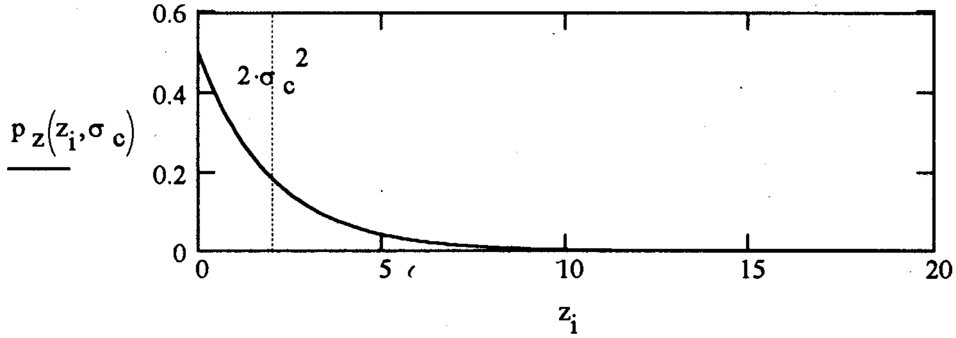


mean $\sqrt{\frac{\pi}{2}}\,\sigma_c$

($\sigma_c = 1$, here)

- Often more convenient to work with $z = r^2 = |c|^2$.
Change of variables gives z an exponential pdf:

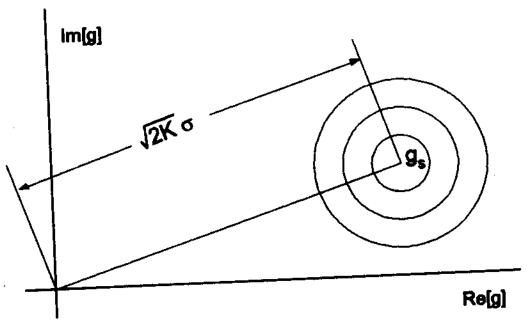
$$p_z(z) = \frac{1}{2\sigma_c^2}e^{-z/2\sigma_c^2} \qquad (\text{or note } \chi^2,\ 2\text{ d.f.})$$



mean $2\sigma_c^2$

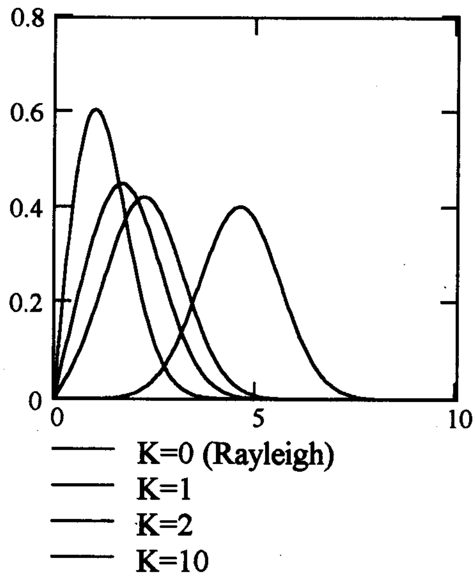
($\sigma_c^2 = 1$ here)

- Note high probability of deep fades.
- If there's a LOS component (common in microcells) or a dominant component, then Rice model

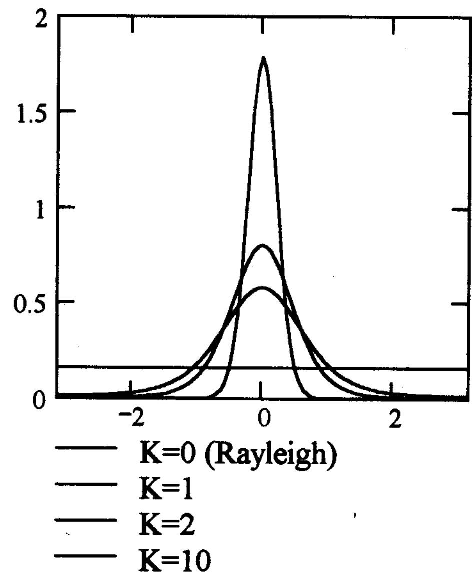


$$p_r(r) = \frac{r}{\sigma_c^2} \exp\left(-\frac{r^2}{2\sigma_c^2} - K\right) I_0\left(\frac{r\sqrt{2K}}{\sigma_c}\right)$$

"K factor": ratio of direct power to scattered power



Rice amplitude pdf



Rice phase pdf (for zero mean)

Note decreased probability of deep fades

- That's all the channel modeling we need for now.