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.]

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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
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

\[
d(x|a, b) = \frac{1}{b^a \Gamma(a)} x^{a-1} \exp\left\{ \frac{x}{b} \right\}
\]

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 \( 10^a(x/10) \)
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:
- $\frac{1}{2} \{ \tanh(ax + b) + 1 \}$

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:
  - \( \mu = -13.35 \)
  - \( \sigma = 2.487 \)
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