Lecture 7 - EE 359: Wireless Communications - Fall 2005

Wideband Fading Models. Multipath Intensity Profile. Doppler Power Spectrum. Channel Capacity.

Lecture Outline

- **Wideband Channel Models**
- **Scattering Function**
- **Multipath Intensity Profile, Delay Spread, and Coherence Bandwidth**
- **Doppler Power Spectrum, Doppler Spread, and Coherence Time**
- **Capacity of Flat Fading Channels**

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 τ and Doppler ρ.
   - $S(\tau, \rho)$ easy to measure empirically and is used to get average delay spread T_M, rms delay spread σ_τ, 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 τ at a fixed time.
   - The average delay T_m and rms delay spread σ_τ 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 Δf_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 coherance 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 Δt.
   - 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 ρ 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 coherance time as $T_c = 1/B_d$. If the coherence time greatly exceeds a bit time, the signal experiences *error bursts*

6. **Shannon Capacity**
   - The maximum mutual information of a channel. Its significance comes from Shannon's coding theorem and converse, which show that capacity is the maximum error-free data rate a channel can support.
   - Capacity is a channel characteristic - not dependent on transmission or reception techniques or limitation.
   - In AWGN, $C = B \log_2(1 + \gamma)$ bps, where B is the signal bandwdith and $\gamma = S/N$ is the received signal-to-noise power ratio.
   - In fading channels capacity depends on what is known about the channel. We consider three cases: 1) Fading statistics known; 2) Fade value known at receiver; 3) Fade value known at transmitter and receiver.
   - When fading statistics are known, capacity is difficult to compute: only known results are for Finite State Markov channels, Rayleigh fading channels, and block fading.

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.
- Capacity of flat-fading channels depends on what is known about the fading at receiver and transmitter.