Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Characterisation of large-scale fading in BAN channels]
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Abstract: [Measurements results of dynamic BAN channel measurements at 820 MHz with characterisation of large-scale fading due to movement of test subjects.]

Purpose: [To promote the inclusion of a large-scale fading model in the BAN channel model document.]

Characterisation of large-scale fading in BAN channels

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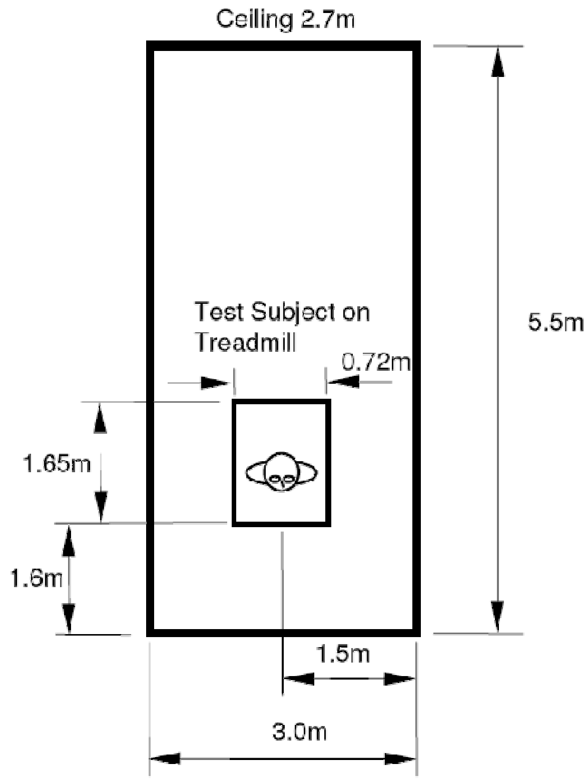
Aim

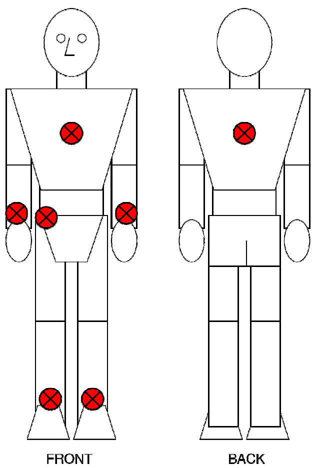
- Statistically characterise fading
  - Static path loss measurements quantify the mean received power level
  - We are looking at deviations below the mean (fades)
    - Dynamic measurements – moving test subject

- Questions:
  - **Rate**: *How often?*
  - **Duration**: *How long?*
  - **Magnitude**: *How big?*

Experiment setup

- Eight test subjects on powered treadmill
- Treadmill set to four different speeds:
  - Walking: 3 kph, 6 kph
  - Running: 9 kph, 12 kph
- Octane Wireless BW-800-900 antennas
  - Strapped tight to body with VELCRO® tape





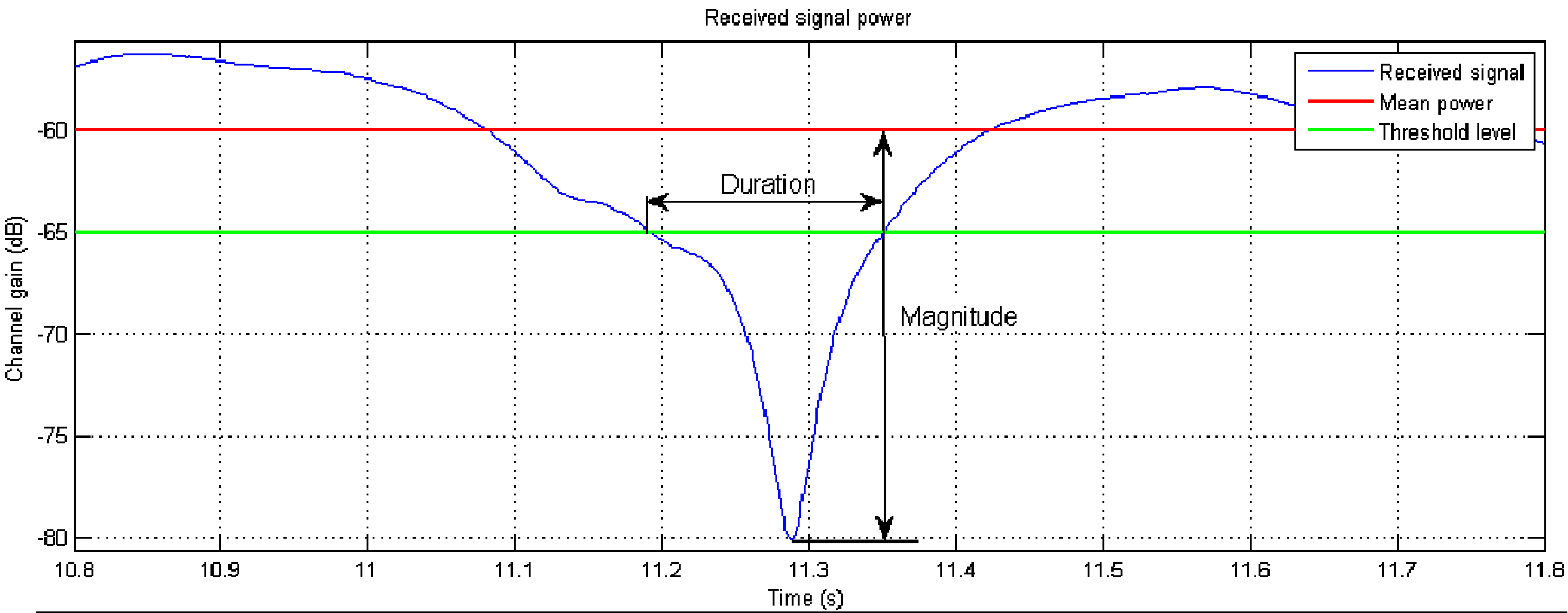
Receiver location	Transmitter location					
	Chest	Right wrist	Left wrist	Right ankle	Left ankle	Back
Right hip	×	×	×	×	×	×
Chest		×		×		×

Measurement technique

- 820 MHz signal sent from transmitter
- 211 measurements of power at receive antenna
  - 60 seconds each
  - Continuous sampling of received power at 100 kHz
  - Every 100 samples is averaged to improve noise performance
    - Result is a 1 kHz signal
- Antennas are considered part of channel

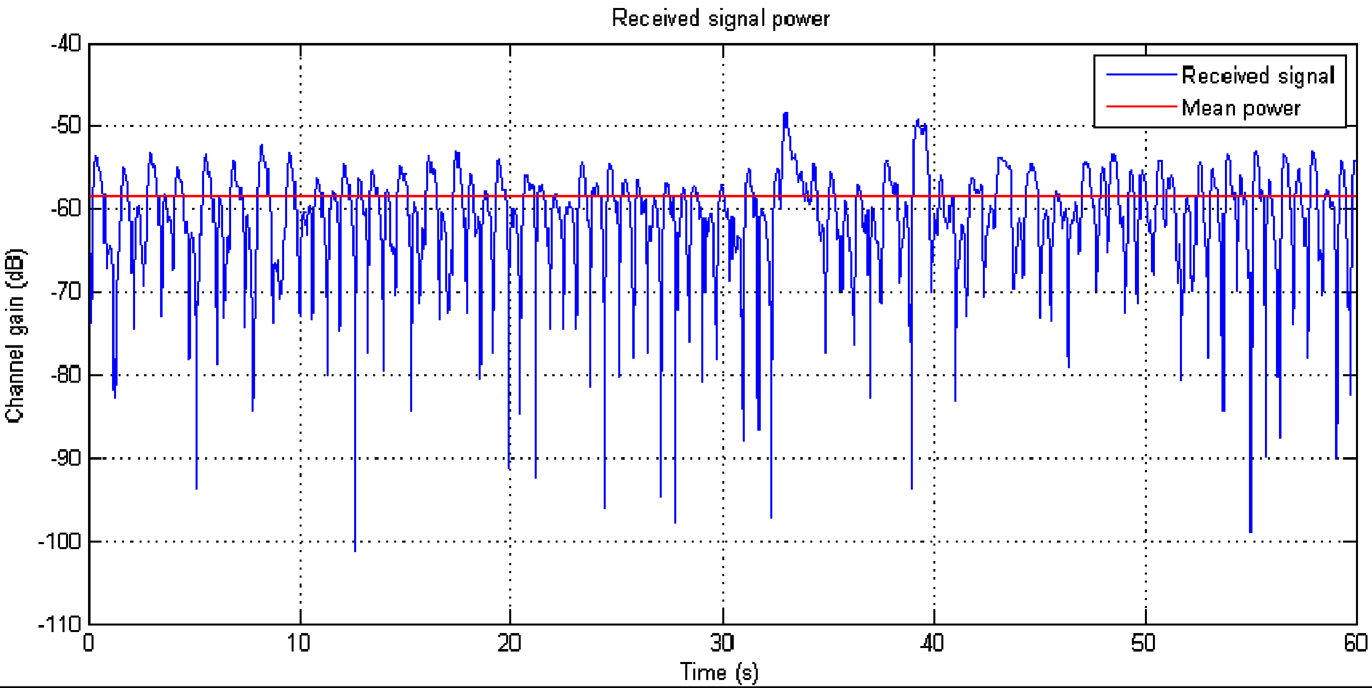
Definitions

- **Fade**: Whenever power drops below threshold level
- **Rate**: Number of fades per second
- **Duration**: Time below threshold
- **Magnitude**: Attenuation below mean



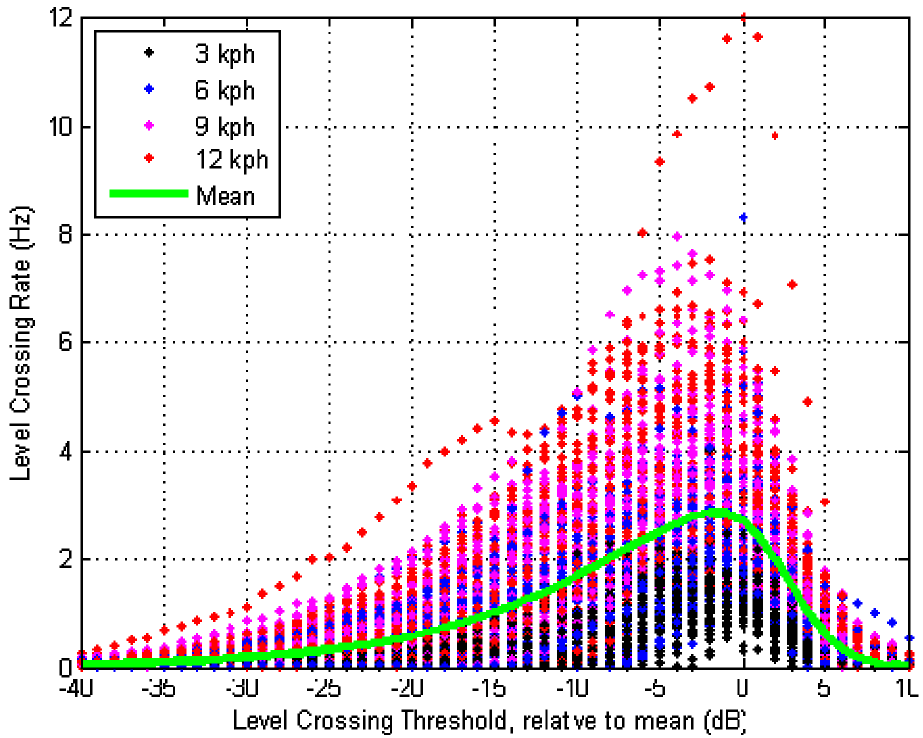
Example measurement

- Tx: Chest → Rx: Right hip; Treadmill speed: 3 kph
  - Regular fades consistent with speed of movement
  - Mean path loss: 58.5 dB
  - Maximum fade: 101.2 dB
    - ~42 dB below mean received signal power



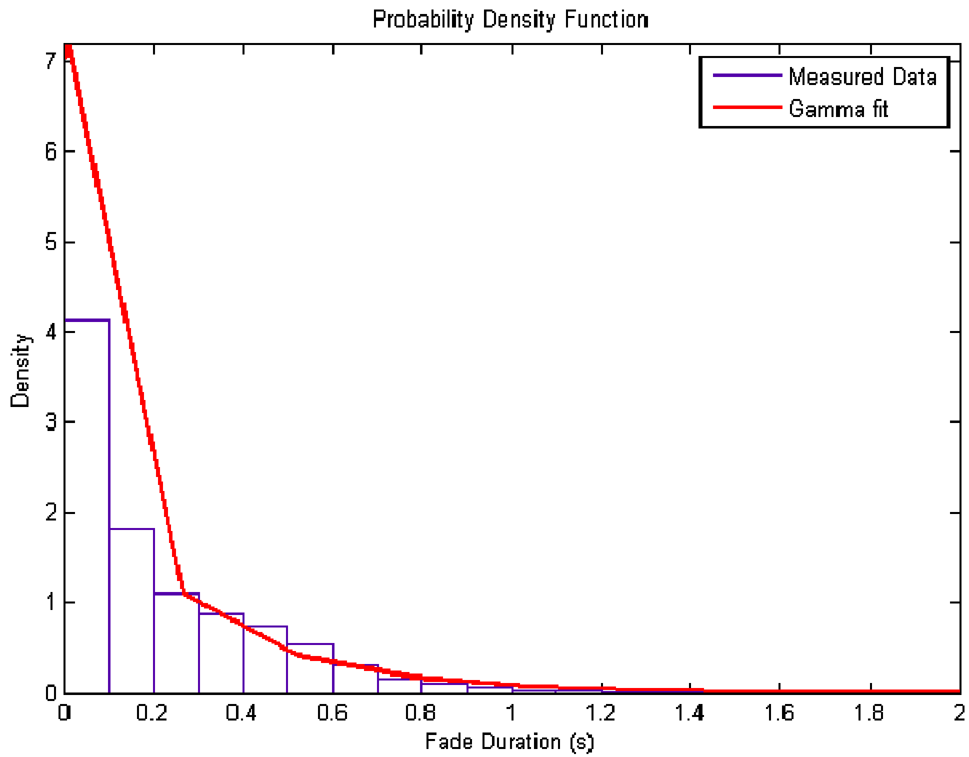
Fading: Rate

- Threshold 0 dB below mean (i.e., threshold at mean)
  - Level crossing rate / fading rate: 2.69 Hz
- Figure below is for all measurements
  - Slower movements generally result in lower fading rates



Fading: Duration distribution

- The Gamma distribution is the best fit to average fade duration



Gamma:

$$f(x|a,b) = \frac{1}{b^a \Gamma(a)} x^{a-1} \exp\left\{\frac{x}{b}\right\}$$

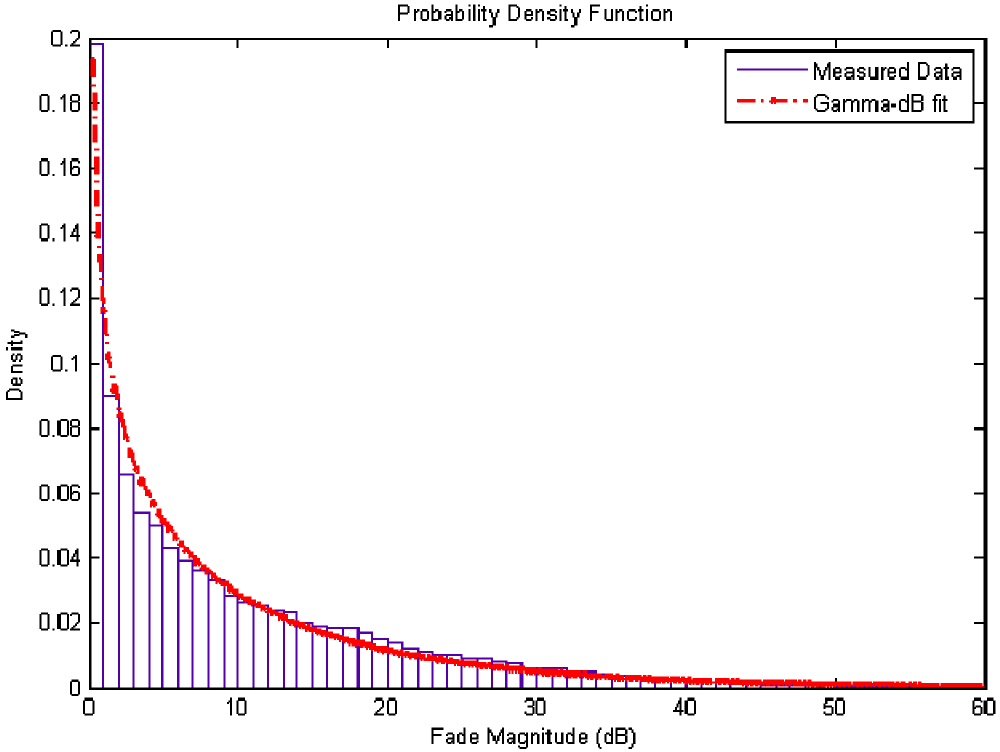
where $\Gamma(\cdot)$ is the Gamma function

Best ML estimates:

- a = 0.688
- b = 0.337

Fading: Magnitude distribution

- The Gamma distribution is the best fit for the fade magnitude (when the magnitude is stipulated in a dB scale)
  - The Gamma distribution is directly fit to the decibels values of the empirical fade magnitude data
  - We call this a Gamma-dB fit



Gamma:

$$f(x|a,b) = \frac{1}{b^a \Gamma(a)} x^{a-1} \exp\left\{\frac{x}{b}\right\}$$

where $\Gamma(\cdot)$ is the Gamma function

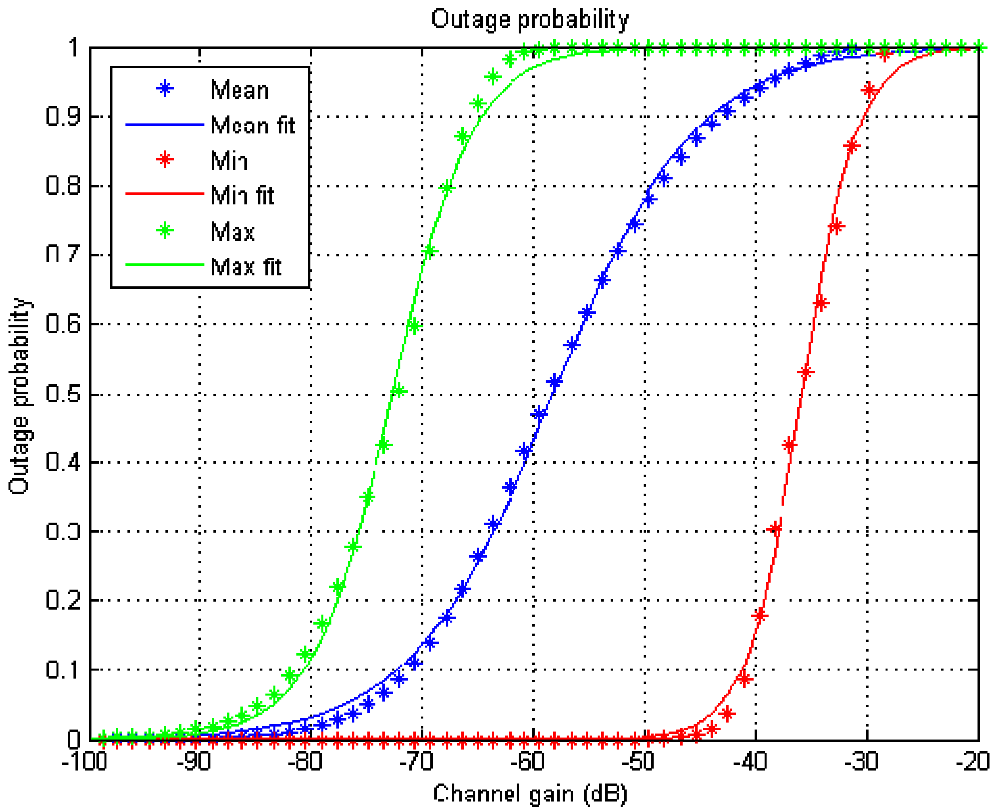
Best ML estimates:

- a = 0.669
- b = 14.46

- Random values (x) can be generated from this Gamma-dB distribution
- The values (x) are dB values; if magnitudes are desired use the conversion 10^(x/10)

Outage probability

- **Definition**: Probability (channel gain < permissible level)
  - "Permissible level":
    - Channel gain must be greater than this for reliable reception
    - It is receiver dependent



Model:

- ½ { tanh(ax + b) +1 }

Best fits:

- Mean (blue):
  - a = 0.07804
  - b = 4.537
- Min (red):
  - a = 0.201
  - b = 7.195
- Max (green):
  - a = 0.1377
  - b = 9.999

Reasons for fading

- Attenuation effects:
  - diffraction, reflection, energy absorption, antenna losses (e.g., orientation), shadowing, etc…
- In general, these effects are multiplicative (additive in the log domain)
- By the central limit theorem, a large number of multiplicative effects will converge to a Normal distribution in the log domain
- Due to the office environment, and also around the body, there are likely to be additive effects due to combination of multiple paths
  - Adding together Lognormal variables results in a distribution that can be well approximated by another Lognormal distribution

Matlab code

- Matlab code for fading model
- Coming soon…

Summary

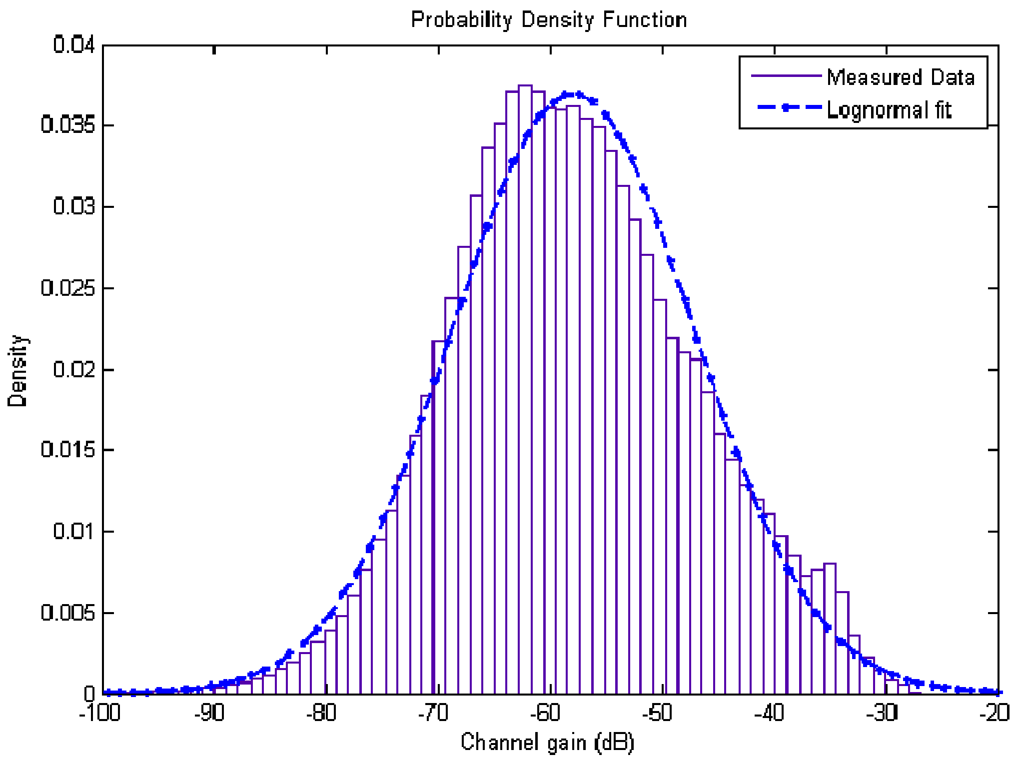
- Measurements
  - 820 MHz signal
  - 8 test subjects
  - Walking/running on treadmill at 4 movement speeds
  - 3.5 hours of data
- Fades characterised statistically
  - Average fading rate is 2.69 Hz (using mean of received power as threshold level)
  - Magnitude distribution best fit is Gamma-dB
  - Duration distribution best fit is Gamma
- Results are consistent with speed of movement

Appendix

Other results that may be interesting

Path loss distribution

- The Lognormal distribution is the best fit to path loss over all measurements



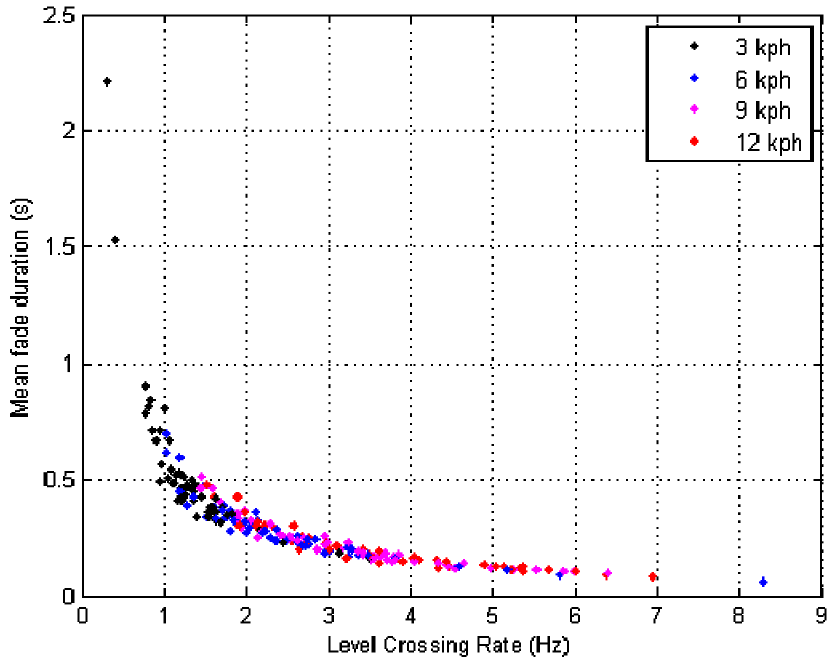
Lognormal:

$$f(x|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left\{\frac{-(\ln(x)-\mu)^2}{2\sigma^2}\right\}$$

- Best ML estimates:
  - μ = -13.35
  - σ = 2.487

Fade rate vs. Fade duration

- Average fading rate for a single trial plotted against the average fade duration for that trial
- Reciprocal relationship (as would be expected)
- Slower movement tends to produce longer fades less often (as would be expected)



Fade duration vs. Fade magnitude

- Fade magnitude is relative to mean
- Shorter fades tend to be larger, but there isn't a tight relationship