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

Submission Title: [Preliminary channel models for wearable WBAN]

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Re: [15-08-0033-00-0006-draft-of-channel-model-for-body-area-network]

Abstract: [This document shows a preliminary report on channel modeling for wearable WBAN. In order to design and evaluate specification of PHY for BAN, a channel model is necessary. We hope this channel model will be referred as a common model to design and evaluate a proposed system.]

Purpose: [To evaluate PHY for IEEE 802.15.6 standard we prepare a preliminary version of a common channel model although a modified version will be reported after more propagation model are measured.]

Summary

- This presentation shows preliminary channel models for wearable WBAN.
- The models shown here are related to the CM3 (“body surface to body surface”) in 15-08-0033-00-0006-draft-of-channel-model-for-body-area-network.
- Updated results will be shown in the next meeting.

Outline

1. Measurement setup
   - Frequency bands
     - 400 MHz, 600 MHz, 900 MHz, 2.4 GHz, and UWB band (3.1-5.1 GHz)
2. Measurement results
3. Preliminary channel models
   - Power profile model
     - only for UWB band
   - Path gain model (distance vs. path gain)
     - for all frequency bands
4. Concluding remarks

Measurement setup

- Measurements were conducted in the frequency-domain.
  - S21 of the channel were measured and stored.
  - Vector network analyzer
    - Agilent 8363B
    - # of points: 801
    - IF BW: 1 kHz
    - Sweep time: auto (740 ms)
    - Calibration: Full-2-Port (Tx power = 0 dBm)

Measurement setup

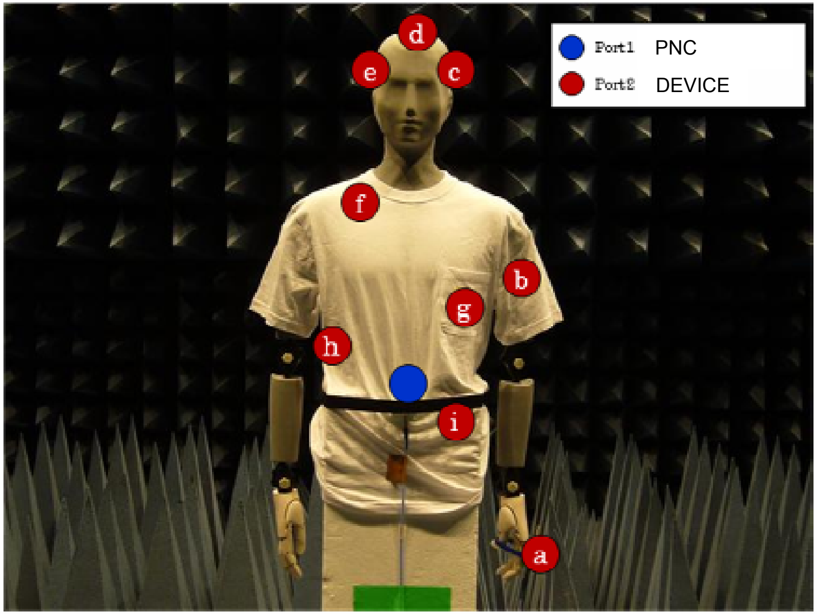
- Frequency bands and antennas

Bands	Range	Antenna
400 MHz	400 - 450 MHz	dipole
600 MHz	608 - 614 MHz	dipole
900 MHz	950 - 956 MHz	dipole
2.4 GHz	2.4 - 2.5 GHz	colinear
UWB	3.1 - 3.5 GHz	skycross

- Human body
  - male, height = 171 cm, weight = 63 kg

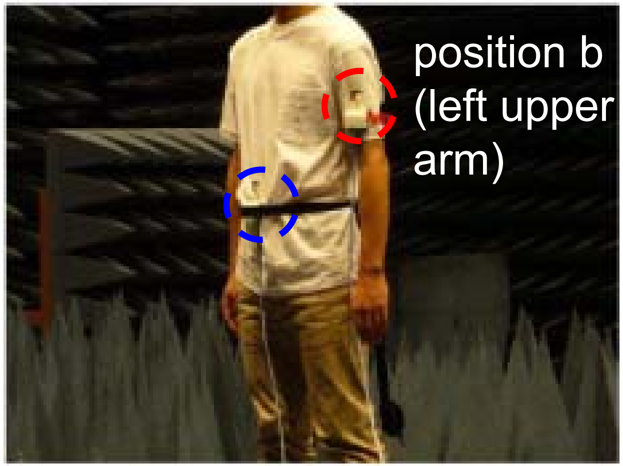
Measurement setup

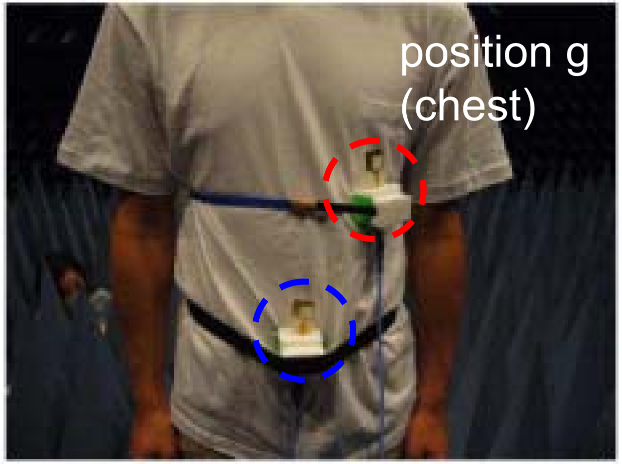
- Measurement positions



a	left wrist
b	left upper arm
c	left ear
d	head
e	right ear

f	shoulder
g	chest
h	right rib
i	left waist





Measurement setup

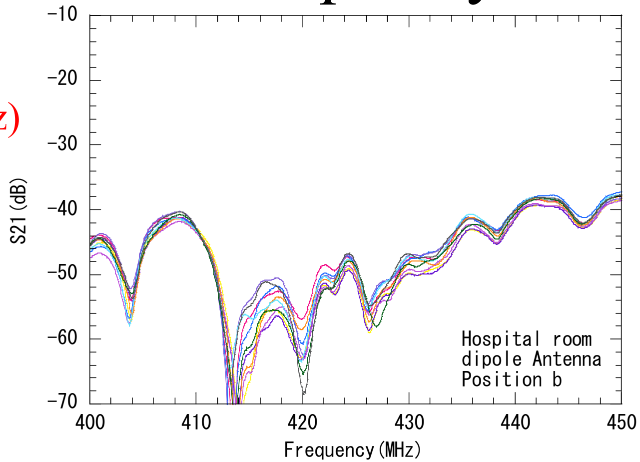
- Measurement environments
  1. Hospital room (Size: 7.0 m x 9.0 m x 2.5 m)

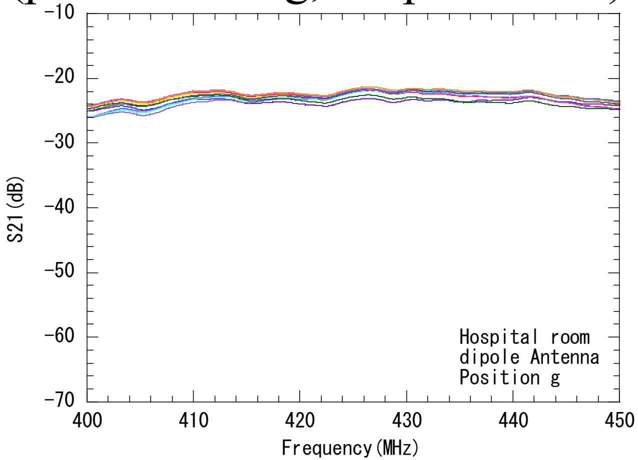
  2. Anechoic chamber
     – without reflections from the floor

Measurement results

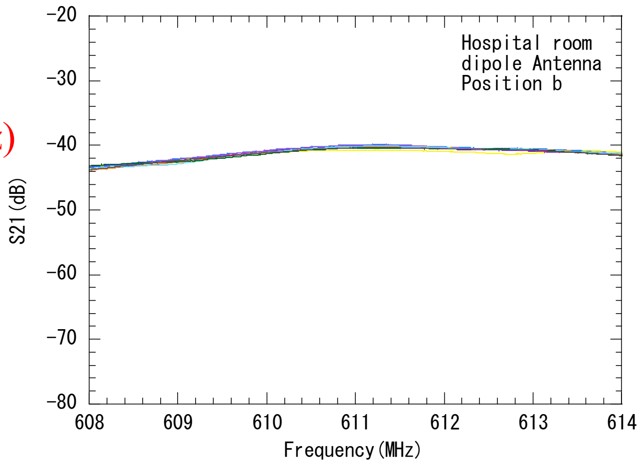
- S21 for each frequency band (position b & g, hospital room)

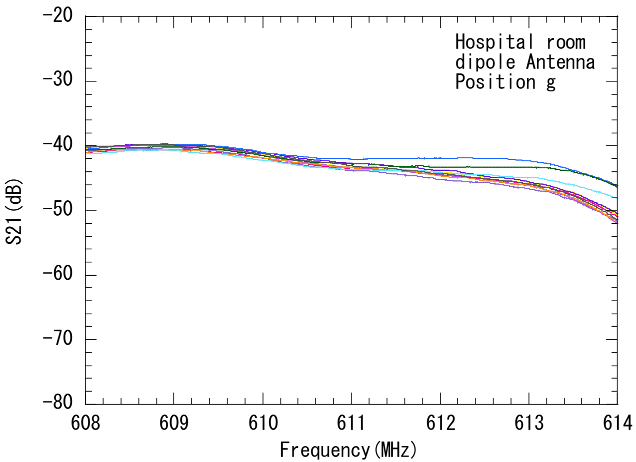
400 MHz
(400-450MHz)
(10 samples)





600 MHz
(608-614MHz)
(10 samples)

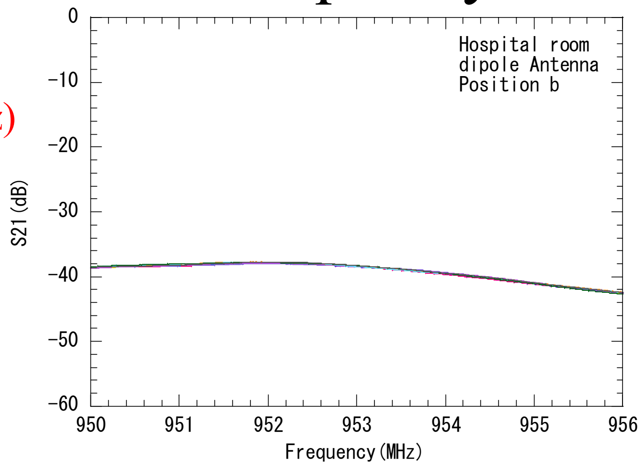


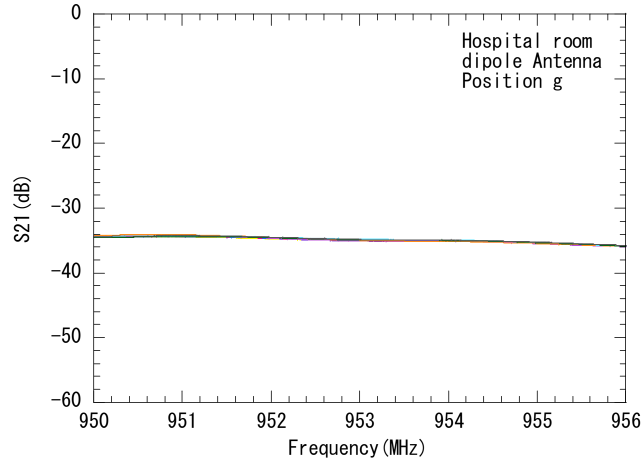


Measurement results

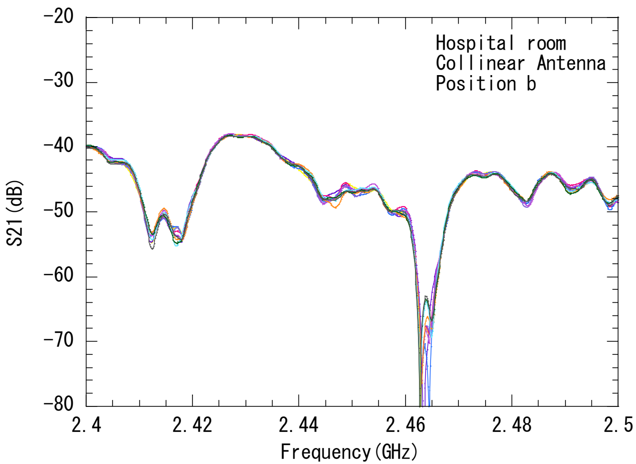
- S21 for each frequency band (position b & g, hospital room)

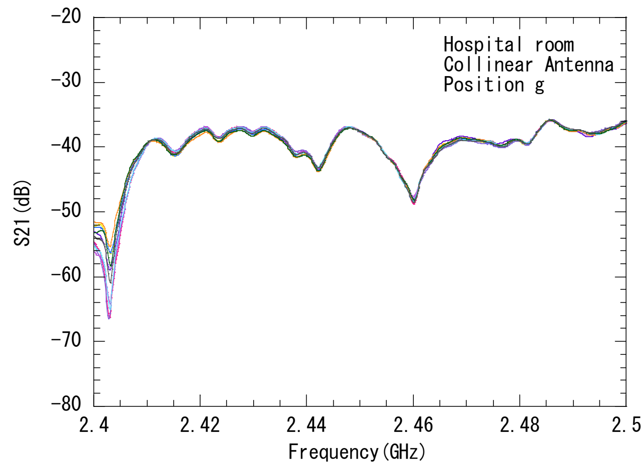
900 MHz
(950-956MHz)
(10 samples)





2.4 GHz
(2.4-2.5GHz)
(10 samples)

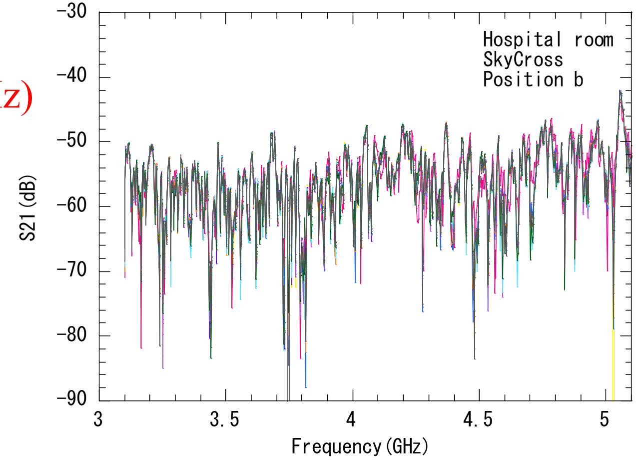


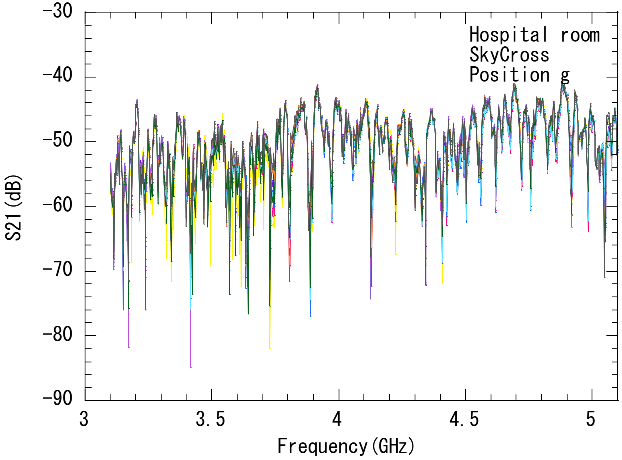


Measurement results

- S21 for each frequency band (position b & g, hospital room)

UWB
(3.1-5.1GHz)
(10 samples)

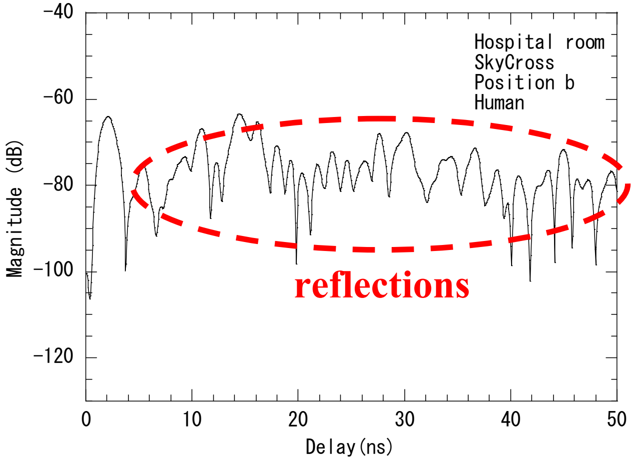


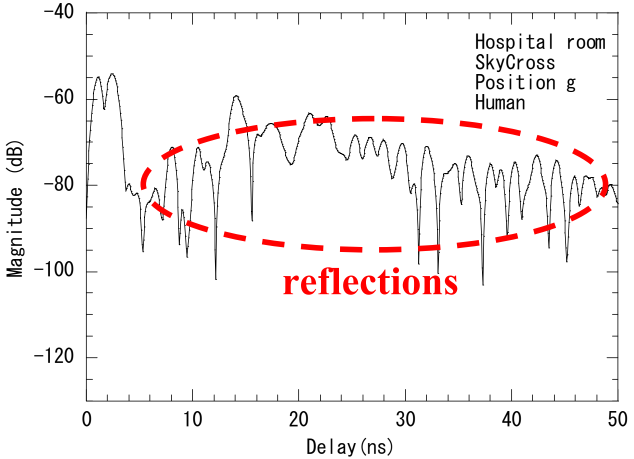


Measurement results

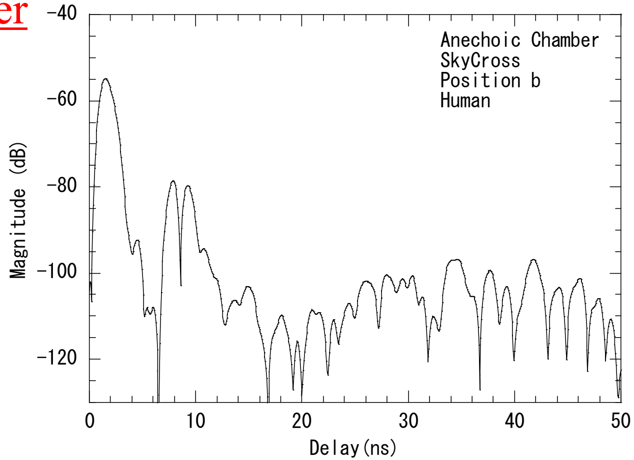
- Time domain waveforms (UWB band)

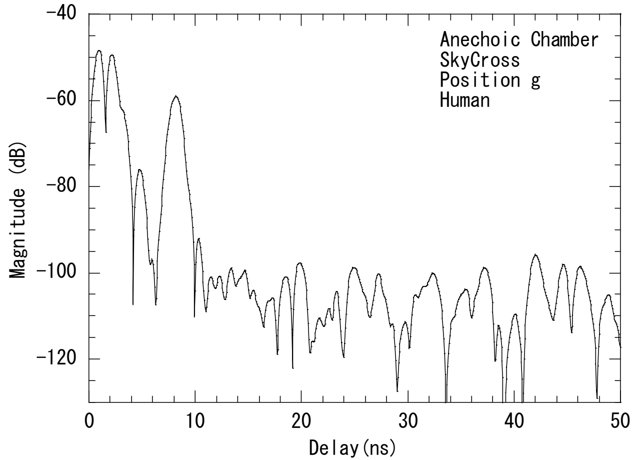
Hospital room





Anechoic chamber





Channel models for wearable WBAN

1. Power profile model
   - ➢ only for UWB band

2. Path gain model
   - ➢ for both narrow band (NB) and UWB band

- Note: these models are not position-specific models.

WBAN channel model - power profile model -

Power profile model

$$h(t) = \sum_{l=0}^{L-1} a_l \exp(j\phi_l)\delta(t - t_l)$$

- $\delta(t)$: Dirac function
- ϕ_l : Phase component uniformly distributed over [0, 2π)
- L : The number of arrivals
- a_l : Tap weight of the l th path
- t_l : Delay of the l th path [ns]

Tap weight (path amplitude) : a_l

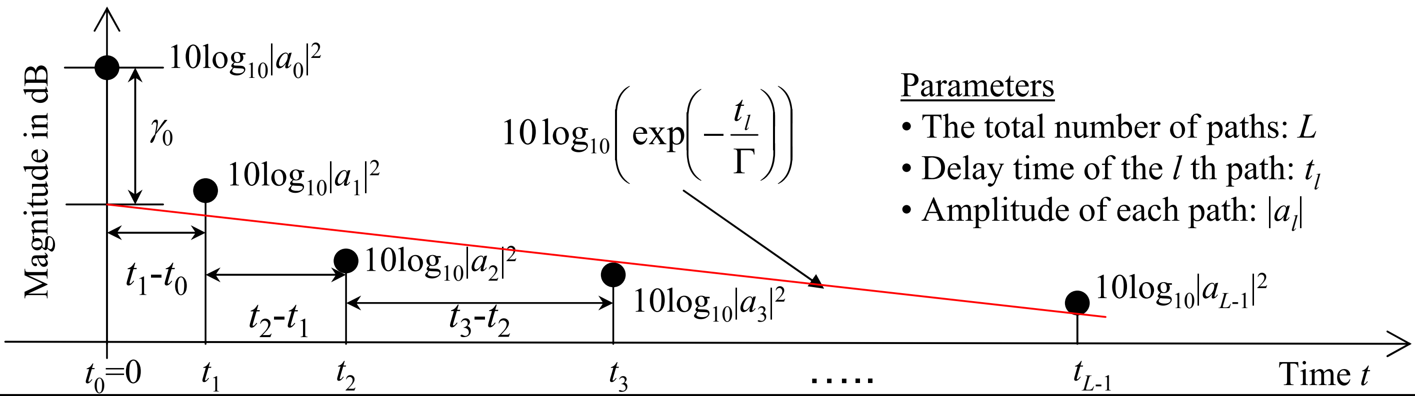
$$10\log_{10}|a_l|^2 = \begin{cases} 0 & l = 0 \\ \gamma_0 + 10\log_{10}\left(\exp\left(-\frac{t_l}{\Gamma}\right)\right) + S & l \neq 0 \end{cases}$$

- γ_0 : Rice factor [dB]
- Γ : Decay time [ns]
- S : Normally distributed variable with standard deviation σ_S

Delay (path arrival time) : t_l

$$p(t_l \mid t_{l-1}) = \lambda \exp[-\lambda(t_l - t_{l-1})]$$

- λ : Path arrival rate



Parameters

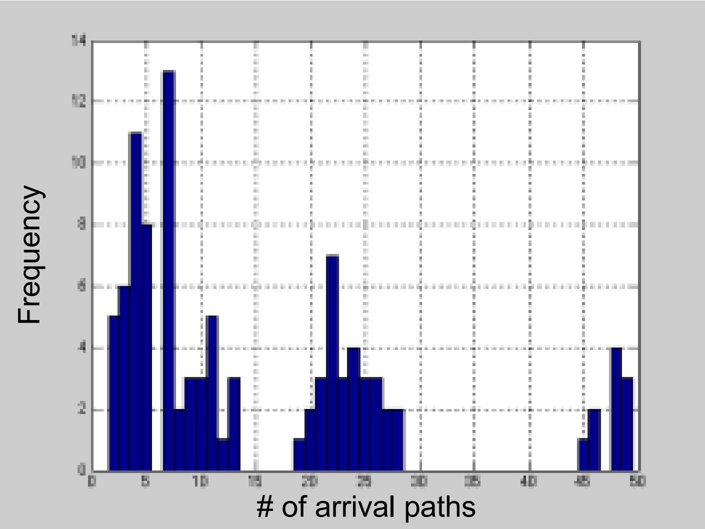
- The total number of paths: L
- Delay time of the l th path: t_l
- Amplitude of each path: $|a_l|$

WBAN channel model - power profile model -

- The number of taps (# of arrival paths): L
  - Poisson distribution $$pdf_L(L) = \frac{(\bar{L})^L \exp[\bar{L}]}{L!}$$

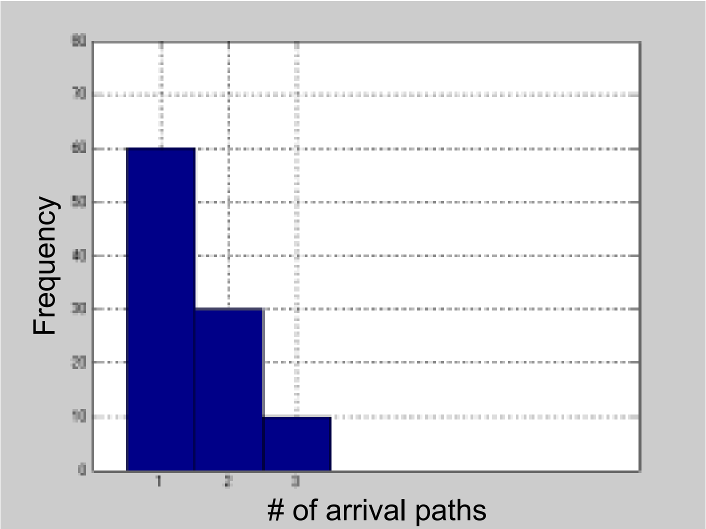
Hospital room

parameters	value
$\bar{L}$	15.6



Anechoic chamber

parameters	value
$\bar{L}$	1.5



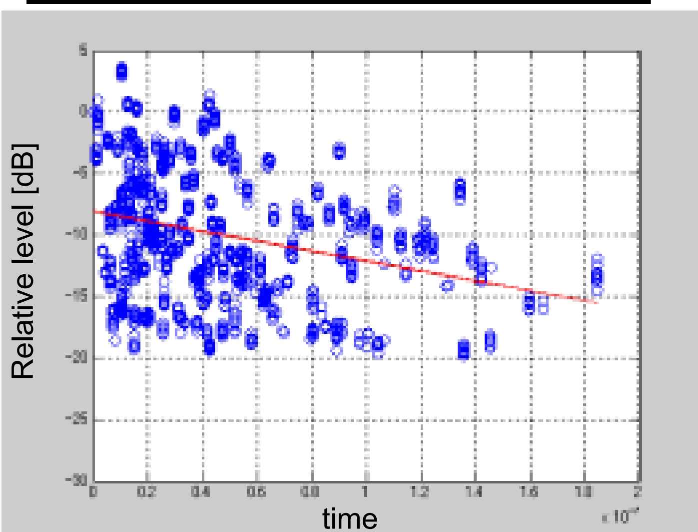
WBAN channel model - power profile model -

- Tap weight (path amplitude): a_l
  - Exponential decay factor Γ and ambiguity component S

$$10\log_{10}|a_l|^2 = \begin{cases} 0 & l = 0 \\ \gamma_0 + 10\log_{10}\left(\exp\left(-\frac{t_l}{\Gamma}\right)\right) + S & l \neq 0 \end{cases}$$

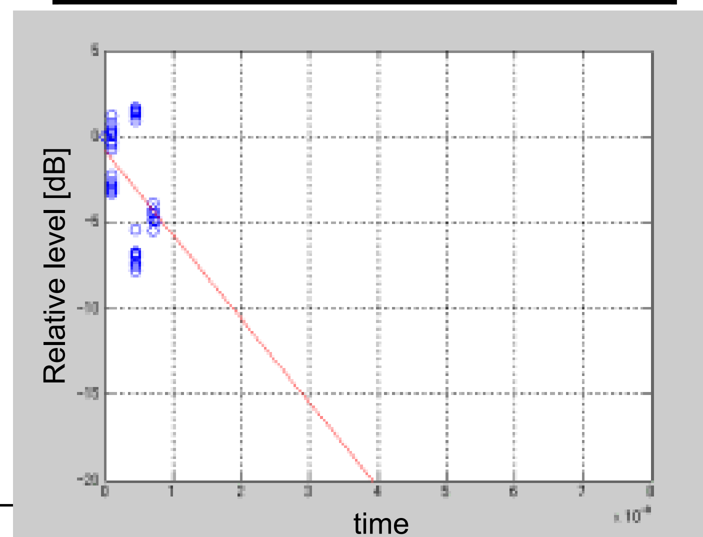
Hospital room

parameters	value
γ_0	-8.08 dB
Γ	155.7 ns
σ_S	4.94 dB



Anechoic chamber

parameters	value
γ_0	-0.48 dB
Γ	8.88 ns
σ_S	2.87 dB



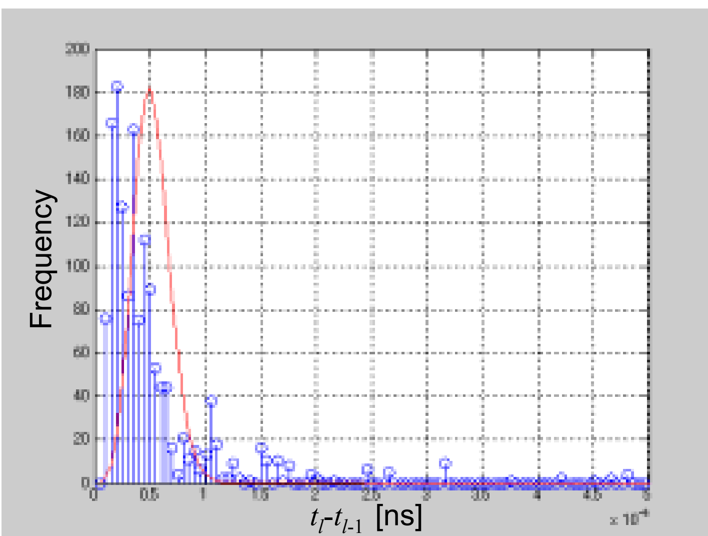
WBAN channel model - power profile model -

- Delay (path arrival time): t_l
  - Poisson distribution

$$p(t_l \mid t_{l-1}) = \lambda \exp[-\lambda(t_l - t_{l-1})]$$

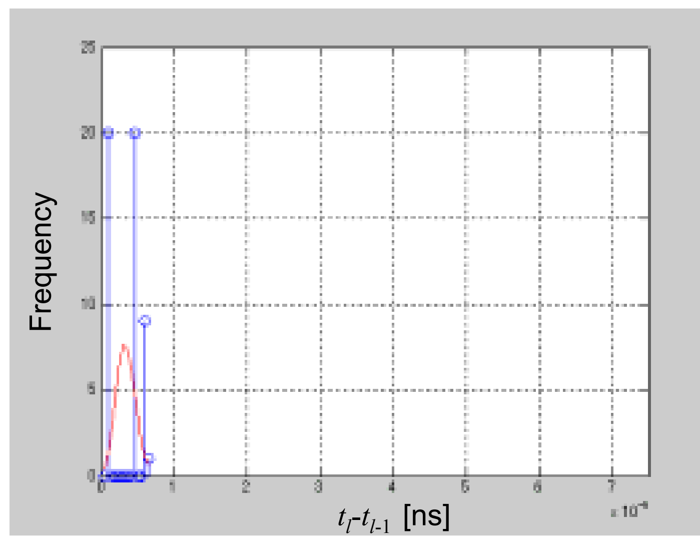
Hospital room

parameters	value
λ	5.17 ns



Anechoic chamber

parameters	value
λ	6.82 ns

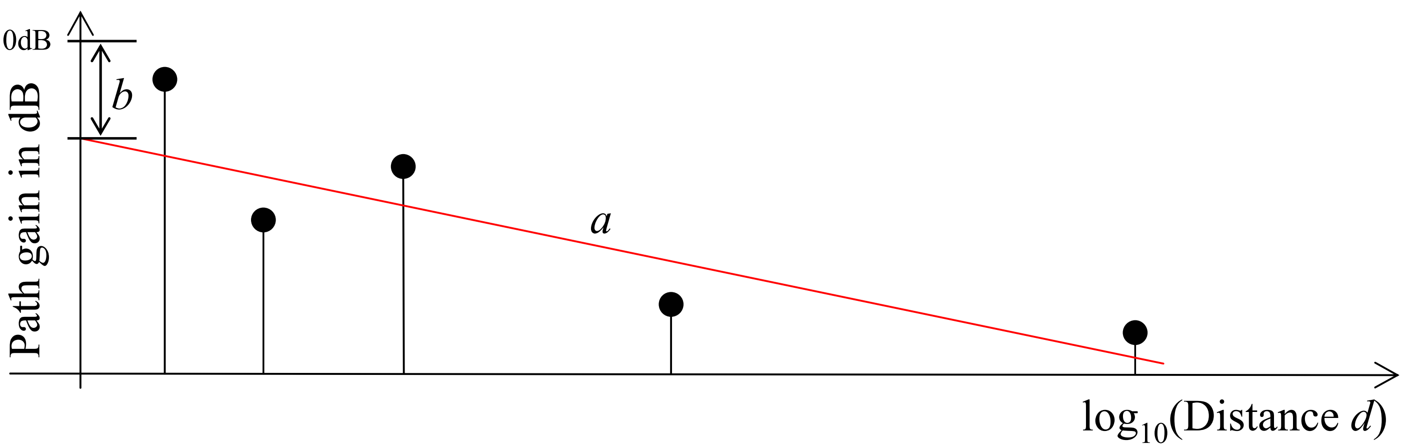


WBAN channel model - path gain model -

Path gain model

$$PG(d) \text{ in dB} = a \log_{10}(d) + b + N$$

- PG: path gain
- a and b : coefficients of linear fitting
- d : Tx-Rx distance in mm.
- N : Normally distributed variable with standard deviation σ_N



Path gain model **400 MHz**

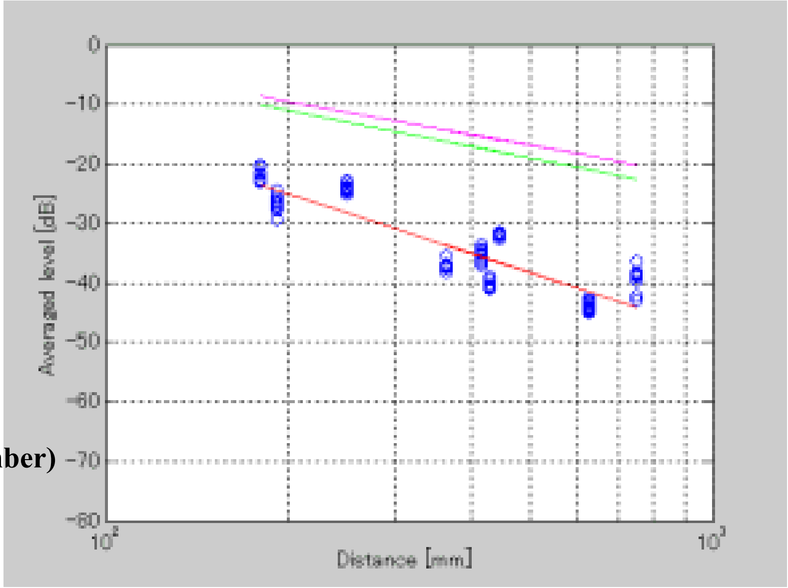
$$PG(d)[\mathrm{dB}] = a \cdot \log_{10}(d) + b + N$$

Hospital room

Parameters	value
a	-19.5
b	18.4
σ_N	6.7

Anechoic chamber

Parameters	value
a	-33.1
b	51.0
σ_N	3.5

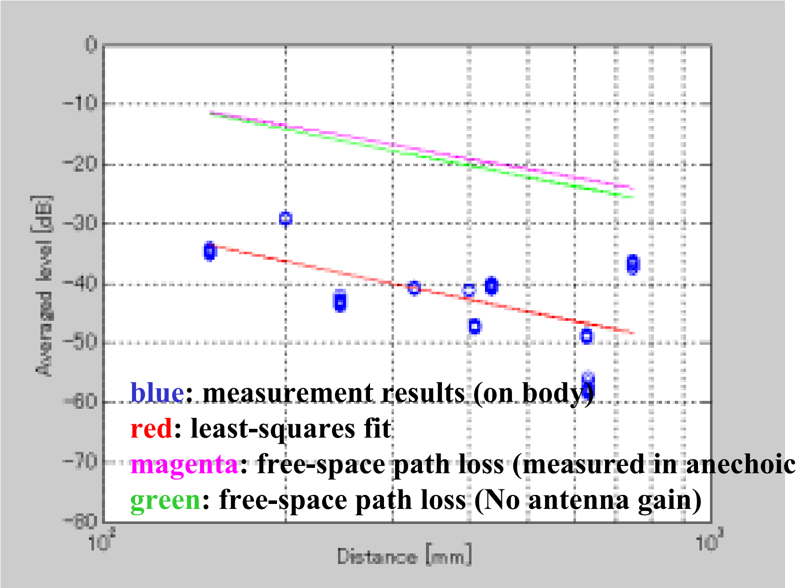


Path gain model 600 MHz

$$PG(d)[\text{dB}] = a \cdot \log_{10}(d) + b + N$$

Hospital room

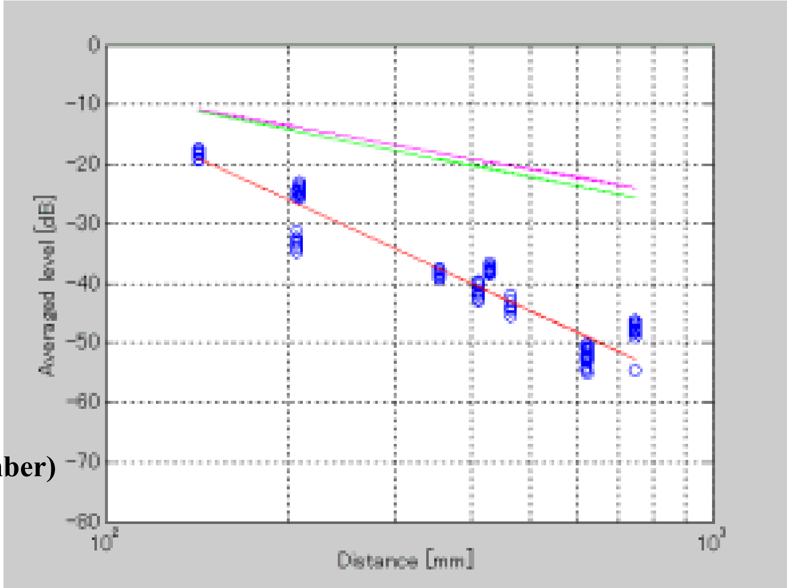
Parameters	value
a	-19.8
b	9.2
σ_N	5.4



blue: measurement results (on body)
red: least-squares fit
magenta: free-space path loss (measured in anechoic chamber)
green: free-space path loss (No antenna gain)

Anechoic chamber

Parameters	value
a	-46.9
b	81.9
σ_N	3.2

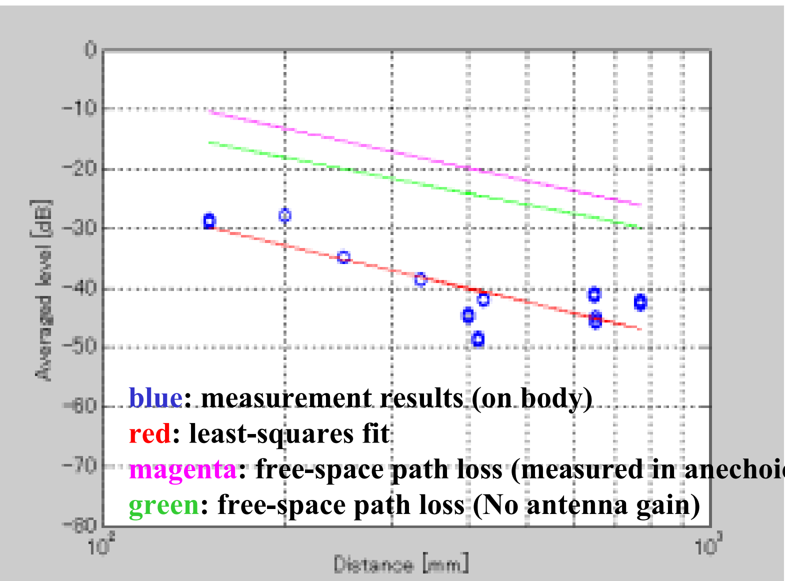


Path gain model 900 MHz

$$PG(d)[\mathrm{dB}] = a \cdot \log_{10}(d) + b + N$$

Hospital room

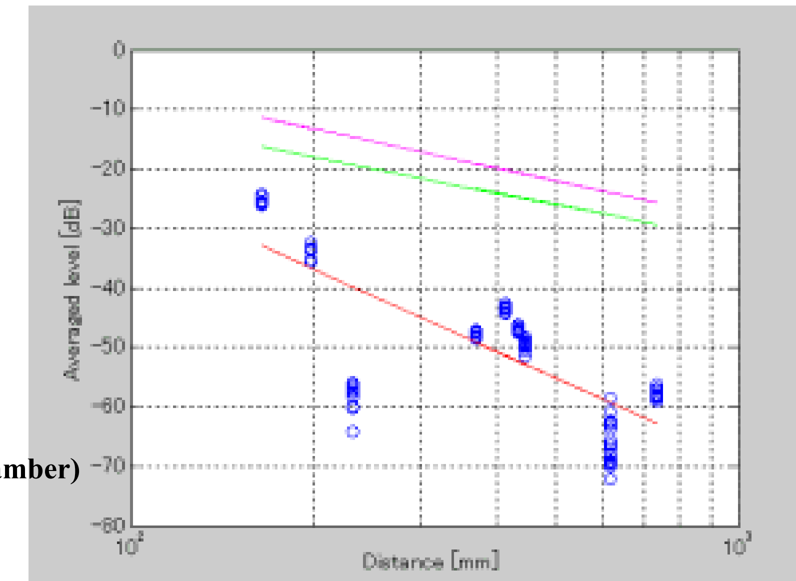
Parameters	value
a	-23.3
b	20.7
σ_N	4.1



blue: measurement results (on body)
red: least-squares fit
magenta: free-space path loss (measured in anechoic chamber)
green: free-space path loss (No antenna gain)

Anechoic chamber

Parameters	value
a	-45.8
b	68.6
σ_N	8.1



Path gain model 2.4 GHz

$$PG(d)[\mathrm{dB}] = a \cdot \log_{10}(d) + b + N$$

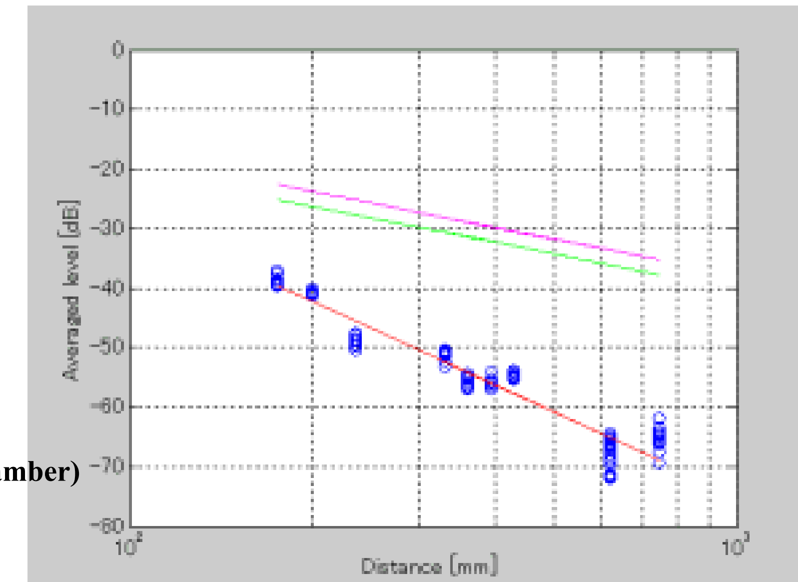
Hospital room

Parameters	value
a	-8.6
b	-20.3
σ_N	2.0

blue: measurement results (on body)
red: least-squares fit
magenta: free-space path loss (measured in anechoic chamber)
green: free-space path loss (No antenna gain)

Anechoic chamber

Parameters	value
a	-46.1
b	63.7
σ_N	2.6

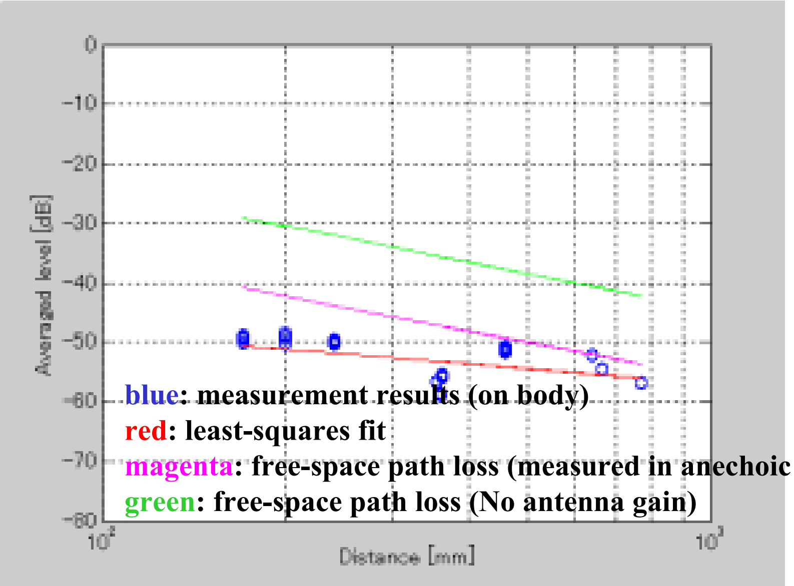


Path gain model UWB

$$PG(d)[\mathrm{dB}] = a \cdot \log_{10}(d) + b + N$$

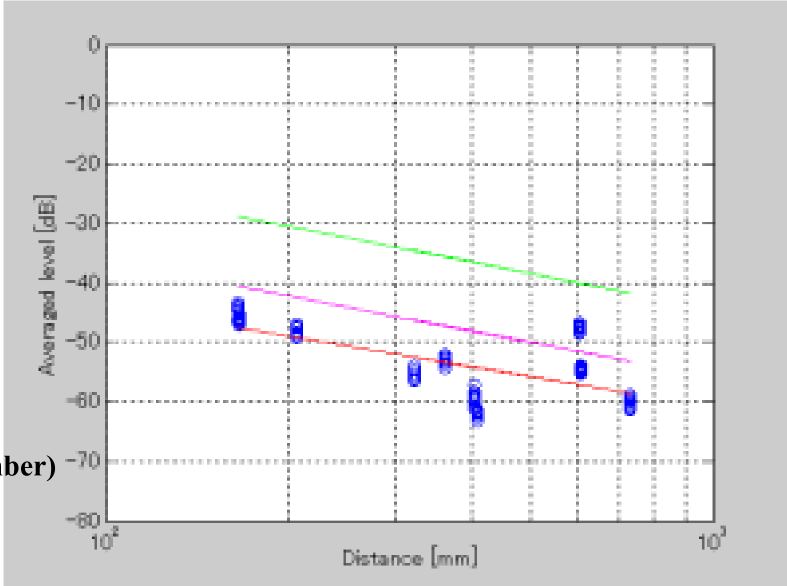
Hospital room

Parameters	value
a	-8.42
b	-31.8
σ_N	2.8



Anechoic chamber

Parameters	value
a	-19.8
b	-9.8
σ_N	4.66



Concluding remarks

- Measurements for modeling wearable WBAN channels
  - 400 MHz, 600 MHz, 900 MHz, 2.4 GHz, and UWB band
- Preliminary model
  1. Power profile model for the UWB band
  2. Path gain models for the all frequency bands
- Updated results will be shown in the next meeting