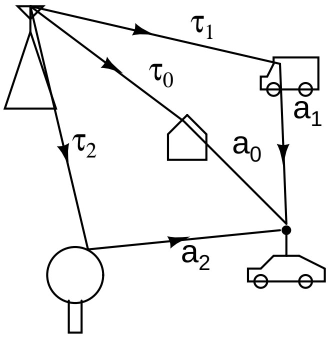
EECE 563 : WIRELESS COMMUNICATIONS
1999/2000 WINTER SESSION, TERM 2

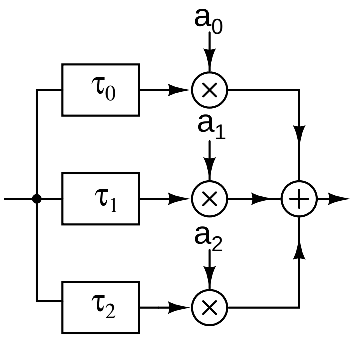
# Lecture 3

## Introduction

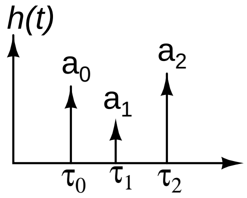
- antennas are usually not within LOS of each other
- signals propagate over multiple paths between transmitter and receiver and combine at receiver



- due to motion of the receiver, the transmitter or the scatterers, the path lengths (and thus delays) change with time
- the wireless channel forms a time-varying linear filter



- with a time-varying impulse response



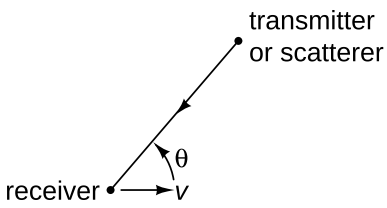
- if we only consider the power of each path, we get a *power delay profile*
- small changes (order of $\lambda$) in location create large changes of phase for each path
- the resultant (sum of all paths) has large amplitude and phase changes (modulation)
- the signal itself is also modulated to transmit information
- different path lengths cause the signals to arrive with different delays and the resultant signal is distorted (typically, ISI)
- this distorts the signal and so communication is made difficult
- the most challenging part of designing a wireless system is coping with this multi-path fading

## Factors Affecting Fading

- reflectors/scatterers: differences in path lengths $(a, \tau)$
- motion: (rate of change of $a, \tau$ with time)

## Doppler Shift

- the phase change per unit time (frequency shift) due to a moving receiver is proportional to frequency, vehicle velocity and angle

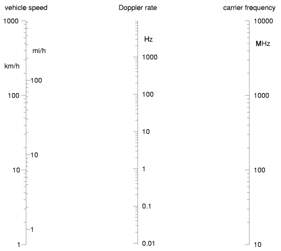


- the Doppler shift due to motion is given by:

$$f_D = \frac{v}{c} f_c cos(\theta)$$

where $v$ is the rate of change of the path distance (relative velocity), $c$ is the signal propagation velocity, $f_c$ is the signal frequency.

- the relationship can be summarized in a nomograph:



## Describing Time Dispersion

- the *excess delay* is a delay measured relative to first arriving component
- *maximum excess delay* is the excess delay of last component
- a threshold (or other criteria such as fraction of total received power) is required to determine which values are to be included as part of the power delay profile
- mean excess delay (if we consider the delay profile as a probability distribution, this is the first moment):

$$\overline{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2}$$

- rms delay spread (second central moment):

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

where

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2}$$

## Coherence Bandwidth

- impulse response and transfer function are Fourier transform pairs
- "bandwidth" of the channel is approximately inversely proportional to maximum (or rms) delay spread
- if "bandwidth" is the range of frequencies for which the correlation coefficient is $> 0.9$, then

$$B_c \approx \frac{1}{50\sigma_\tau}$$

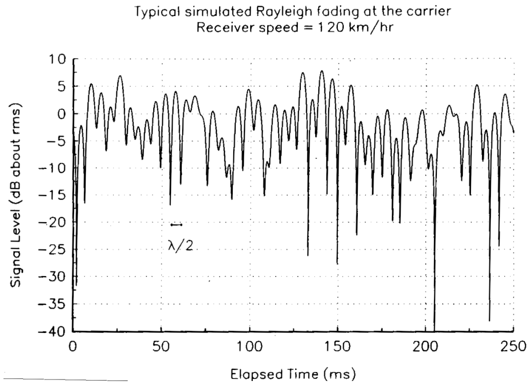
- or, for 0.5 correlation:

$$B_c \approx \frac{1}{5\sigma_\tau}$$

- actual values will depend on the shape of the delay profile

## Doppler Spread

- motion causes time-varying signal (and thus Doppler spreading)
- for example, the amplitude with time or position:



- Doppler spread $B_D$ is the spectral broadening due to this modulation
- typically have components over the range from $f_c - f_D$ to $f_c + f_D$ where $f_c$ is the carrier frequency

- coherence time is approximately the reciprocal of coherence bandwidth:

$$T_C \approx \frac{1}{f_D}$$

- for correlation in time of more than 0.5, the coherence time is:

$$T_C \approx \frac{9}{16\pi f_D}$$

- or (is use a value between the two above):

$$T_C \approx \frac{0.423}{f_D}$$

## Types of Fading

- the effect of multipath phenomena depends on the nature of the signal (it's symbol rate or it's reciprocal, the bandwidth)
- if the signal bandwidth is much less than the coherence bandwidth, the channel is said to be a *flat-fading* channel, otherwise it's a *frequency-selective* channel
- equivalently, for a flat-fading channel the delay spread is much shorter than the symbol period
- the channel can also be characterized as *fast-fading* or *slow-fading*, depending on whether the Doppler spread is much greater than or much less than the signal bandwidth
- it can also be neither fast- nor slow-fading

## Flat- and Frequency-Selective Channels

- the flat-fading channel is also called *narrowband* channel because signal bandwidth is much smaller than the coherence bandwidth:

$$B_S \ll B_C$$

- or, equivalently, the symbol period is much greater than the delay spread:

$$T_S \gg \sigma_\tau$$

- for a frequency-selective channel (also known as a *wideband* channel) the delay spread of the channel is not much shorter than the symbol period
- the energy from one symbol is received during subsequent symbol periods causing intersymbol interference (ISI)
- the frequency-selective channel channel is specified by it's power delay profile
- rule of thumb: channel is frequency-selective if rms delay spread $\sigma_\tau$:

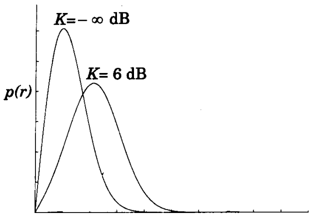
$$\sigma_\tau > \frac{T_S}{10}$$

- a channel can be any of the four combination of slow/fast and flat- or frequency-selective
- it's also possible the channels cannot be clearly classified as either (e.g. fading rate not much greater or much less than symbol period)

## Rayleigh Distribution

- if the real and imaginary components of a complex r.v. are normally distributed as $\sim (0, \sigma)$, the amplitude of the r.v. is Rayleigh distributed:
- probability density:

$$p(r) = \begin{cases} \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right) & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases}$$

- 

- cumulative distibution:

$$P(R) = Pr(r < R) = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right)$$

- envelope has a mean $1.25\sigma$, variance $0.43\sigma^2$ and median $1.18\sigma$

## Ricean Distribution

- if add a (complex) constant of magnitude $A$ to the above r.v., the magnitude has a Ricean distribution
- probability density:

$$p(r) = \begin{cases} \frac{r}{\sigma^2} \exp\left(-\frac{r^2+A^2}{2\sigma^2}\right) I_0(\frac{Ar}{\sigma^2}) & (A \geq 0, r \geq 0) \\ 0 & (r < 0) \end{cases}$$

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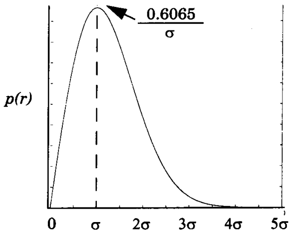

- often use ratio of fixed to random signal powers:

$$K = \frac{A^2}{2\sigma^2}$$