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

**Submission Title:** [MAC Channel for WBAN-A Walking Model Example]

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**Re:** [15-08-0421-00-0006]

**Abstract:** [Proposed MAC channel model for WBAN, which means the channel model from the "MAC" point of view. It correctly reflects the end to end latency and queuing in MAC layer that existing TG6 channel model does not support yet.]

**Purpose:** [Develop a channel model for MAC simulation.]

# MAC Channel Model for WBAN

## -A Walking Model Example-

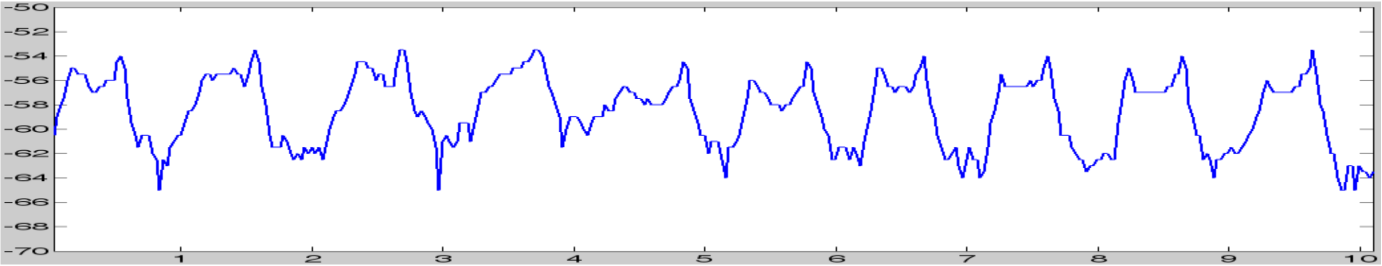
# Outline

- Relative WBAN Walking Channel model
- Two state walking channel model
- End to end Simulation using two-state Walking Model
  - UDP
  - TCP
- Conclusion

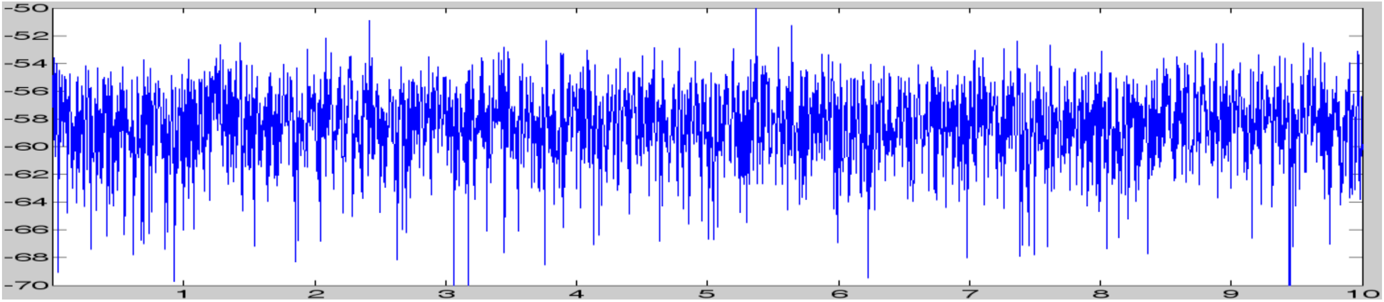
# Relative WBAN Walking Channel model

Preliminary WBAN channel models are available [1].
However, without considering  the effects from human activity, existing models may lead to inaccurate simulation results in WBAN experiments.
Ex. End to end communication using Gamma walking model.

- Measured RSSI during walking




- Gamma distribution waking model



# Relative WBAN Walking Channel model

Ex. End to end communication using NICTA walking model.

- ➢Up to 74% miss in end to end delay Jitter
- ➢Up to 81% miss in end to end throughput

***Reason:***

Existing models focus on the statistical analysis in PHY layer.
It ignores the time domain correlation that affects the
data queuing in higher layers like MAC and Transport layer.

# Design strategy: Two state channel model

Two state model

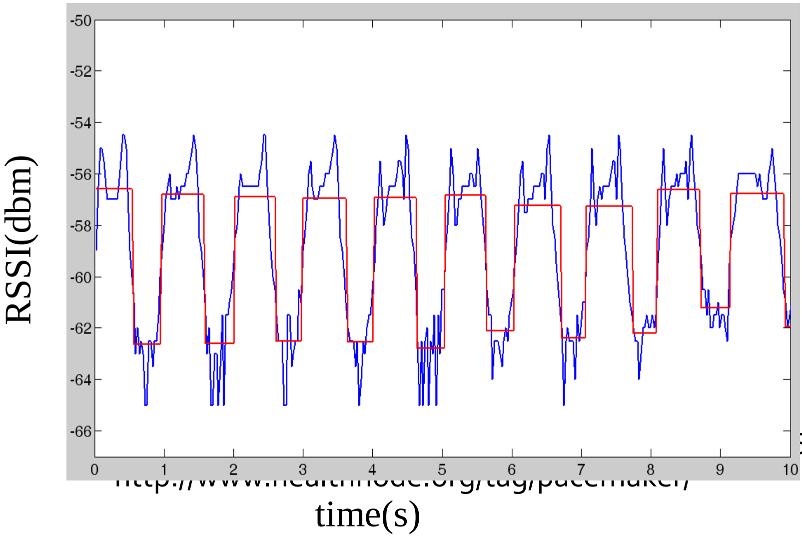
–Considering the time domain correlation when walking.

Reflect the real data queuing in higher layers

–Low state ➔ low success rate and low Throughput. Start queuing.

–High state ➔ high success rate and high Throughput. Start transmitting.

- Measured Data – Right wrist to right hip

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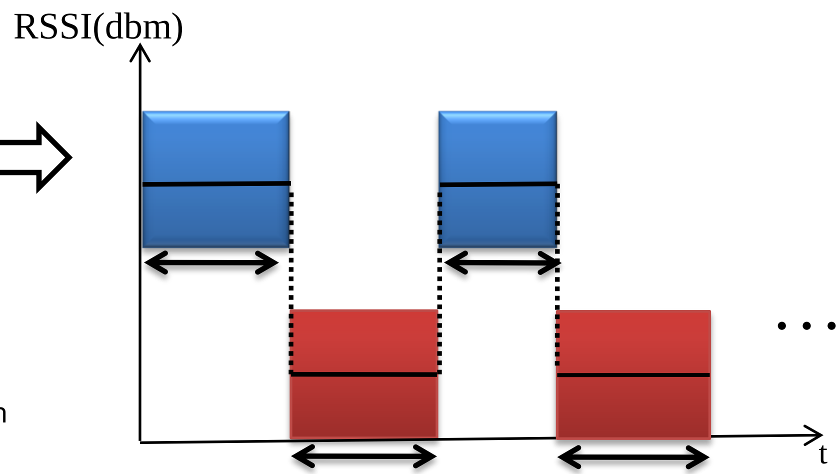
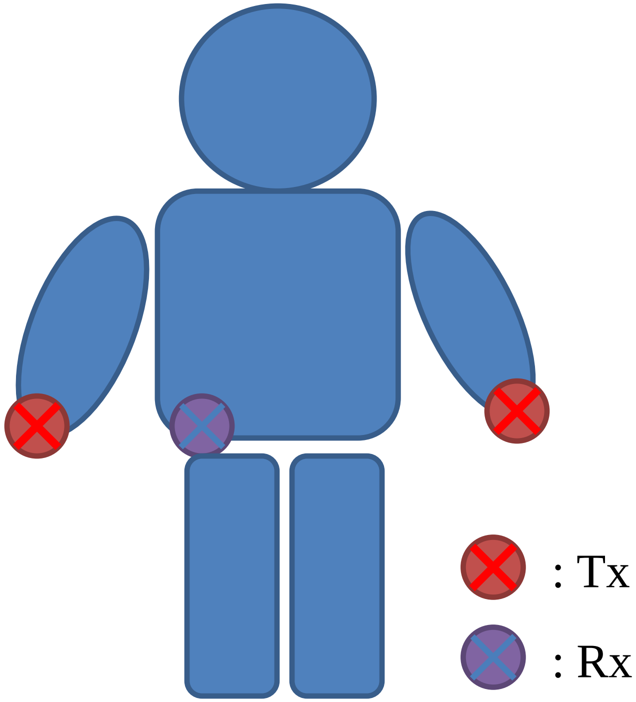
- Proposed two state model



# Walking Channel Measurement

| Parameters | Value |
|---|---|
| Tx Power | 0dBm |
| Operation frequency | 2.4GHz |
| Sampling rate | 37Hz |
| Links | Left / Right wrist to right hip |
| Scenario | Free walk in campus |

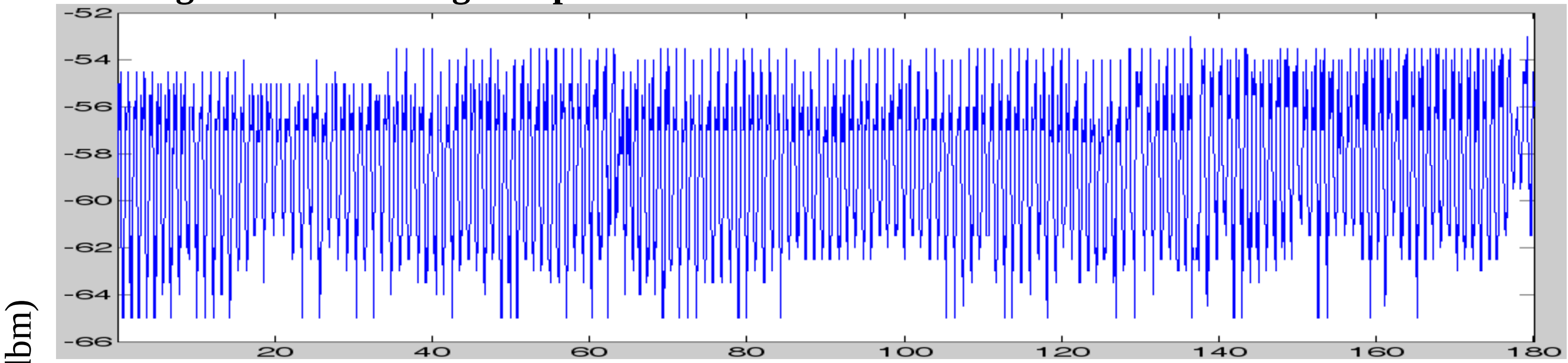


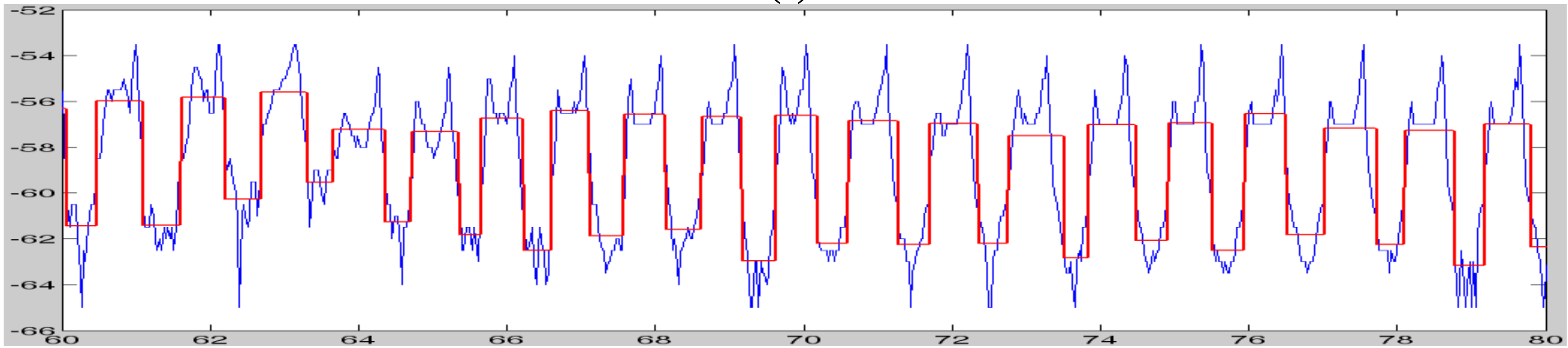
# Measurement Result

Properties of walking model:

Periodic RSSI variation – can be simplified as two states

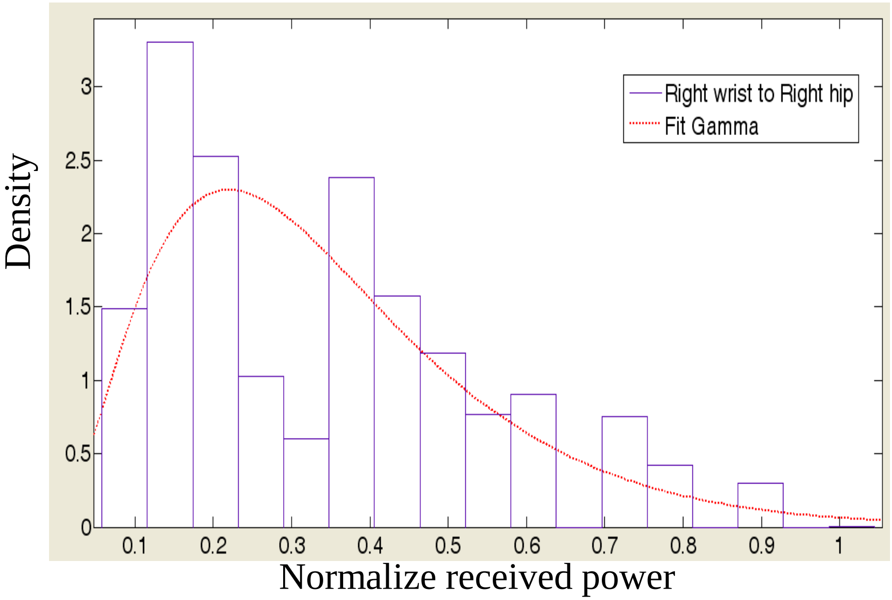
**Tx: Right wrist / Rx: Right Hip**

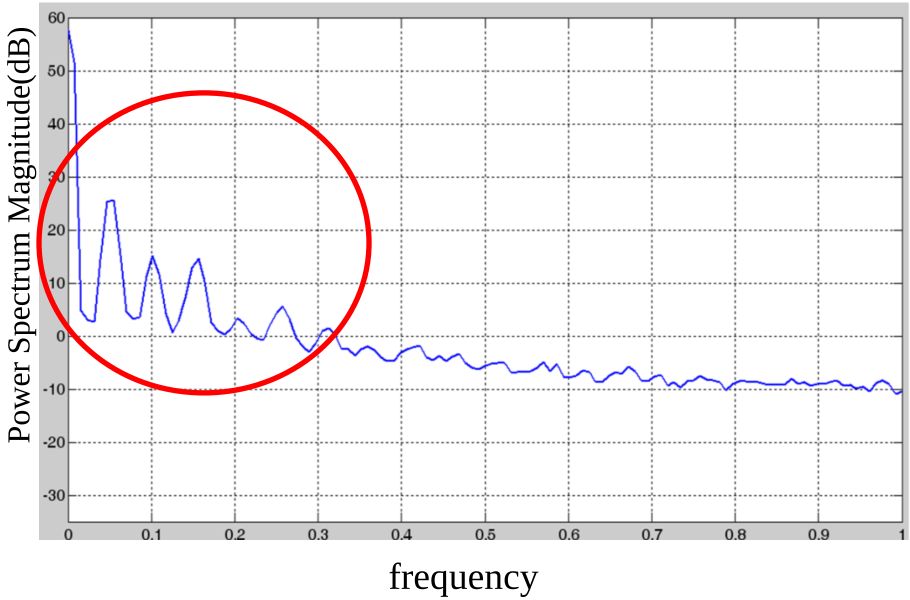


# Correlation & Distribution of Received Power

- Regular amplitude distribution – Gamma distribution properly fits the normalized received power [1].
- Strong time domain correlation – May require multi-states model to describe the correlation.



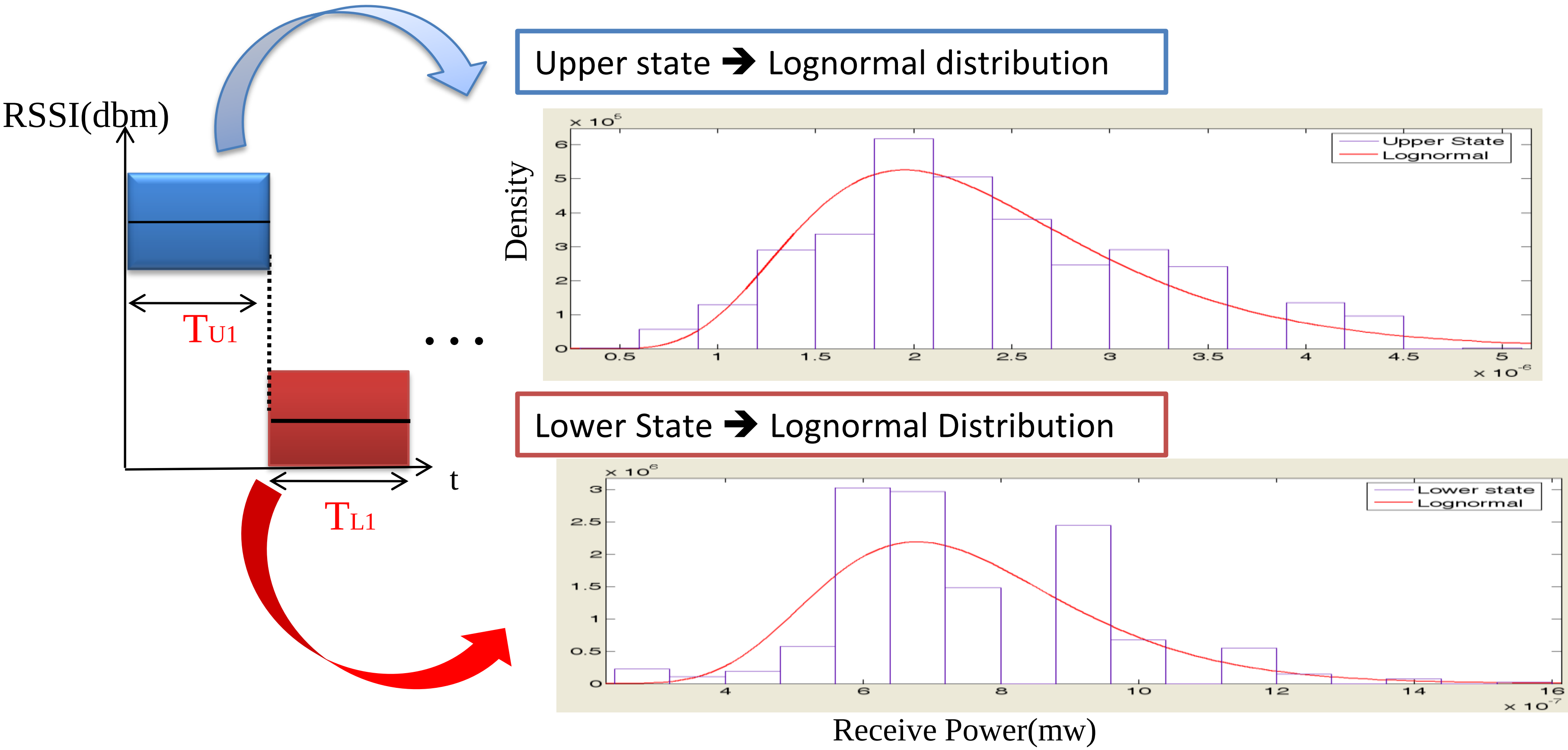
# Two-state walking Channel Model

- Periodic RSSI variation
- Two states – Upper & Lower state
  - Due to the swing of arms & body movement during walking

# Two-state Walking Channel Model

## (U&L state amplitude distribution)

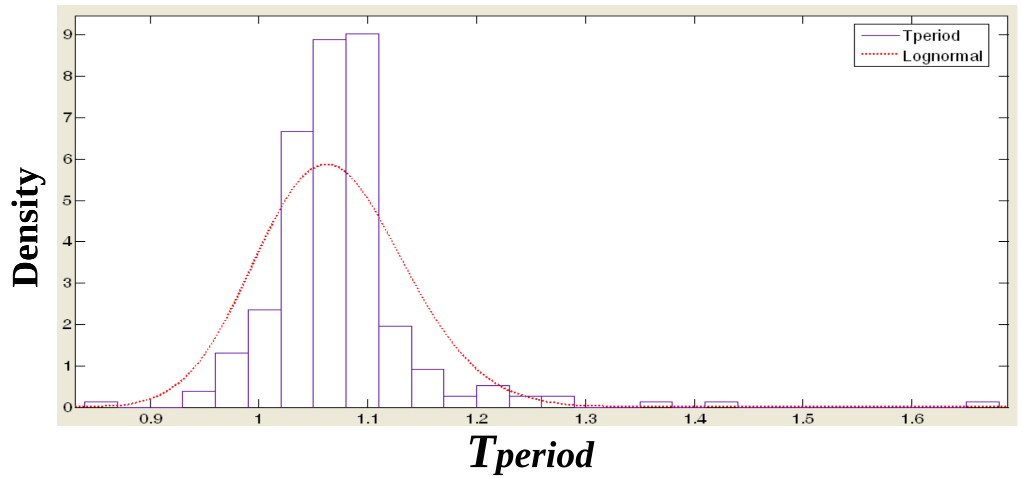
Lognormal distribution properly fits the amplitude distribution in both Upper and lower state.

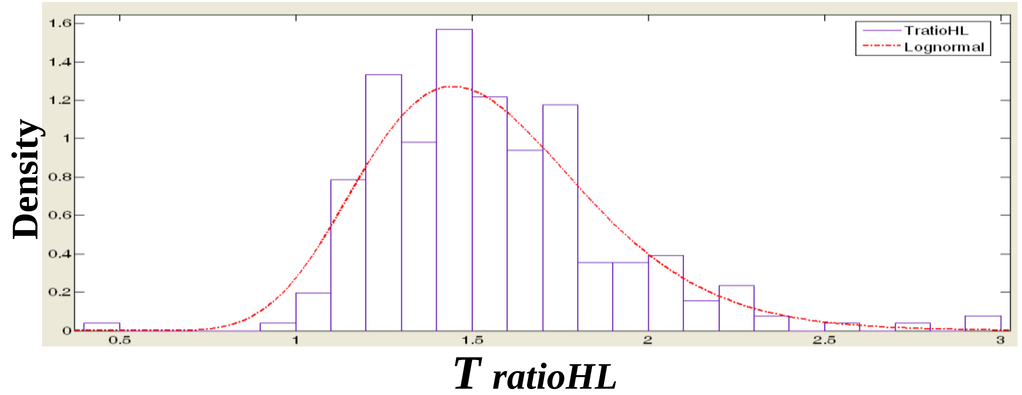


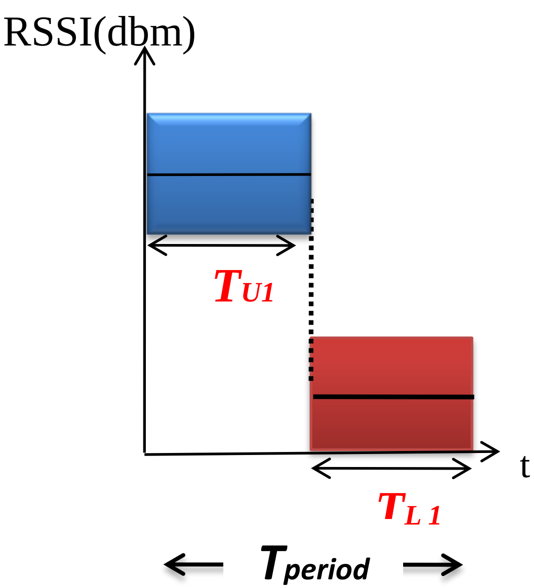
# Two-state Walking Channel Model

(duration of each H&L period )

Lognormal distribution well fits both $T_{period}$ and $T_{rationHL}$ .



# Two-state walking Channel Model

- ***Duration of each state ****

$$T_{period\ n} = lognormal\left(\mu_{t_{period}}, \sigma_{t_{period}}\right), n = 1,2,3, \ldots$$

$$T_{ratioUL\ n} = lognormal(\mu_{t_{ratioUL}}, \sigma_{t_{ratioUL}}), n = 1,2,3, \ldots$$

$$T_{L_n} = {T_{period\ n}}/{(1 + T_{ratioUL\ n})}, \quad T_{U_n} = T_{period\ n} - T_{L_n}$$

| Data | Lognormal | |
|---|---|---|
| | μ | σ |
| *Tperiod* | 0.064 | 0.063 |
| *TratioHL* | 0.415 | 0.212 |
| *PowerU* | -13.013 | 0.363 |
| *PowerL* | -14.136 | 0.259 |

- ***RSSI value ****

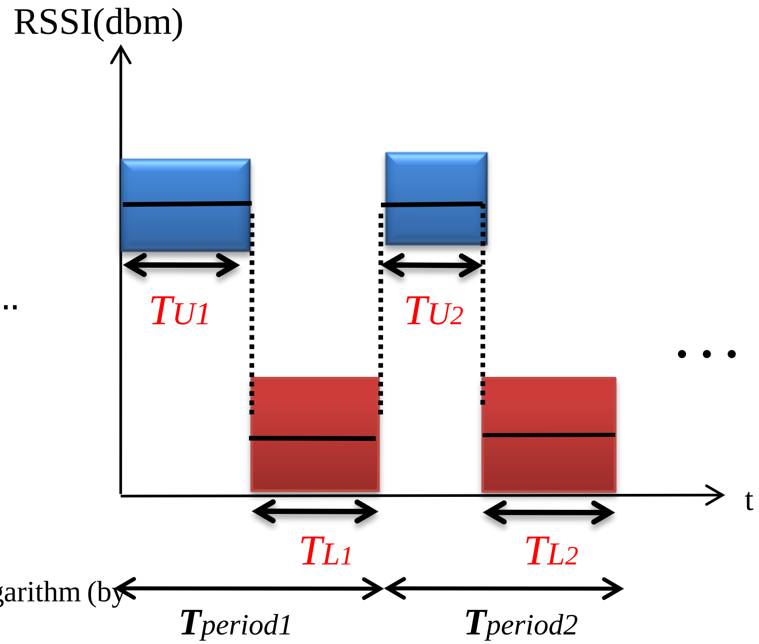
$$Power_U = lognormal(\mu_{PowerU}, \sigma_{PowerU})$$

$$Power_L = lognormal(\mu_{PowerL}, \sigma_{PowerL})$$

$$RSSI(t) = \begin{cases} RSSI_{Upper} = 10\log(Power_U), & t \in T_{U_n} \\ RSSI_{Upper} = 10\log(Power_L), & t \in T_{L_n} \end{cases}, n = 1,2,3, \ldots$$

➢ Lognormal:

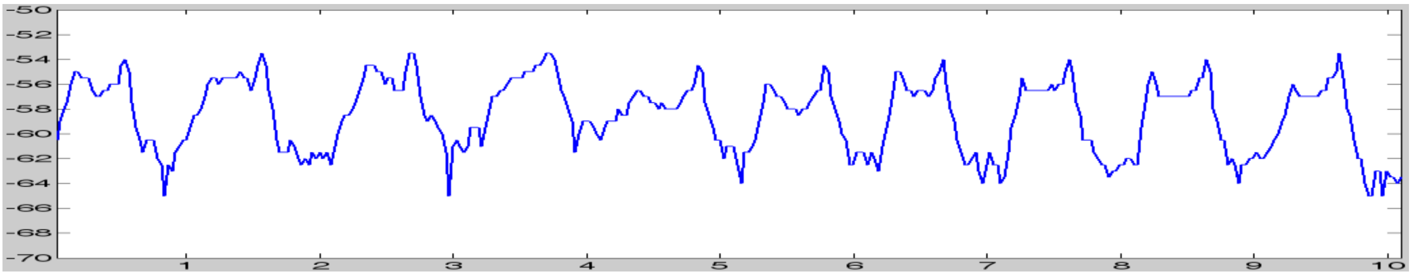
$$f(x|\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} exp\left\{\frac{-(ln(x)-\mu)^2}{2\sigma^2}\right\}$$



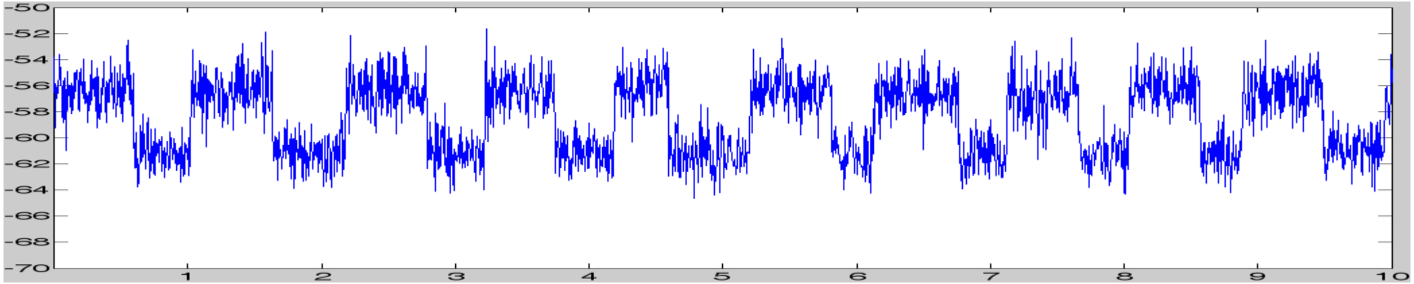

* for $x > 0$, where $\mu$ and $\sigma$ are the mean and standard deviation of the variable's natural logarithm (by definition, the variable's logarithm is normally distributed).

# Example – Generated channel model

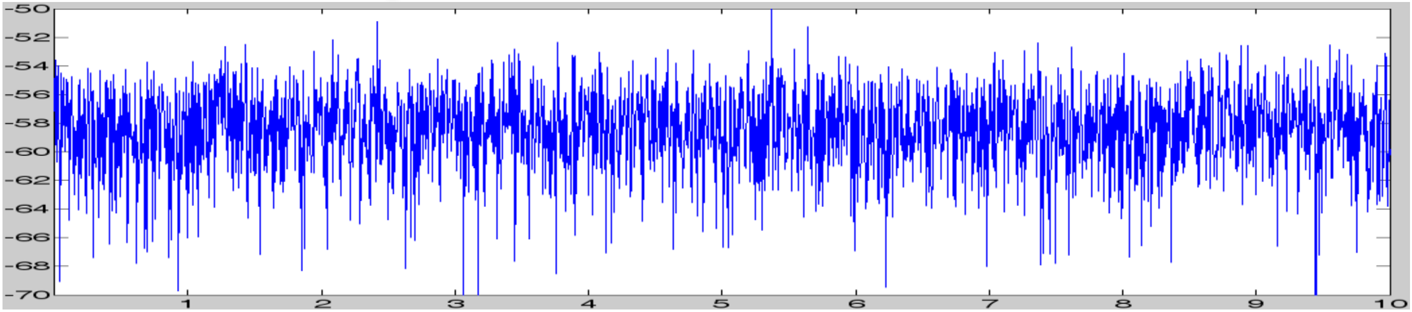
- Measured Data




- Proposed Walking Model




- Gamma Walking model




Path Loss (dB)

Time (s)

# End to end Simulation using Two-state Walking Model

- NS3 simulation for Two-state Walking Model
  - Topology
    point-to-point
  - Packet size / Traffic loading / PHY speed
    250bytes / Uplink 50kbps / 6Mbps
  - Tx Power
    -10dbm
  - Access control
    CSMA/CA
  - Transport layer

    TCP, UDP
  - Evaluation

    end-to-end delay Jitter*, throughput


* The delay Jitter is defined as the delay difference between the consecutive packets.

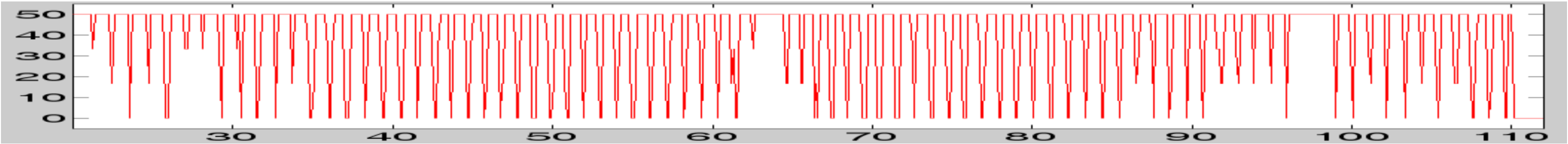
# UDP Analysis

- *Throughput*
- *Delay Jitter and Packet Error Rate*

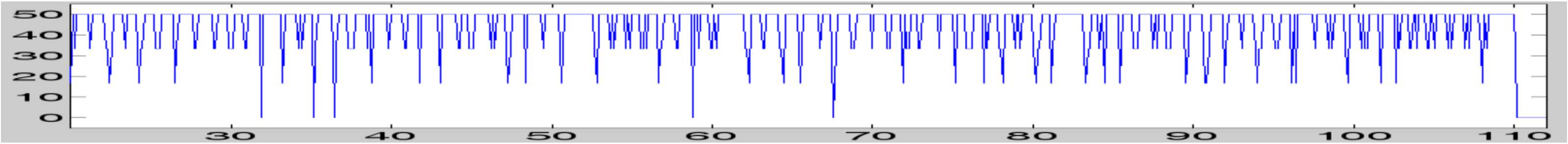
# UDP Analysis (1) - Throughput

Throughput (kbps)

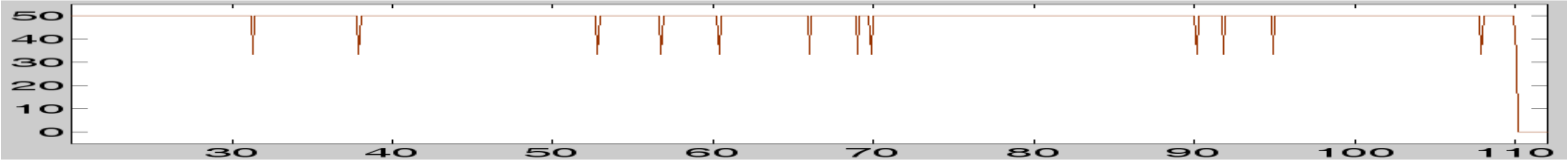
- Measured Data




- Two-state model

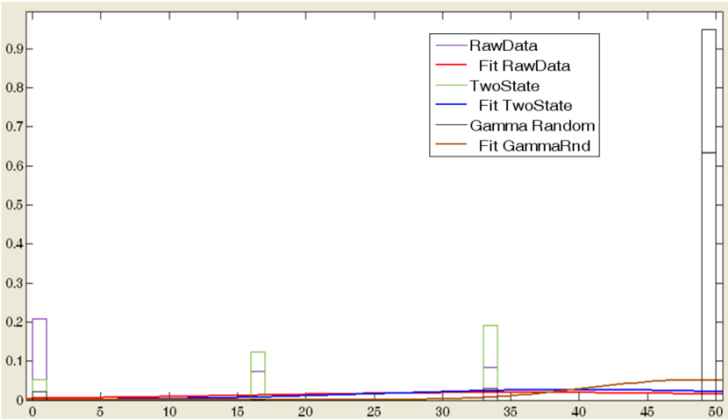



- Gamma model




Tx Time(s)

density




Throughput (kbps)

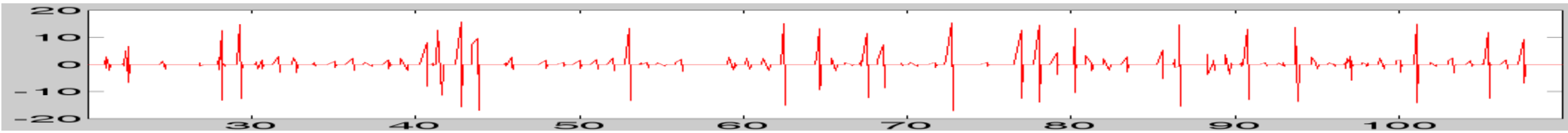
| | Mean of throughput | σ of throughput |
|---|---|---|
| Msu Data | 38.53 | 18.91 |
| Two-State | 44.11 | 11.66 |
| Gamma | 48.67 | 7.43 |

*Unit: kbps*

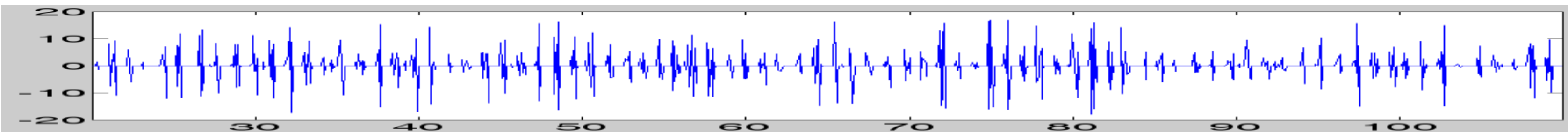
# UDP Analysis (2) – Delay Jitter

Delay Jitter(ms)

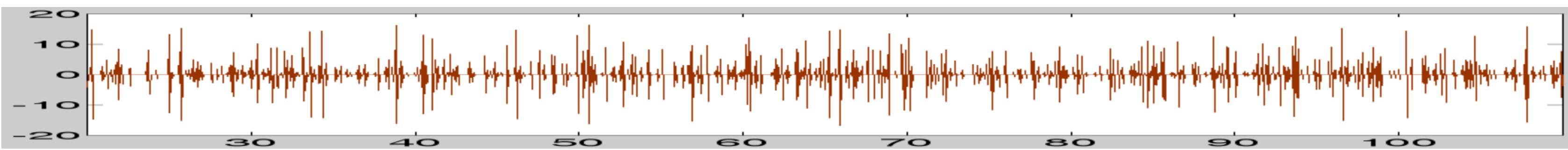
- Measured Data



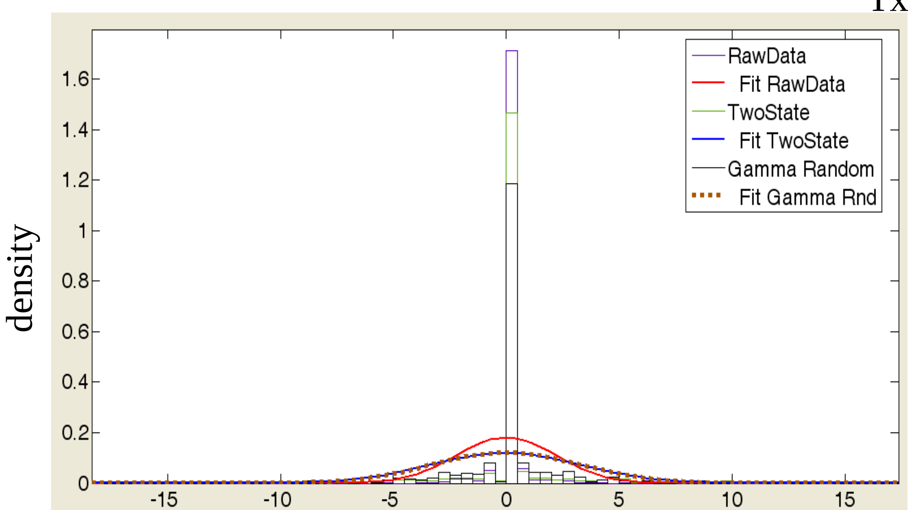

- Two-state model




- Gamma model




Tx time(s)




Jitter (sec)

| | Mean of jitter | σ of jitter | Packet error rate |
|---|---|---|---|
| Msu Data | ~=0 | 2.20 | 0.27 |
| Two-State | ~=0 | 3.34 | 0.19 |
| Gamma | -0.002 | 3.28 | 0.009 |

*Unit: ms*

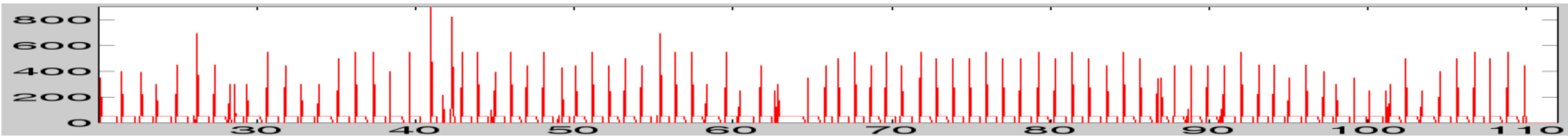
◆ UDP has incomplete delay info due to pkt dropping. Thus, both two-state and gamma model cannot correctly reflect statistic of jitter.

# TCP Analysis

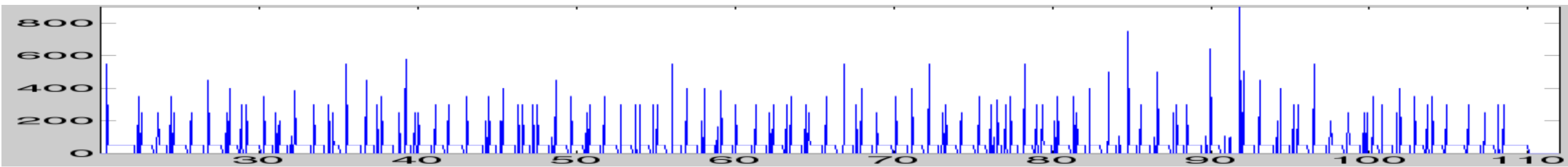
- *Throughput*
- *Delay Jitter*

# TCP Analysis (1) - Throughput

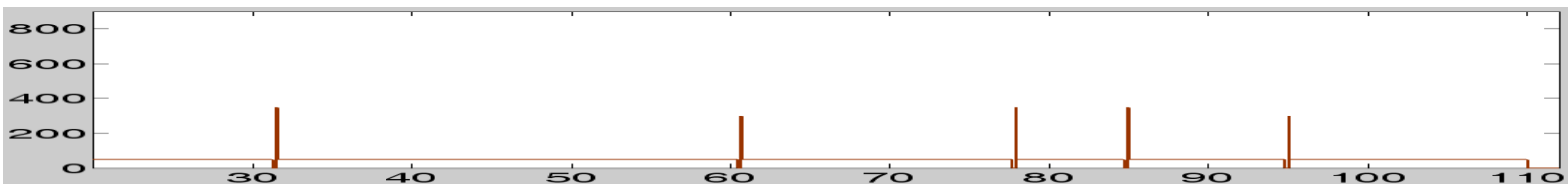
- Measured Data

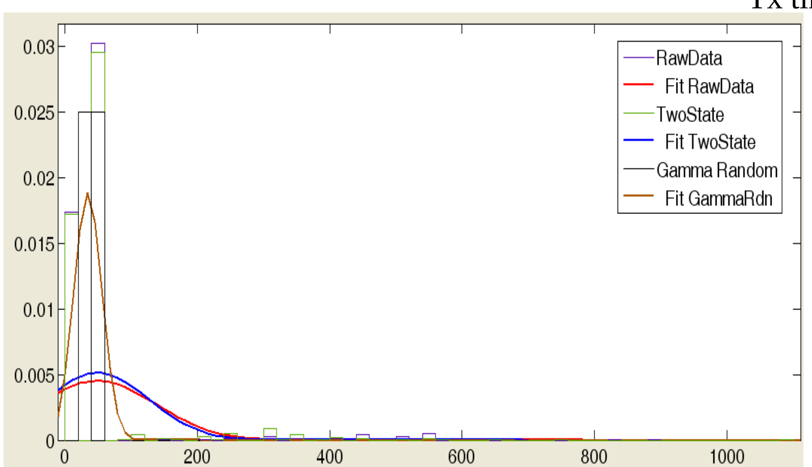



- Two-state model




- Gamma model



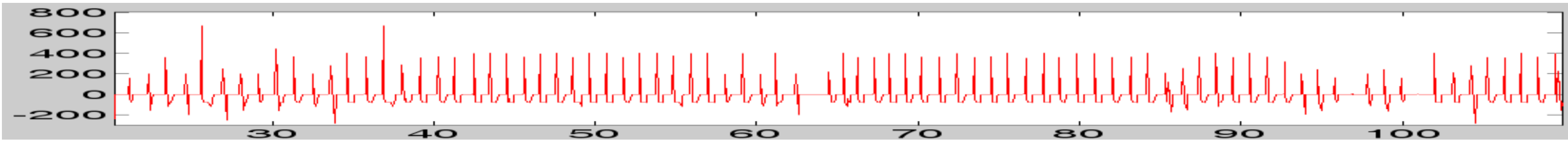

| | Mean of throughput | σ of throughput |
|---|---|---|
| Msu Data | 49.02 | 88.54 |
| Two-State | 48.96 | 78.12 |
| Gamma | 48.93 | 15.95 |

*Unit: kbps*

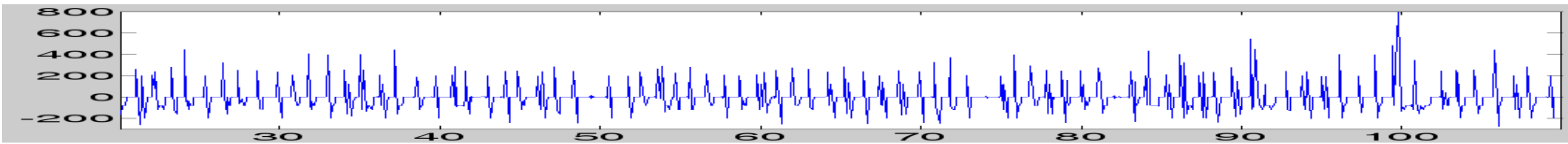
# TCP Analysis (2) – Delay Jitter

Delay Jitter (ms)

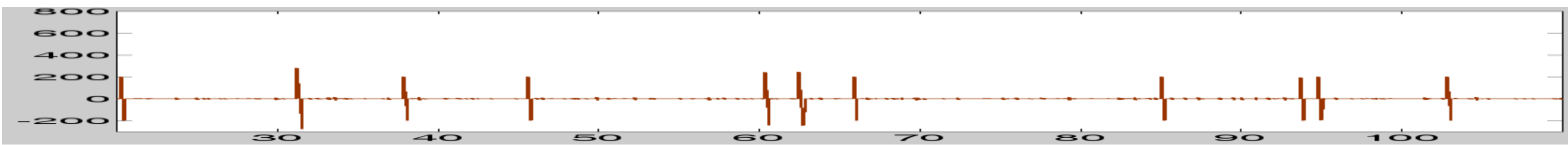
- Measured Data




- Two-state model

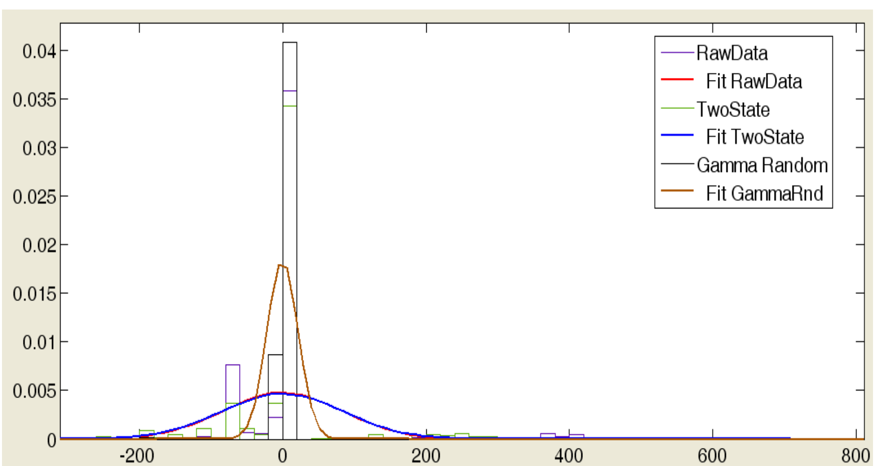



- Gamma model




Tx time(s)

density




Delay Jitter(ms)

| | Mean of jitter | σ of jitter |
|---|---|---|
| Msu Data | 0.04 | 83.64 |
| Two-State | -0.24 | 85.65 |
| Gamma | -0.002 | 21.73 |

*Unit: ms*

# Conclusion

- Two state walking model
- Key parameters
  - Amplitude of Upper & Lower state
    - Lognormal distribution
  - Tperiod & TratioHL
    - Lognormal distribution
- Two-state channel model correctly reflects the performance indexes in end to end communication.

| ***Miss rate*** | UDP Throughput | | UDP Jitter | | TCP Throughput | | TCP Jitter | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | μ | σ | μ | σ | μ | σ | μ | σ |
| *Two-Stata* | 14.48% | 38.34% | 23.17% | 51.82% | 0.12% | 11.77% | 700% | 2.40% |
| *Gamma* | 26.32% | 60.71% | $10^{13}$ % | 49.09% | 0.18% | 81.99% | 105% | 74.02% |

**Red points out the miss rate < 40%*

# Reference

[1] D. Miniutti, L. Hanlen, D. Smith, A. Zhang, D. Lewis, D. Rodda and B. Gilbert, "*Narrowband Channel Characterization for Body Area Networks,"* 15-08-0421-00-0006-narrowband-channel-characterization-for-BAN.

# Thanks for your listening