

# Wideband Models. Multipath Intensity Profile. Doppler Spectrum.

## Lecture Outline

- Wideband Channel Models
- Scattering Function
- Multipath Intensity Profile, Delay Spread, and Coherence Bandwidth
- Doppler Power Spectrum, Doppler Spread, and Coherence Time

### 1. Wideband Channel Models

- In wideband multipath channels the individual multipath components can be resolved by the receiver. True if  $T_m > 1/B$ .
- If the components can be resolved then they can be combined for diversity gain (e.g. using an equalizer).

### 2. Channel Scattering Function:

- For deterministic channels, the scattering function is defined as the Fourier transform of  $c(\tau, t)$  with respect to  $t$ .
- Typically  $c(\tau, t)$  is unknown, so it must be characterized statistically.
- Since underlying process  $c(\tau, t)$  is Gaussian and WSS, only need to characterize its mean and correlation, which is independent of time. We assume  $c(\tau, t)$  has mean zero.
- Autocorrelation of  $c(\tau, t)$  is  $A_c(\tau_1, \tau_2; \Delta t) = A_c(\tau_1, \tau_2; \Delta t)\delta(\tau_1 - \tau_2) = A_c(\tau; \Delta t)$  since we assume channel response associated with different scatterers is uncorrelated.
- Statistical scattering function defined as  $S(\tau, \rho) = \mathcal{F}_{\Delta t}[A_c(\tau, \Delta t)]$ . This function measures the average channel gain as a function of both delay  $\tau$  and Doppler  $\rho$ .
- $S(\tau, \rho)$  easy to measure empirically and is used to get average delay spread  $T_M$ , rms delay spread  $\sigma_\tau$ , and Doppler spread  $B_d$  for empirical channel measurements.

### 3. Multipath Intensity Profile and Delay Spread

- Multipath intensity profile (delay power spectrum) defined as  $A_c(\tau; \Delta t = 0) = A_c(\tau)$ , i.e. the autocorrelation relative to delay  $\tau$  at a fixed time.
- The average delay  $T_m$  and rms delay spread  $\sigma_\tau$  are defined relative to  $A_c(\tau)$ . These parameters approximate the maximum delay of nontrivial multipath components.

### 4. Coherence Bandwidth

- The coherence bandwidth is defined relative to the Fourier transform of  $A_c(\tau)$ , given by  $A_C(\Delta f) = \mathcal{F}[A_c(\tau)]$ . Note that  $A_C(\Delta f) = A_C(\Delta f, \Delta t = 0)$ .
- Since  $A_C(\Delta f)$  is the autocorrelation of a Gaussian process, multipath components separated by  $\Delta f_0$  are independent if  $A_C(\Delta f_0) \approx 0$ .
- By the Fourier transform relationship, the bandwidth over which  $A_C(\Delta f)$  is nonzero is roughly  $B_c \approx 1/T_m$  or  $B_c \approx 1/\sigma_\tau$  (can also add constants to these denominators).

- $B_c$  defines the coherence bandwidth of the channel, i.e. the bandwidth over which fading is correlated.
- A signal experiences *frequency selective fading* or *ISI* if its bandwidth exceeds the coherence bandwidth of the channel.

#### 5. Doppler Power Spectrum, Doppler Spread, and Coherence Time:

- Doppler power spectrum defined as the Fourier transform of  $A_c(\tau = 0; \Delta t) = A_c(\Delta t)$ , which is the autocorrelation of  $c(t, \tau)$  for a fixed delay over time  $\Delta t$ .
- Specifically, the doppler power spectrum is  $S_c(\rho) = \mathcal{F}[A_C(\Delta f = 0, \Delta t)]$ , which measures channel intensity as a function of Doppler frequency.
- The maximum value of  $\rho$  for which  $|S_c(\rho)| > 0$  is called the channel Doppler spread, which is denoted by  $B_d$ .
- By the Fourier transform relationship,  $A_c(\Delta t) \approx 0$  for  $\Delta t > 1/B_d$ . Thus, the channel becomes uncorrelated over a time of  $1/B_d$  seconds.
- We define the channel coherence time as  $T_c = 1/B_d$ . If the coherence time greatly exceeds a bit time, the signal experiences *error bursts*

#### Main Points

- Wideband models characterized by scattering function, which measures average channel gain relative to delay and Doppler.
- Scattering function used to obtain key channel characteristics of rms delay spread and Doppler spread, which are important for system design.
- Multipath delay spread defines the maximum delay of significant multipath components. Its inverse is the channel coherence bandwidth. Signals separated in frequency by the coherence bandwidth have independent fading.
- Doppler spread defines the channel's maximum nonzero doppler. Its inverse is the channel coherence time. Signals separated in time by the coherence time have independent fading.