EE359 Discussion Session 1
Signal Propagation Models

Jan 15, 2020

Administation

Let us know if you:

- Need project topic suggestions
- Have requests for material in discussion sessions
- Have conflicts with OH/Discussions

Outline

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1. Signal representation and propagation models

2. Other models for path loss

3. System design considerations

Baseband versus passband

Passband

$$s_p(t) = s_I(t)\cos(2\pi f_c t) - s_Q(t)\sin(2\pi f_c t)$$

Baseband

$$s_b(t) = s_I(t) + j s_Q(t)$$

Baseband → passband

$$s_p(t) = \mathrm{Re}\left(s_b(t)e^{j2\pi f_c t}\right)$$

Passband → baseband (under narrowband assumption $T \gg \frac{1}{f_c}$)

$$s_I(t) \approx \frac{2}{T}\int_0^T s_p(t)\cos(2\pi f_c t)dt, s_Q(t) \approx -\frac{2}{T}\int_0^T s_p(t)\sin(2\pi f_c t)dt.$$

When to use baseband and passband?

- Baseband signal convenient for DSP (digital signal processing) and mathematical analysis

- Passband signal (EM wave of frequency $\approx f_c$) is what is transmitted and received through medium

dB versus linear

- Power often measured in dB or dBm
- If P is in linear units (e.g. watts), then the same quantity in dB units is defined as

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- Power in dBm is relative to 1 mW:

$$P(\text{dBm}) = 10 \log_{10} \left(\frac{P(\text{in watts})}{1 \text{ mW}} \right)$$

Point-to-point wireless channel

Main effects

1. Path loss
   - Due to diffraction/finite area of antennas
   - Large scale effects ($\sim$ Km)
2. Signal attenuation or shadowing
   - Due to absorption/scattering/reflection
   - Medium scale effects ($\sim$ tens of metres)
3. Fading (we will revisit this later)
   - Due to phase cancellation/reinforcement due to multipath combining and doppler effects.
   - Small scale ($\sim$ cm)

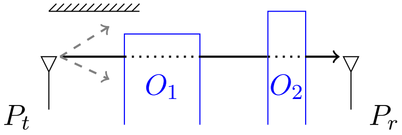

Figure: Representative wireless channel

Effect 1: Path loss

- Energy spreads due to finite area of transmitters (*diffraction*)
- Finiteness with respect to the wavelength
- Wavelength dependence is due to this diffraction effect

Free space path loss (wavelength λ)

- Line of sight: $\frac{P_r}{P_t} = \left(\frac{\lambda}{4\pi d}\right)^2 G_t G_r$ where G represent gains
- Valid in far field with no reflectors e.g. satellite communications

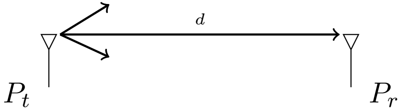

Figure: Free space path loss

Effect 2: Signal attenuation or shadowing

- Power of EM wave suffers attenuation $e^{-\alpha_i d_i}$ when it passes through object i of thickness d_i

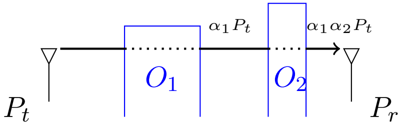

Figure: Shadowing (randomness comes from random number of objects)

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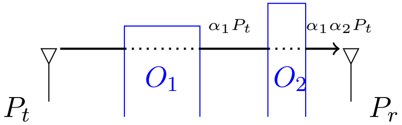

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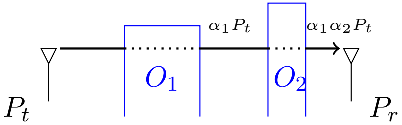

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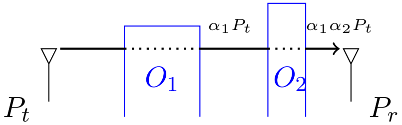
- Account for spatial density of scatterers by modeling dependence between spatially close points, e.g.



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Effect 3: Multipath combining or fading

- Multipath not always bad (if resolvable); e.g. RAKE receivers
- Variation of the order of wavelength λ since $\lambda/2$ shift causes π phase shift (thus causing cancellations $\lambda/2$ distance away from peaks)

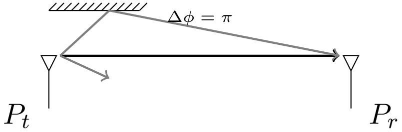

Figure: Multipath causing destructive interference

Outline

Two ray model

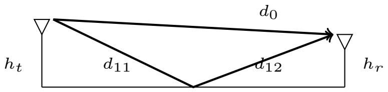

Figure: Two ray model

- For small d, close to free space behavior: loss proportional to d^2.
- For large d, $d_0 \to d_1, \Delta\phi \to 0$, phase inversion of reflected ray gives destructive interference: loss proportional to d^4.
- Cutoff distance d_c capturing change in *rate of decay* can be found empirically or from heuristics (e.g. set the phase difference to be π)

Ten ray models/ray tracing

- Ten ray models
  - Models rectilinear streets with buildings on both sides
  - Transmitters and receivers close to ground
  - Includes all rays undergoing up to three reflections

- Ray-tracing models
  - Useful when geometric information available
  - Useful for site planning

Empirical/simplified/mmWave models

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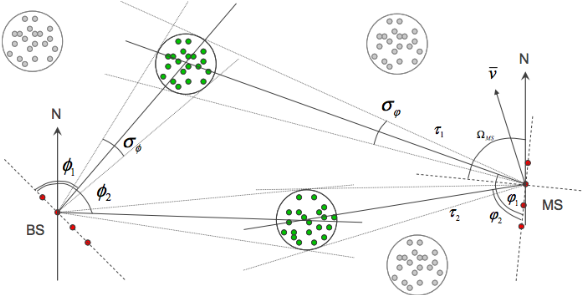
  - Useful for analytically modeling general power falloff
- mmWave propagation
  - In addition to path loss and shadowing, faces additional attenuation from rain and atmospheric (oxygen) effects.

LTE Channel Model

WINNER II model is based on statistical multipath model:

$$h(t) = \text{Pathloss} + \text{Shadowing} + \sum_{i=0}^{M-1} \alpha_i e^{-j2\pi f_{D,i}} \delta(\tau_i - t) \tag{1}$$



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Received power needs to be above threshold P_τ (noise, rate, coding, ...)

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Given path loss (e.g. simplified) and shadowing models (e.g. log normal), one can compute outage probability (shadowing variance assumed to be 1)

$$P_{\text{out}} = 1 - Q\left(\frac{10\log(\tau) - 10\log(KP_t) + 10\gamma\log(d_0/d)}{\sigma_{\psi_{\text{dB}}}}\right)$$

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where $Q(x) \triangleq \int_x^\infty \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy$

Constant received power contour

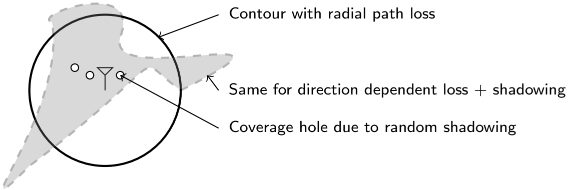

Figure: Contour plots of received power for different effects

- Without random fluctuations, contours of constant received power would be circular
- With direction dependent gains and shadowing the contours are *amoeba like*
- With random shadowing they are amoeba like with *holes*

Cell coverage area

Definition

Expected fraction of locations within a cell where the received power is above threshold τ

- If A is the area of cell

$$C = \frac{1}{A}\mathbb{E}\left[\int_A \mathbb{1}(P_r > P_\tau)dA\right]$$

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- Note that we ignore out of cell interference which would be a more pertinent limiting factor

Homework 1

Disclaimer

- Answer may vary depending on assumptions made - clearly state them
- Feel free to ignore the suggestions/references