Submission Title: [Power delay profiles for dynamic narrowband body area network channels]

Date Submitted: [10 March, 2009]

Source: [David Smith$^{12}$, Dino Miniutti$^{12}$, Leif Hanlen$^{12}$, Andrew Zhang$^{12}$, David Rodda$^{1}$, Ben Gilbert$^{1}$]

Company: [NICTA$^{1}$, The Australian National University$^{2}$]

Address: [7 London Circuit, Canberra, ACT, 2600, Australia]

Voice: [+61-2-6267-6256], FAX: [+61-2-6267-6220], E-Mail: [dino.miniutti@nicta.com.au]

Abstract: [Power delay profile analysis for dynamic BAN channel measurements around 2400MHz, 900MHz and 400MHz]

Purpose: [To promote discussion of the dynamic channel model in 802.15.6.]

Notice: This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

Release: The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.
Power delay profiles for dynamic narrowband body area network channels

NICTA & The Australian National University
David Smith, Dino Miniutti, Leif Hanlen, Andrew Zhang

NICTA
David Rodda, Ben Gilbert
Introduction

• PDPs based on analysis of measurements of motion at 427 MHz and 820 MHz and 2360 MHz

• Aim: evaluate severity of multipath (ISI)
  – Absolute magnitude
  – Relative (to first arrival) magnitude
Experiment setup

- -10dBm Tx power,
- 63-symbol BPSK PN sequence at 12.5Mbps
- Modulated separately at 2360, 820 and 427MHz using National Instruments VSA

Data capture:
- Snapshot (40micro-sec)

Antenna: (considered part of channel)
- 2360MHz & 820MHz: Pharad wearable antenna for
- 427MHz: Miracle Baby 1” stub
  - Miracle Baby substantially different to Pharad (results are not comparable to 2360, 820)
Estimation of power delay profiles

- transmitted waveform $G$
- Measured $X$

\[
\text{taps ML estimates} = (G^\dagger G)^{-1} G^\dagger X
\]
Tap Power (absolute)

- To illustrate general magnitudes will first provide without ratios i.e. with subject moving (walking and running) all 9 Tx-Rx pair locations at 2360 MHz and 820 MHz – empirical pdf – normalization to mean first tap power over each scenario
- Note noise floor is approximately -35 dB (due to quantization noise of VSA)
Tap Power (absolute)

- 427 MHz non-ratios + table of fits – all for subject moving
PDFs of power ratios (subject moving) 2360MHz

- Empirical pdfs of power ratios—all scenarios with movement/motion (walking and standing with best fit—guidelines—need conditional pdfs best indicator) (example a few slides time)
- [Note significant second tap at 2360 MHz]
PDFs of power ratios (subject moving) 820MHz

3rd tap is below confidence region of measurements

*Our processing gain allowed detection, but tap likely to be below a real receiver’s sensitivity*

820 MHz – 2\textsuperscript{nd} to 1\textsuperscript{st}

820 MHz 3\textsuperscript{rd} to 1\textsuperscript{st} tap –
PDFs of power ratios 427MHz

3rd tap is below confidence region of measurements

Our processing gain allowed detection, but tap likely to be below a real receiver’s sensitivity

427 MHz – 2\textsuperscript{nd} to 1\textsuperscript{st}

427 MHz – 3\textsuperscript{rd} to 1\textsuperscript{st}
PDF of power ratios (conditional)

- Conditional PDF example, based on best fits, less first tap power $\rightarrow$ more relatively significant second taps (and also third tap), for 2360 MHz subject moving- i.e. reflections become stronger relative to first received ray.

![Graph showing PDF of power ratios](image-url)
Summary

- Means over agglomerate moving data at 427, 820 and 2360 MHz, $2^{nd}$ to $1^{st}$ tap power ratio and $3^{rd}$ to $1^{st}$ tap power ratio

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Action</th>
<th>2nd to 1st tap mean power ratio</th>
<th>3rd to 1st tap mean power ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>-17.1 dB</td>
<td>-31.4 dB</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>-20.9 dB</td>
<td>-33.3 dB</td>
</tr>
<tr>
<td>2360 MHz</td>
<td>Moving</td>
<td>-14.1 dB</td>
<td>-25.2 dB</td>
</tr>
</tbody>
</table>

Less than 0.1% main tap power
Summary

• PDP found for 427MHz, 820MHz, 2360MHz

• 2360MHz showed significant 2nd tap
  – Different antenna for 427MHz -- not directly comparable

• Dynamics more significant than ISI
[appendix] Channel dynamics over 10 hours

Subject removed sensors.
Tx moved to from right hip to left hip

changed clothing (sensors removed)

Subject removed sensors

Receive Signal Strength (dBm)

Time (hr)

0 2 4 6 8 10 12

office Drive car Home (skype) cook Tv, computer
Appendix (more info), best fits conditional and overall

[might be useful – shows comprehensiveness of analysis+measurements]

Distributions of power ratios 2nd to 1st tap, 1st tap power norm. to mean of each scenario (0 dB), all Tx/Rx pair locations considered

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Action</th>
<th>1st tap power</th>
<th>Distribution of power ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>&gt; 5 dB</td>
<td>Nakagami-m ($\mu = 0.646, \omega = 0.006228$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>0 → 5 dB</td>
<td>Weibull ($\alpha = 0.0139, b = 1.35$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>5 → 0 dB</td>
<td>Weibull ($\alpha = 0.016, b = 1.12$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>-10 → -5 dB</td>
<td>Gamma ($\alpha = 1.06, \beta = 0.0205$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>&lt; -10 dB</td>
<td>Lognormal ($\mu = -3.88, \sigma = 1.52$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>All</td>
<td>Lognormal ($\mu = -4.54, \sigma = 1.15$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>&gt; 5 dB</td>
<td>Weibull ($\alpha = 0.000626, b = 0.71$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>0 → 5 dB</td>
<td>Weibull ($\alpha = 0.000128, b = 0.695$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>5 → 0 dB</td>
<td>Lognormal ($\mu = -6.71, \sigma = 1.64$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>-10 → -5 dB</td>
<td>Weibull ($\alpha = 0.00621, b = 0.606$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>&lt; -10 dB</td>
<td>Lognormal ($\mu = -5.03, \sigma = 2.16$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>All</td>
<td>Lognormal ($\mu = -6.65, \sigma = 1.93$)</td>
</tr>
<tr>
<td>2460 MHz</td>
<td>Moving</td>
<td>&gt; 5 dB</td>
<td>Lognormal ($\mu = -6.54, \sigma = 1.59$)</td>
</tr>
<tr>
<td>2460 MHz</td>
<td>Moving</td>
<td>0 → 5 dB</td>
<td>Weibull ($\alpha = 0.00087, b = 0.65$)</td>
</tr>
<tr>
<td>2460 MHz</td>
<td>Moving</td>
<td>5 → 0 dB</td>
<td>Weibull ($\alpha = 0.026, b = 0.833$)</td>
</tr>
<tr>
<td>2460 MHz</td>
<td>Moving</td>
<td>-10 → -5 dB</td>
<td>Weibull ($\alpha = 0.0444, b = 0.509$)</td>
</tr>
<tr>
<td>2460 MHz</td>
<td>Moving</td>
<td>&lt; -10 dB</td>
<td>Weibull ($\alpha = 0.0302, b = 0.575$)</td>
</tr>
<tr>
<td>2460 MHz</td>
<td>Moving</td>
<td>All</td>
<td>Lognormal ($\mu = -4.77, \sigma = 1.98$)</td>
</tr>
</tbody>
</table>
Appendix cont. (more info), best fits conditional and overall

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Action</th>
<th>1st tap power</th>
<th>Distribution of power ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>&gt; 5 dB</td>
<td>Weibull ($a = 0.000385, b = 1.29$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>0 → 5 dB</td>
<td>Weibull ($a = 0.000386, b = 1.09$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>-5 → 0 dB</td>
<td>Weibull ($a = 0.000483, b = 0.972$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>-10 → -5 dB</td>
<td>Weibull ($a = 0.000775, b = 0.922$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>&lt; -10 dB</td>
<td>Lognormal ($\mu = -7.08, \sigma = 1.51$)</td>
</tr>
<tr>
<td>427 MHz</td>
<td>Moving</td>
<td>All</td>
<td>Lognormal ($\mu = -8.08, \sigma = 1.34$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>&gt; 5 dB</td>
<td>Lognormal ($\mu = -10.8, \sigma = 1.2$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>0 → 5 dB</td>
<td>Lognormal ($\mu = -10.5, \sigma = 1.52$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>-5 → 0 dB</td>
<td>Lognormal ($\mu = -9.71, \sigma = 1.59$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>-10 → -5 dB</td>
<td>Weibull ($a = 0.000353, b = 0.642$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>&lt; -10 dB</td>
<td>Lognormal ($\mu = -7.97, \sigma = 2.26$)</td>
</tr>
<tr>
<td>820 MHz</td>
<td>Moving</td>
<td>All</td>
<td>Lognormal ($\mu = -9.61, \sigma = 1.89$)</td>
</tr>
<tr>
<td>2360 MHz</td>
<td>Moving</td>
<td>&gt; 5 dB</td>
<td>Lognormal ($\mu = -8.99, \sigma = 1.39$)</td>
</tr>
<tr>
<td>2360 MHz</td>
<td>Moving</td>
<td>0 → 5 dB</td>
<td>Lognormal ($\mu = -8.15, \sigma = 1.62$)</td>
</tr>
<tr>
<td>2360 MHz</td>
<td>Moving</td>
<td>-5 → 0 dB</td>
<td>Lognormal ($\mu = -7.29, \sigma = 1.72$)</td>
</tr>
<tr>
<td>2360 MHz</td>
<td>Moving</td>
<td>-10 → -5 dB</td>
<td>Lognormal ($\mu = -6.66, \sigma = 1.81$)</td>
</tr>
<tr>
<td>2360 MHz</td>
<td>Moving</td>
<td>&lt; -10 dB</td>
<td>Lognormal ($\mu = -6.71, \sigma = 1.99$)</td>
</tr>
<tr>
<td>2360 MHz</td>
<td>Moving</td>
<td>All</td>
<td>Lognormal ($\mu = -7.43, \sigma = 1.87$)</td>
</tr>
</tbody>
</table>

Distributions of power ratios 3rd to 1st tap, 1st tap power norm. to mean of each scenario (0 dB), all Tx/Rx pair locations considered