mmWave Propagation, Shadowing, Combined Path Loss/Shadowing, Model Parameters from Data.

Lecture Outline

- mmWave Propagation
- Log Normal Shadowing
- Combined Path Loss and Shadowing
- Outage Probability
- Model Parameters from Empirical Data

1. mmWave Propagation Models:
   - mmWave communication consists of carrier frequencies in the 60-100 GHz range
   - Why exciting: All commercial systems today fit in a fraction of this band, and it is lightly/not regulated
   - mmWave propagation models are still maturing. There are extensive measurements but few analytical models
   - Path loss proportional to $\lambda^2$, very high at these frequencies.
   - In addition, measurements indicate heavy oxygen absorption from the atmosphere and heavy rain attenuation (wavelength at 60 GHz on the order of a water molecule).
   - Measurements also indicate that attenuation due to shadowing from objects more severe at these frequencies
   - Bottom Line: mmWave communications will either be short range or require large antenna arrays (MIMO) to get larger range, leading to the dynamic duo of mmWave Massive MIMO

2. Log-normal Shadowing:
   - Statistical model for variations in the received signal amplitude due to blockage.
   - The received signal power with the combined effect of path loss (power falloff model) and shadowing is, in dB, given by
     \[ P_r(dB) = P_t(dB) + 10 \log_{10} K - 10 \gamma \log_{10}(d/d_0) - \psi(dB). \]
   - Empirical measurements support the log-normal distribution for $\psi$:
     \[ p(\psi_{dB}) = \frac{1}{\sqrt{2\pi}\sigma_{\psi dB}} \exp \left[ -\frac{(\psi_{dB} - \mu_{\psi dB})^2}{2\sigma_{\psi dB}^2} \right]. \]
   - This empirical distribution can be justified by a CLT argument.
   - The autocorrelation based on measurements follows an autoregressive model:
     \[ A_{\psi}(\delta) = \sigma_{\psi dB}^2 e^{-\delta/X_c} = \sigma_{\psi dB}^2 e^{-\nu \tau / X_c}, \]
     where $X_c$ is the decorrelation distance, which depends on the environment.
3. Combined Path Loss and Shadowing

- Linear Model:
  \[ \frac{P_r}{P_t} = K \left( \frac{d}{d_0} \right)^\gamma \psi. \]

- dB Model:
  \[ \frac{P_r}{P_t}(dB) = 10 \log_{10} K - 10\gamma \log_{10}(d/d_0) - \psi_{dB}. \]

- Average shadowing attenuation: when \(10 \log_{10} K\) captures average dB shadowing, \(\mu_{\psi_{dB}} = 0\), otherwise \(\mu_{\psi_{dB}} > 0\) since shadowing causes positive attenuation.

4. Outage Probability under Path Loss and Shadowing

- With path loss and shadowing, the received power at any given distance between transmitter and receiver is random.
- Outage probability \(p_{out}(P_{min}, d)\) is defined as the probability that the received power at a given distance \(d\), \(P_r(d)\), is below a target \(P_{min}\): \(p_{out}(P_{min}, d) = p(P_r(d) < P_{min})\).
- For the simplified path loss model and log normal shadowing this becomes
  \[ p(P_r(d) \leq P_{min}) = 1 - Q \left( \frac{P_{min} - (P_t + 10 \log_{10} K - 10\gamma \log_{10}(d/d_0))}{\sigma_{\psi_{dB}}} \right). \]

5. Model Parameters from Empirical Data:

- Constant \(K\) obtained from measurement at distance \(d_0\).
- Power falloff exponent \(\gamma\) obtained by minimizing the MSE of the predicted model versus the data.
- The resulting path loss model will include average attenuation, so \(\mu_{\psi_{dB}} = 0\).
- The shadowing variance \(\sigma^2_{\psi_{dB}}\) obtained by determining MSE of the data versus the empirical path loss model with the optimizing \(\gamma\).

Main Points

- mmWave a promising frequency band. Propagation not well understood and likely needs “massive MIMO” for reasonable range.
- Random attenuation due to shadowing modeled as log-normal (empirical parameters).
- Shadowing decorrelates over decorrelation distance.
- Combined path loss and shadowing leads to outage and amoeba-like cell shapes.
- Path loss and shadowing parameters are obtained from empirical measurements.