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

Submission Title: [Dynamic channel measurements around 400MHz for Body Area Networks]
Date Submitted: [10 March, 2009]
Source: [David Smith[1,2], Dino Miniutti[1,2], Leif Hanlen[1,2], Andrew Zhang[1,2], 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: [We present details of channel measurements around 400MHz for on-body to on-body radio communication using human subjects. The results extend previous works IEEE 802.15-08-354-01-0006]]

Purpose: [To promote discussion of channel dynamics within 802.15.6]

Dynamic channel measurements around 400MHz for Body Area Networks

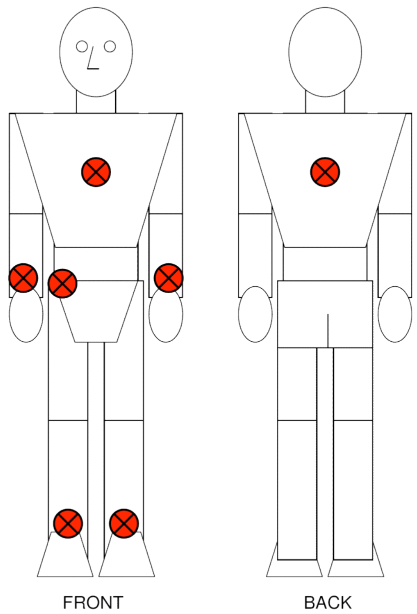
David Smith, Dino Miniutti, Leif Hanlen, Andrew Zhang,
David Rodda, Ben Gilbert

Power variation (large scale fading)

- Statistical characterisation of 400MHz band
  - Extension of previous work into 400MHz band
- Measurements at 427MHz
  - (due to interference + license)
- On-Body to On-body
- Moving subjects: Walking, Running
- Also produced power delay profiles (see next presentation)

Experiment setup

- -10 dBm transmit power
- 255-symbol BPSK PN sequence at 12.5Mbps
- Time domain sampling
- *Miracle baby*^{TM} 1” stub antenna



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

Path loss over time

- Example Chest → Right hip at 427 MHz
- Variation (peak to trough) consistent with movement
- Smaller average path losses (as expected) than previously reported 820 MHz and 2360 MHz

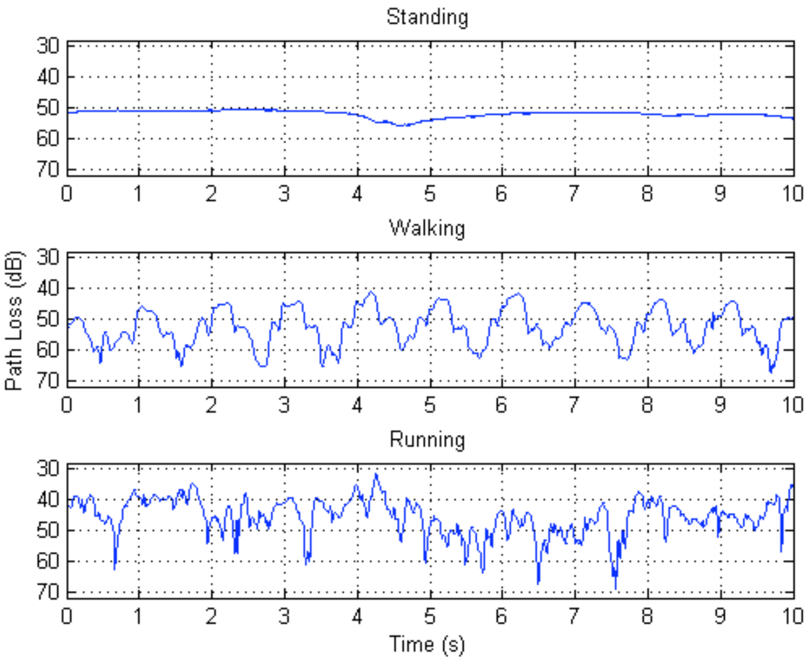


TABLE I: Average path loss (dB) at 427 MHz

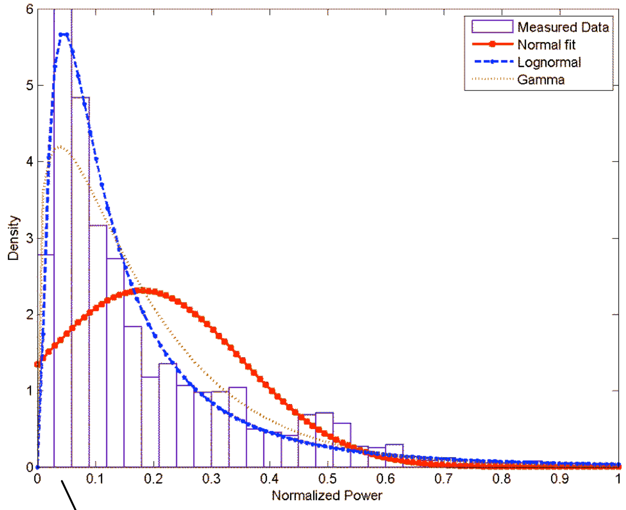
Action	Receiver at Right Hip; Transmitter at:						Receiver at chest; Transmitter at:		
	Chest	Right Wrist	Left Wrist	Right Ankle	Left Ankle	Back	Back	Right Wrist	Right Ankle
Standing	51.8	41.4	72.2	36.1	44.2	53.1	58.9	45.8	48.6
Walking	49.2	43.9	62.2	30.2	39.6	42.4	58	44.4	36.4
Running	42.5	42.4	59.1	27.4	37.2	51.6	51.5	41.8	31.2

TABLE II: Path loss variation (dB) at 427 MHz

Action	Receiver at Right Hip; Transmitter at:						Receiver at chest; Transmitter at:		
	Chest	Right Wrist	Left Wrist	Right Ankle	Left Ankle	Back	Back	Right Wrist	Right Ankle
Standing	5.22	2.4	2.45	3.08	2.49	2.95	3.52	4.01	8.22
Walking	26.3	34.2	17.9	20.8	29	28.3	14.3	35.9	17.2
Running	37.6	36.3	23.1	30.4	29.5	31.1	33	40.2	38.1

Statistical Analysis of Received Power

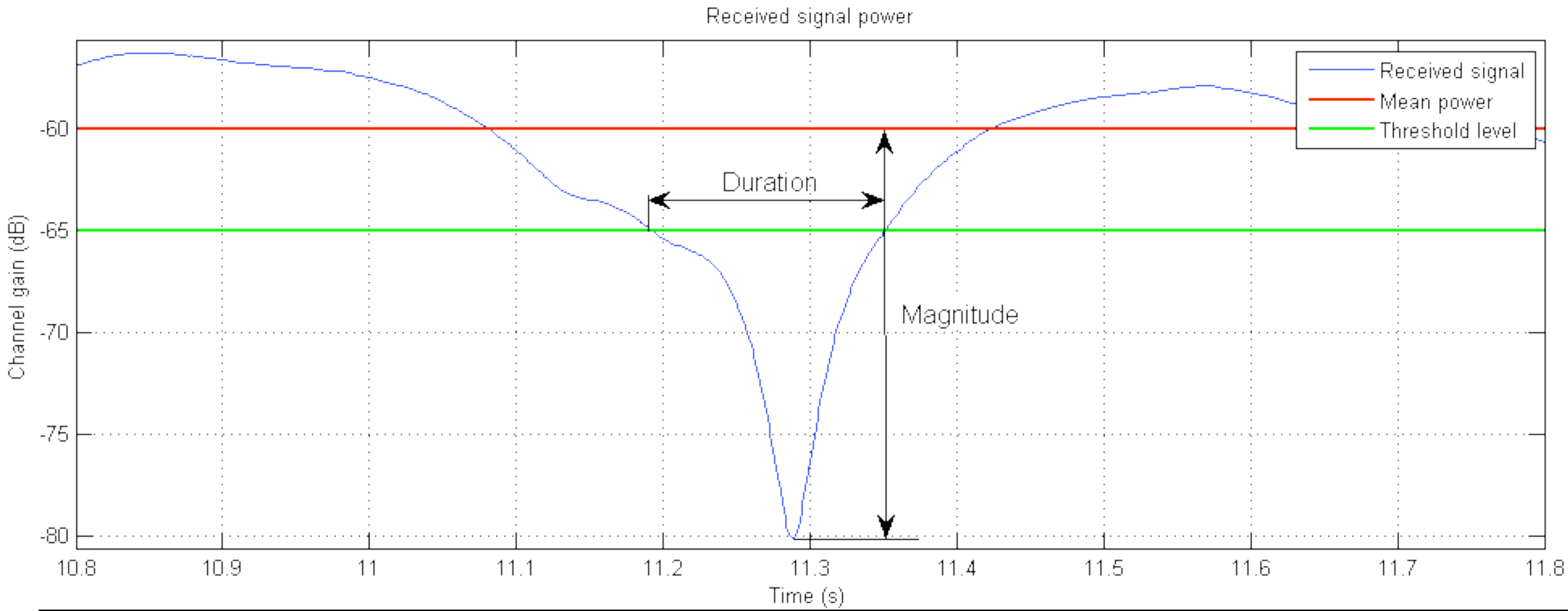
- Find best fit for received signal power
  - Normal, Lognormal, Weibull, Nakagami-m, Gamma, Rayleigh distributions
- Motion, typically Lognormal or Gamma
  - Normal/Rayleigh were never best fit



Tx Antenna	Rx Antenna	Action	Distribution 427 MHz
Chest	Right Hip	Standing	Weibull
Chest	Right Hip	Walking	Lognormal
Chest	Right Hip	Running	Weibull
Right Wrist	Right Hip	Standing	Nakagami-m
Right Wrist	Right Hip	Walking	Gamma
Right Wrist	Right Hip	Running	Weibull
Left Wrist	Right Hip	Standing	Lognormal
Left Wrist	Right Hip	Walking	Lognormal
Left Wrist	Right Hip	Running	Lognormal
Right Ankle	Right Hip	Standing	Lognormal
Right Ankle	Right Hip	Walking	Gamma
Right Ankle	Right Hip	Running	Gamma
Left Ankle	Right Hip	Standing	Lognormal
Left Ankle	Right Hip	Walking	Nakagami-m
Left Ankle	Right Hip	Running	Weibull
Back	Right Hip	Standing	Lognormal
Back	Right Hip	Walking	Gamma
Back	Right Hip	Running	Lognormal
Back	Chest	Standing	Lognormal
Back	Chest	Walking	Weibull
Back	Chest	Running	Lognormal
Right Wrist	Chest	Standing	Weibull
Right Wrist	Chest	Walking	Weibull
Right Wrist	Chest	Running	Lognormal
Right Ankle	Chest	Standing	Weibull
Right Ankle	Chest	Walking	Gamma
Right ankle	Chest	Running	Gamma

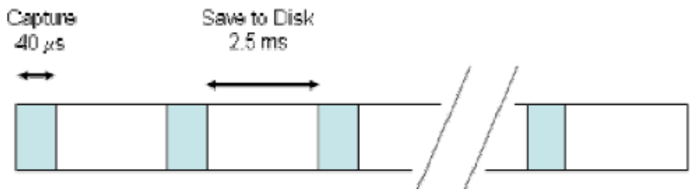
Characterising small scale fading

- **Fade**: Deviation below mean receive power
- **Rate**: Number of fades per second
- **Duration**: Time below threshold
- **Magnitude**: Attenuation below mean



Experimental setup

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



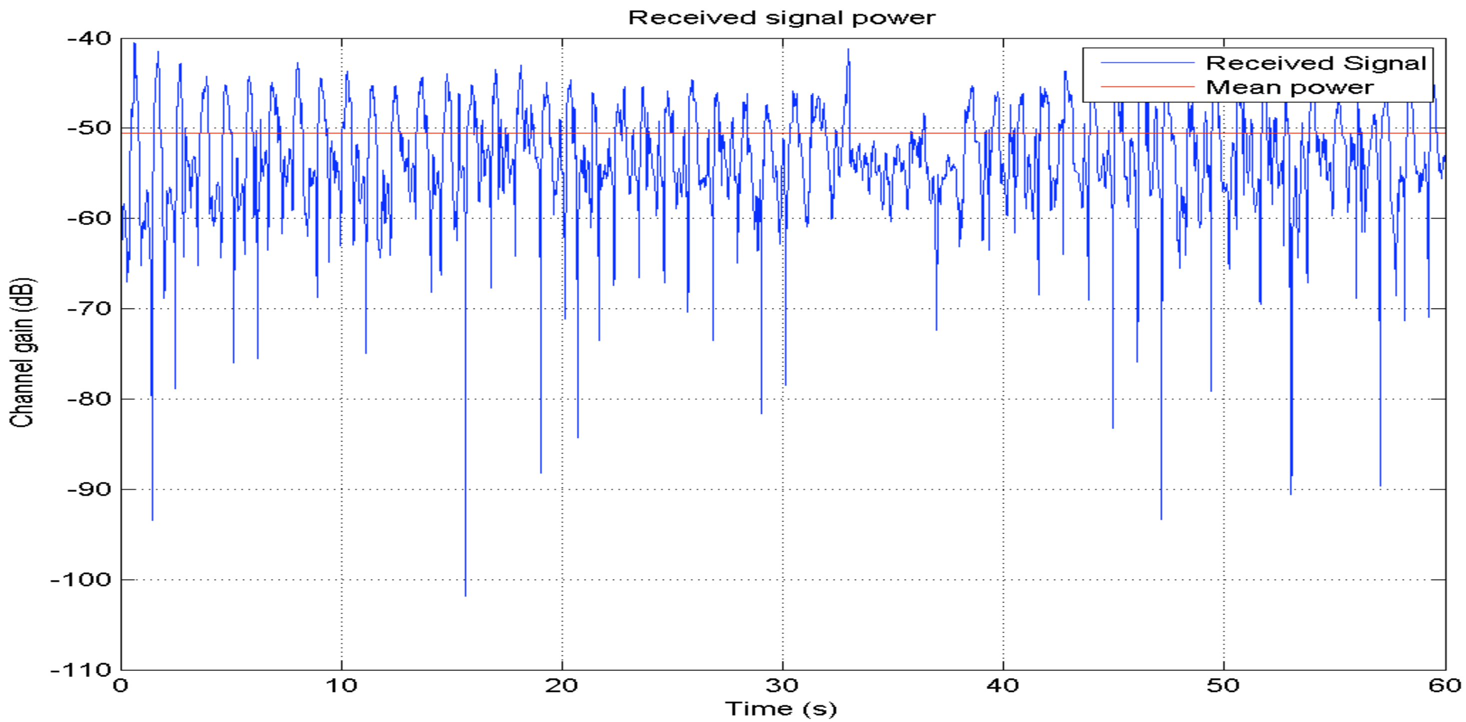
- Continuous data
  - Snapshot of 40micro-seconds every 25ms.
  - Assume channel static over 25ms

- 18 transmit-receive scenarios.
  - 60 seconds each
  - Continuous sampling of received power at 100 kHz
  - Every block of 100 samples is averaged to improve noise performance
    - Result is a 1 kHz signal

- Antennas *(miracle baby)* are considered part of channel

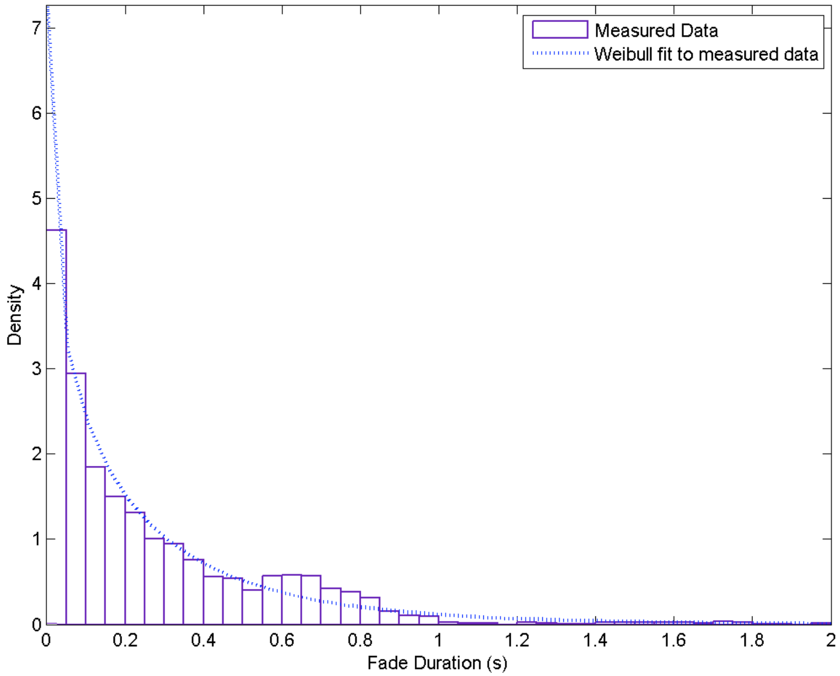
Example measurement

- Tx: Right wrist → Rx: Chest; Subject walking
  - Regular fades consistent with speed of movement
  - Mean path loss: 50.6 dB
  - Maximum fade: 101.8 dB



Fading: rate and duration

- Fading Rate – 2.36 Hz (level crossing rate at mean receive power level)
- Duration distribution - The Weibull distribution is the best fit to average fade duration



Weibull:

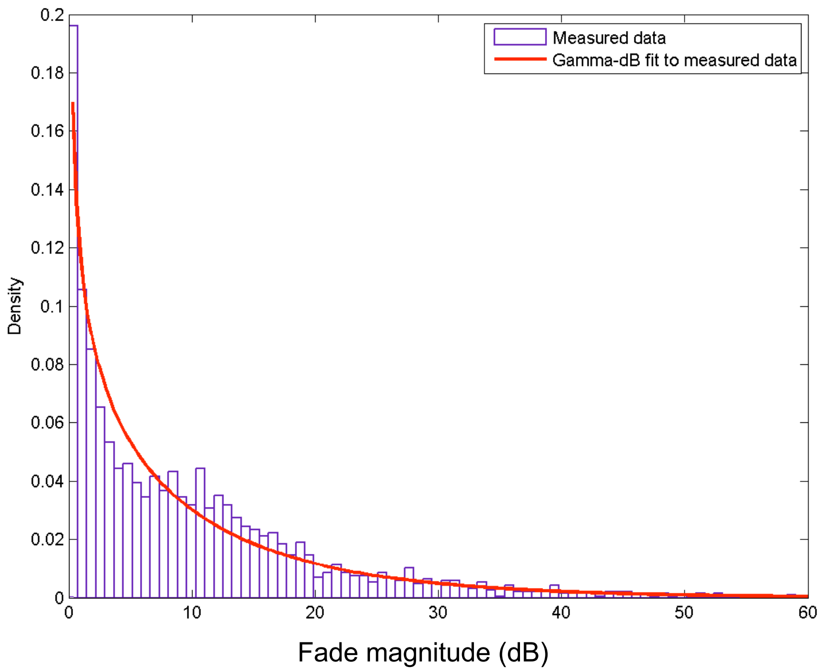
$$f(x|a,b) = \begin{cases} ba^{-b}x^{b-1}\exp\left\{-x/a^{b}\right\} & x \geq 0 \\ 0 & \text{else}. \end{cases}$$

Maximum-Likelihood (ML) estimates:

- a = 0.258
- b = 0.842

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

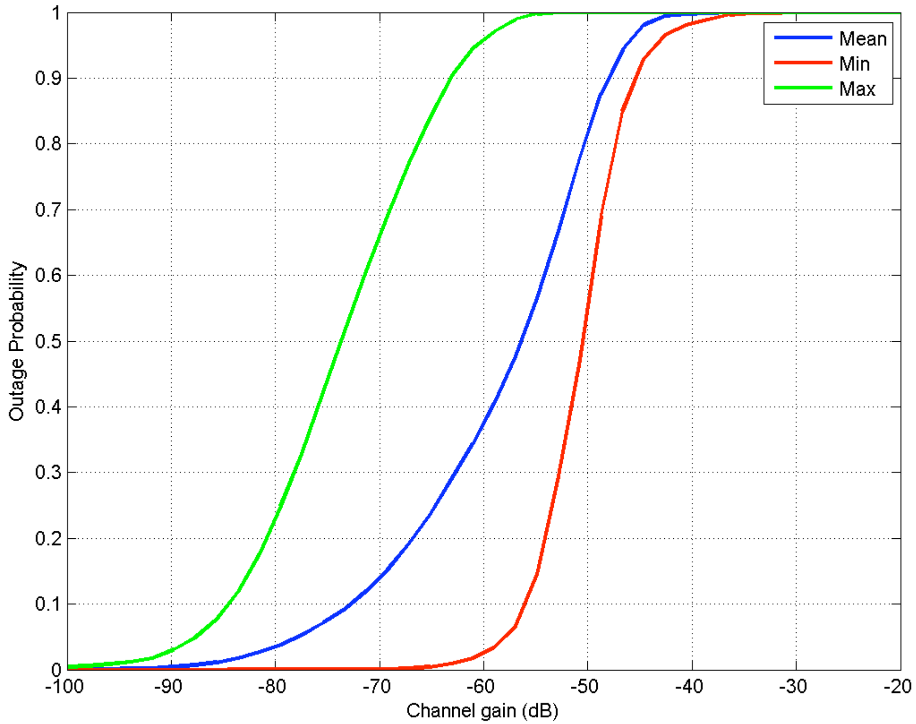
Best ML estimates:

- a = 0.713
- b = 13.41

- 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



Aggregate over all moving scenarios

Channel Coherence

- Used autocorrelation with continuous data (1kHz samples)
- Time when autocorrelation first drops below 0.7 gives approximate coherence time [Paulraj03]
- Aggregate for all scenarios:
  - Subject walking coherence time *at least* 96ms
  - Subject running coherence time *at least* 42ms

$$c(\tau) = \frac{\int_0^T x(t)\overline{x(t-\tau)}\,dt}{\int_0^T |x(t)|^2\,dt \cdot \int_0^T |x(t-\tau)|^2\,dt}$$

[Paulraj03] - A. Paulraj, R. Nabar, D. Gore, "Introduction to Space-Time Wireless Communications", *Cambridge University Press,* 2003.

Summary

- **Large-scale power variation characterized**
  - Lognormal and Gamma were best statistical fits
  - Path-loss found (consistent with expectation)

- **Small-scale power variation characterized**
    - Walking coherence time approx. 96ms
    - Running coherence time approx. 42ms
  - Fade rate approx. 2.36Hz
  - Weibull gives fade duration
  - Gamma-dB gives fade magnitude (in dB)
  - Outage probability (CDF) provided

- ***Direct comparisons to 2400MHz & 900MHz not possible due to different antenna***