Body Area Network for Medical and Healthcare Applications

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Antenna Technology Workshop 2008

Seoul, Korea

April 24, 2008

Biography

- Professor and Chair,
  Department of International Development Engineering,
  Tokyo Institute of Technology
- Visiting researcher,
  Medial ICT Institute, NICT
- Major
  - Propagation and channel modeling
  - ICT applications for social development

Contents

- Introduction to body area network (BAN)
- Channel models for BAN

What is BAN?

- Short range wireless communication in the vicinity of, or inside, a human body

  (IEEE 802.15.6 draft PAR)

- Smaller than PAN
- Applications
  - Medical / healthcare
  - Entertainment

Contents

- Introduction to body area network (BAN)
  - **Applications**
  - New standard – IEEE 802.15.6
  - Regulatory
- Channel models for BAN

Examples

- IEEE 802.15-05-0694-00-wng0
- IEEE 802.15-06-0125-00-wng0
- IEEE 802.15-08-0154-00-0006
- IEEE 802.15-08-0162-00-0006
- IEEE 802.15-08-0163-00-0006
- IEEE 802.15-08-0169-01-0006

Medical Applications
Wearable BAN (WMTS) [1]

Medical telemetry

- Electroencephalography (EEG, brain)
- Electrocardiogram (ECG, heart)
- Electromyography (EMG, muscular)
- Vital signals monitoring
- Temperature (wearable thermometer)
- Respiratory monitor
- Wearable heart rate monitor
- Wearable pulse oximeter (Oxygen saturation in blood)
- Wearable blood pressure monitor
- Wearable glucose sensor

Medical Applications Wearable BAN (WMTS) [1]

Disability assistance

- Muscle tension sensing and stimulation
- Wearable weighing scale
- Fall detection

Human performance management

- Aiding professional and amateur sport training
- Assessing emergency service personnel performance
- Assessing soldier fatigue and battle readiness

Medical Applications Implant BAN (MICS) [1]

Medical Telemetry

- implanted glucose sensor
- Sugar density
- Cardiac arrhythmia monitor/recorder
- Brain liquid pressure sensor
- wireless capsule endoscope (gastrointestinal)

Medical treatment

- wireless capsule for drug delivery

Medical Applications
Implant BAN (MICS) [1]

Stimulators

- Deep brain stimulator
- Cortical stimulator
- Visual neuro-stimulator
- Audio neuro-stimulator
- Parkinson’s disease
- Epilepsy Stimulator
- Brain-computer interface

Medical Applications Implant BAN (MICS) [1]

Remote control of medical devices

- Pacemaker
- Implantable cardioverter defibrallitor (ICD)
- Insulin pump
- Hearing aid
- Retina implants

Healthcare Applications [1]

- Hospital and Bed Side Monitoring and Assistance
- Health and Fitness
- Chronic Disease Management
- Elderly Monitoring

Non-Medical Applications including Entertainment [1]

Real-time Video Streaming

- Video streaming among portable devices
- Video streaming from portable device to external displays

Real-time Audio Streaming

- Headsets for voice communications
- Headsets for music
- 5.1 channel music/sound track

Non-Medical Applications including Entertainment [1]

Data File Transfer

- Data file (office suite etc.)
- Image file (digital camera, scanner, etc.)
- Video file (camcorder, multimedia player and etc.)

Small Data transfer

- Remote control of entertainment devices
- Body motion capture/gesture recognition
- Control signal from PC peripheral devices
  (e.g. mouse click)

Contents

- Introduction to body area network (BAN)
  - Applications
  - **New standard – IEEE 802.15.6**
  - Regulatory
- Channel models for BAN

Standard Activity IEEE 802.15.6

Scope [2]

- Standard for short range, wireless communication in the vicinity of, or inside, a human body
- Use of existing ISM bands as well as frequency bands approved by national medical and/or regulatory authorities
- Support for Quality of Service (QoS), extremely low power, and data rates up to 10 Mbps
- Considering effects on portable antennas due to the presence of a person, radiation pattern shaping to minimize SAR into the body, and changes in characteristics as a result of the user motions

Standard Activity IEEE 802.15.6

Purpose [2]

- Short range, low power, highly reliable wireless communication
- For use in close proximity to, or inside, a human body
- Data rates, typically up to 10Mbps
- Current Personal Area Networks
  - Not meeting the medical (proximity to human tissue) and relevant communication regulations
  - Not support the combination of reliability (QoS), low power, data rate and noninterference

Standard Activity IEEE 802.15.6

Technical requirement [3]

- Medical/healthcare applications
- Non-medical applications
- Network from a few sensor or actuator devices to potentially hundreds of sensors and actuators

Standard Activity IEEE 802.15.6

Technical requirement [3]

- Devices with high constraint
  - CPU, battery and memory
  - Unstable environments
- Physically small to be wearable or implantable
- Wearable access points also with resource constraint, although more powerful

Standard Activity IEEE 802.15.6

Technical requirement [3]

- Biomedical and vital signals with low frequency and period
  - Packet generation rates from 1/ms to 1000/s
- Motion detection and tumble sensors for elders
  - Event-based or bursty
- Detection of alarm conditions
  - With low latency and high reliability transmission
- Low-rate remote control
  - Close loop with latency within 100ms to seconds

Standard Activity
IEEE 802.15.6

Expected PHY and MAC [3]

- Self-forming, self-healing, secure, robust and reliable
- Throughput of some tens of kb/s in most of the cases
- Self-powered operating time from several hours to several years
- Duty cycle from 0.1% or less to a medium/high value
- QoS management and reliability for high priority alarm Security being lightweight, scalable and energy efficient
- Coexistence
  - Wearable and implant BANs
  - BAN and other wireless technologies
  - BAN in medical environments (EMC/EMI)

Standard Activity
IEEE 802.15.6

Timeline [4]	2006		2007											
	11	12	1	2	3	4	5	6	7	8	9	10	11	12
SG Formed	*													
Project Authorization Request (PAR) & Functional Requirements Standards Development Criteria (5C)											*			
TRD (Technical Requirements Doc)											>	>	>	>
SCD (Select Criteria Document)											>	>	>	>
Channel Model					>	>	>	>	>	>	>	>	>	>

Standard Activity
IEEE 802.15.6

Timeline [4]	2008											
	1	2	3	4	5	6	7	8	9	10	11	12
TG CFA (Call for Applications)	>	>	>	>	>							
Affirm Apps matrix					^							
TRD (Technical Requirements Doc)	>	>	>	>	>	>	>					
SCD (Select Criteria Document)	>	>										
Channel Model	>	>	>	>	>	>	>					
CFI (Call for Intent)			>	>	>	>	^					
CFP (Call for Proposals)					>	>	>	>	>	>	^	
Issue CFP							^					
Close CFP											^	
Hear Proposals									>	>	>	>
Technical editorial team in place									^			

Standard Activity
IEEE 802.15.6

Timeline [4]	2009											
	1	2	3	4	5	6	7	8	9	10	11	12
Hear Proposals	^											
Base line selection	>	>	^									
Technical Comments Resolution	>	>	>	>	>							
Draft ready for letter ballot					>	>	>	>	^			
Draft ready for Sponsor ballot									>	>	>	>

Contents

- Introduction to body area network (BAN)
  - Applications
  - New standard – IEEE 802.15.6
  - **Regulatory**
- Channel models for BAN

Regulatory Issues of BAN

Frequency allocation

- Common bands
  - 402-405 MHz for MICS
  - 2.4 GHz for ISM
- Example in Japan / Korea
  - 420 – 450 MHz for WMTS
  - 3.4 – 4.8 GHz, 7.2(5) – 10.2(5) GHz for UWB
- Example in USA
  - 608–614 MHz, 1395–1400 MHz, 1427–1429.5 MHz for WMTS
  - 3.1 – 10.6 GHz for UWB

Regulatory Issues of BAN

EMC/EMI issues

- Protection of human body
  - Measured by specific absorption rate (SAR)

$$\mathrm{SAR} = \frac{\sigma |E|^2}{\rho} \left[\mathrm{W/kg}\right]$$

    σ: conductivity, E: electric field, ρ: mass density
  - ICNIRP: protection criteria
    - Localized SAR (head/trunk) < 10 W/kg for 10 g
  - IEC/TC106: SAR measurement
    - Not yet available for other than mobile phones

Regulatory Issues of BAN

EMC/EMI issues

- Immunity of medical devices
  - IEC 60601-1-2: EMC
    - 3 V/m @ 80 MHz – 2.5 GHz for non-life-support devices
    - 10 V/m @ 80 MHz – 2.5 GHz for life-support devices
  - Cardiac pacemaker is sensitive but there seems no EMC standard for implant pacemakers yet.

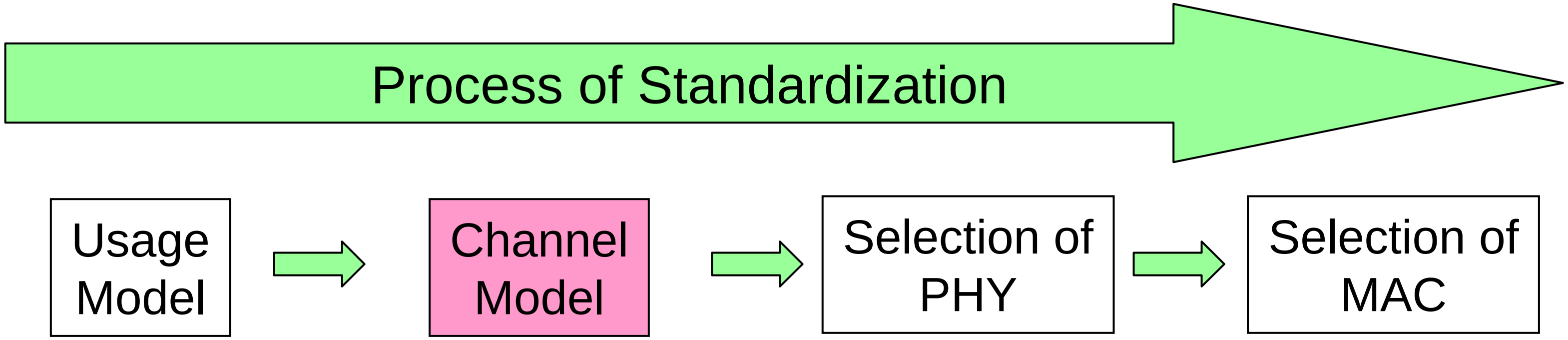
Contents

- Introduction to body area network (BAN)
- Channel models for BAN
  - **Specific features and modeling strategy**
  - Preliminary results

Requirements for Channel Models

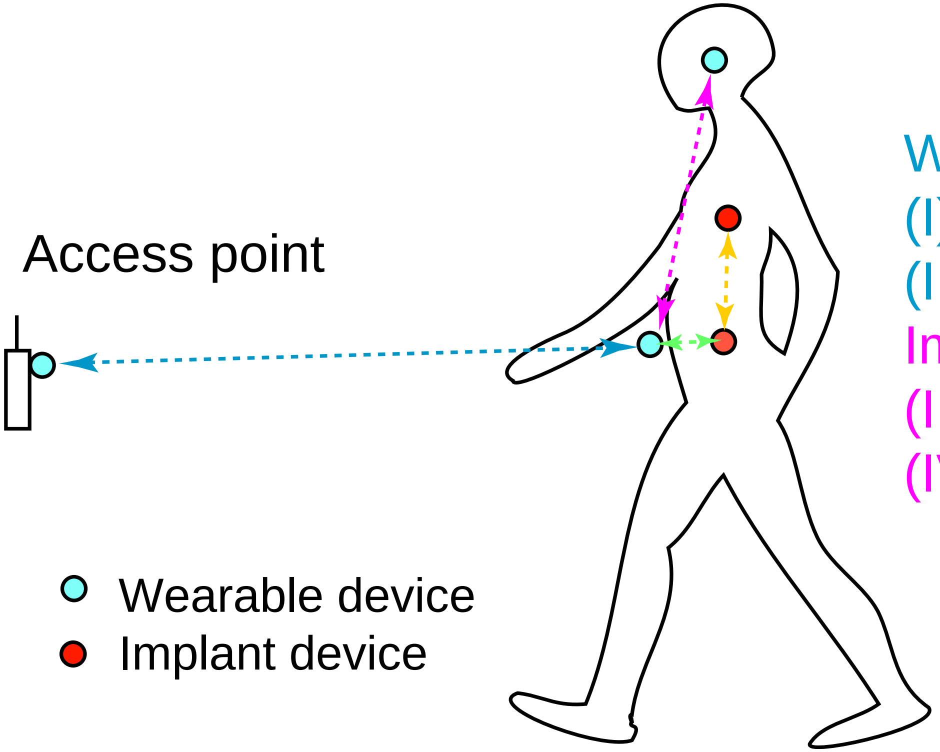
- Useful for link budget calculation
  - Propagation path loss
- Transmission simulation at PHY/MAC levels
  - Monte Carlo simulation of dynamic impulse responses
- Relevant to usage scenarios
  - “standard” scenarios in consensus

Role of Channel Model in Standardization



Evaluation of PHY property by using channel model simulating the usage scenario

Classification of BAN Channel Models



Wearable BAN
(I) Access point – Wearable device
(II) Wearable device – Wearable device
Implant BAN
(III) Wearable device – Implant device
(IV) Implant device – Implant device

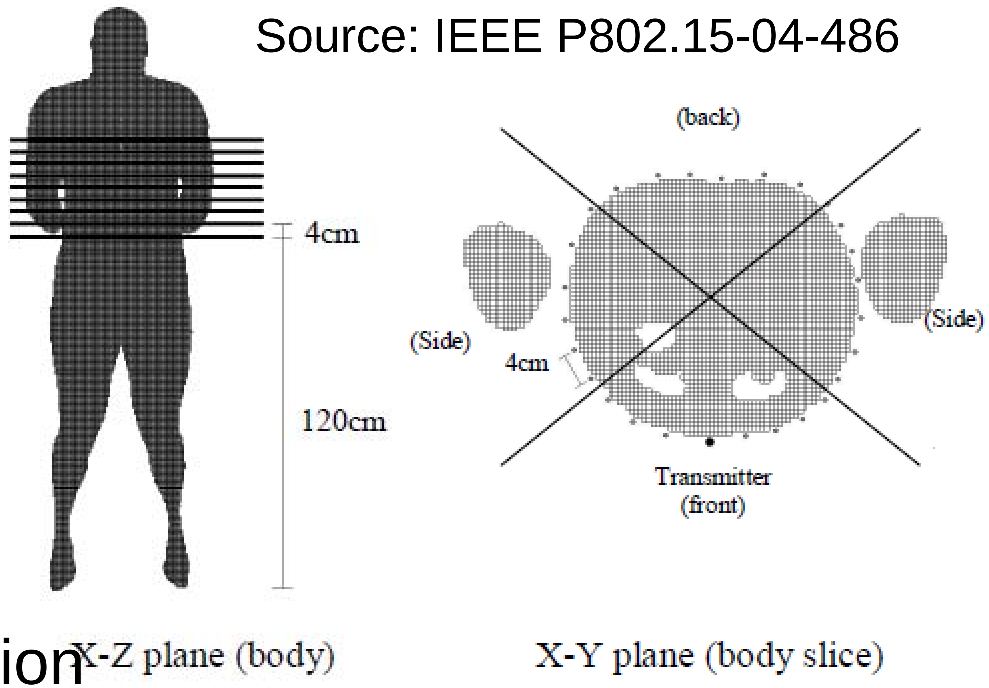
(I) may be interpreted as PAN channel, but is yet classified as BAN channel as these four cases are integrated into a whole BAN system.

Existing BAN Channel Model

IEEE802.15.4a
(low-rate UWB)

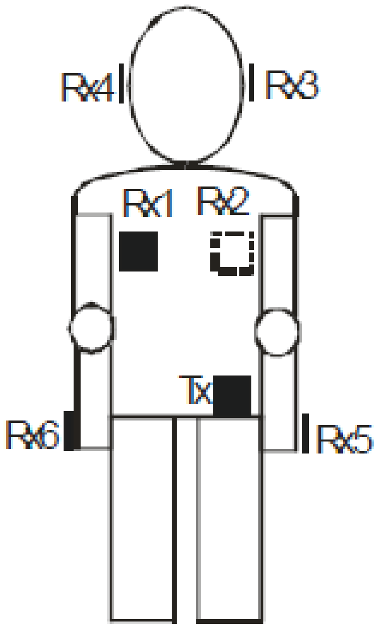
- Path loss +
  delay profile
- FDTD simulation
- Human torso only
- Without antenna
  - Direct E-field application
- Propagation loss factor:
  107.8 dB/m

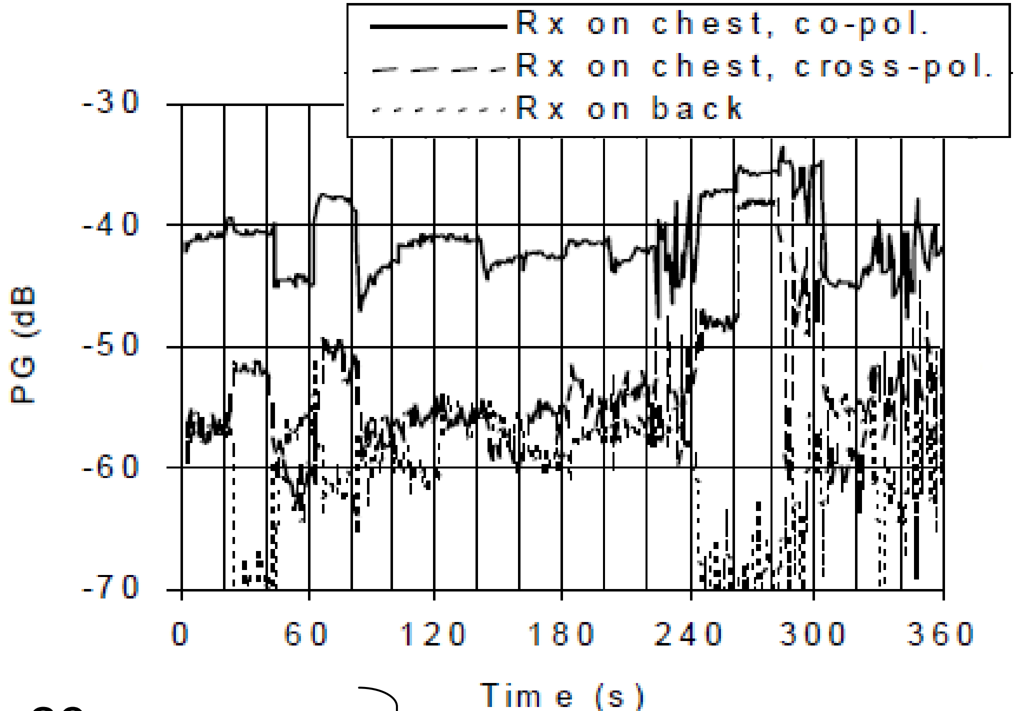
Source: IEEE P802.15-04-486



Phantom from
US Visible Human Project

Existing BAN Channel Model





Different Postures for every 20 sec.

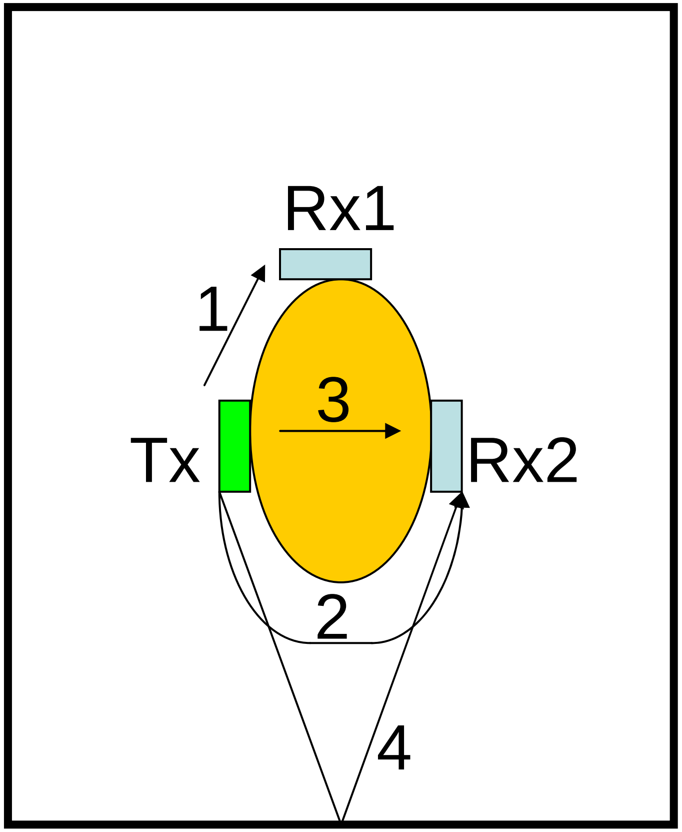
- Big change due to shadowing
- Minor impact from breath and heart beat

These results are not yet relevant for channel model.

Y. Hao, et.al., "Antennas and propagation for body centric wireless communications," in Proc. IEEE/ACES 2005, pp. 586-589,

Major Propagation Mechanisms

1. Direct path (LOS)
2. Body surface path (NLOS)
3. Penetration (dominant for implant)
4. Scattering from surroundings (more dominant than 2 in NLOS)



Attenuation of 20-40 dB due to shadowing

Significant Differences of BAN Channel from Conventional Channel

Conventional channel

- Ideal antenna
  - V-pol omni

or

- Directional channel
  - Convolution between directivity and angular power spectrum

BAN channel

- Mutual interactions between body and antenna
  - Distortion of directivity
    - Null appearance
  - Loss due to body
    - Absorption, mismatch
    - Distance dependence
  - Polarization rotation due to installation
  - Types of antennas
    - Electric type / magnetic type
    - Antenna size
  - SAR limit

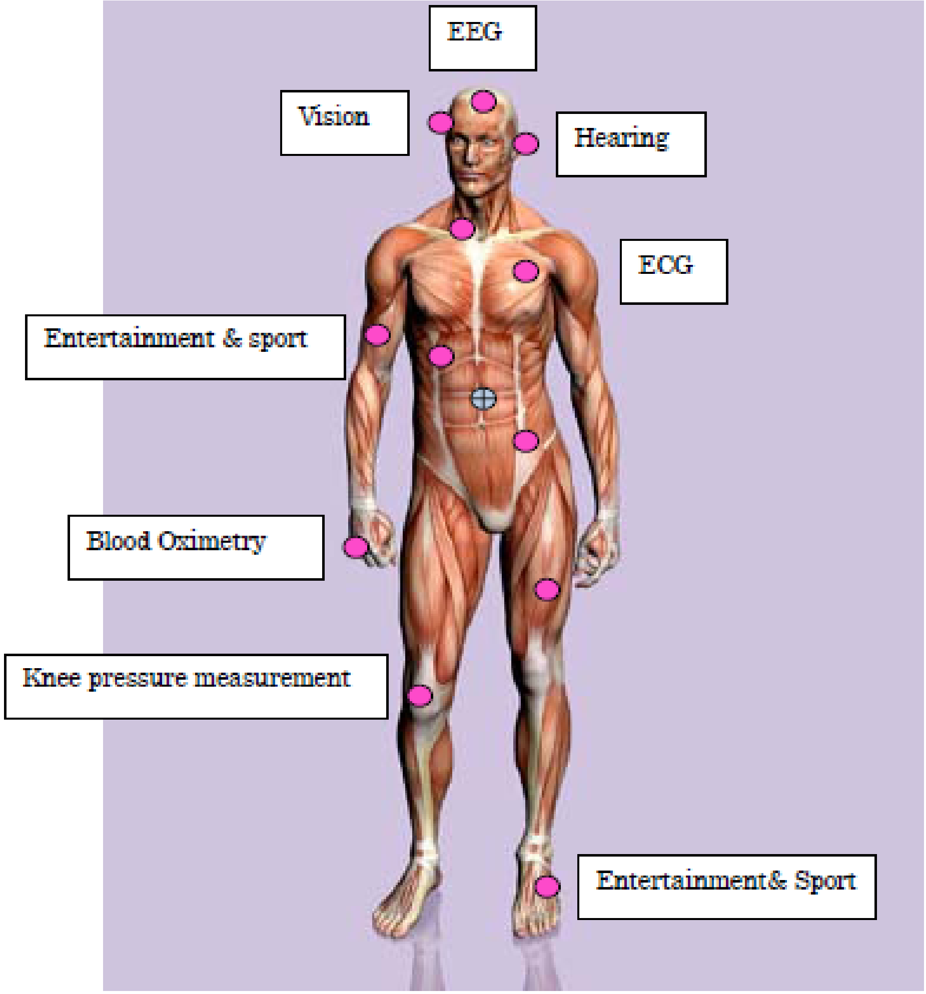
Channel Sounding Systems

- Vector network analyzer (VNA)
  - Wideband
  - Static
- SG + Real time spectrum analyzer
  - Narrowband
  - Dynamic
- Pulse generator + Oscilloscope
  - Wideband
  - Dynamic
  - Small dynamic range

Each system has its pros and cons.

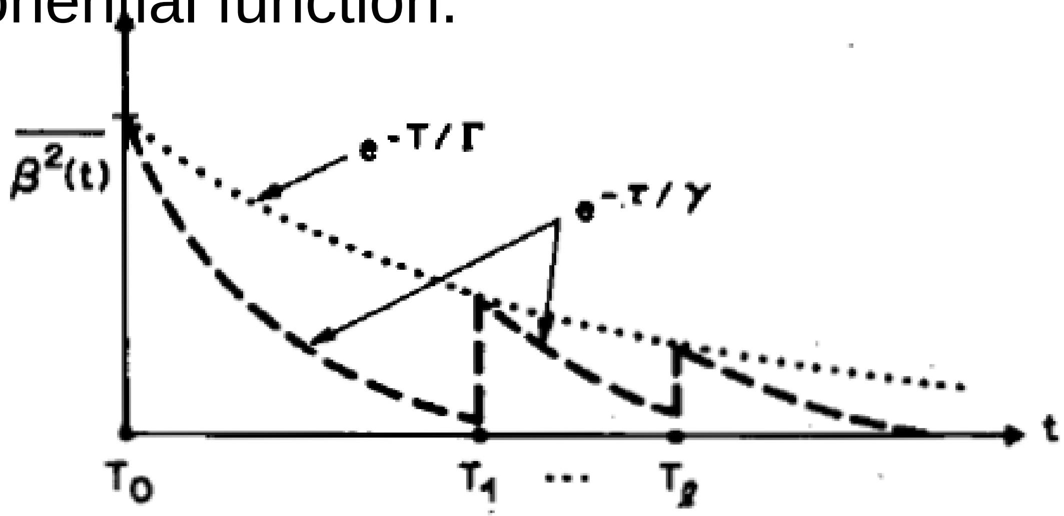
Question on Modeling of Path Loss

- Path loss is defined along body surface in IEEE802.15.4a.
- Sensors are not arbitrarily placed.
  - Specific positions for specific sensors
- Distance depends on distance.



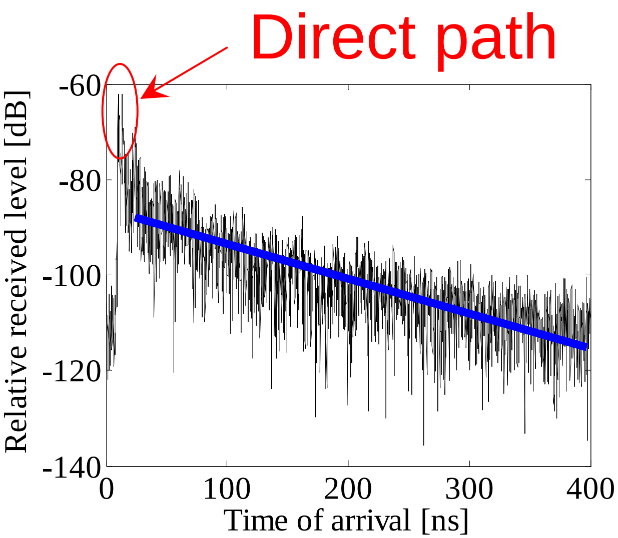
Modeling of Impulse Response

- Saleh-Valenzuela (SV) cluster model is commonly used among IEEE802.
  - Delay profile of clusters is modeled by exponential function.
  - Delay profile within a cluster is modeled by exponential function.

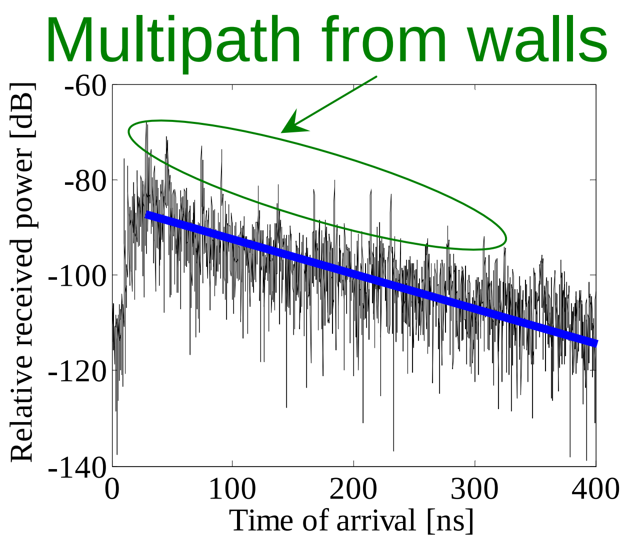


A. Saleh and R. Valenzuela, IEEE JSAC, Vol. 5, No. 2, pp. 128-137, Feb. 1987.

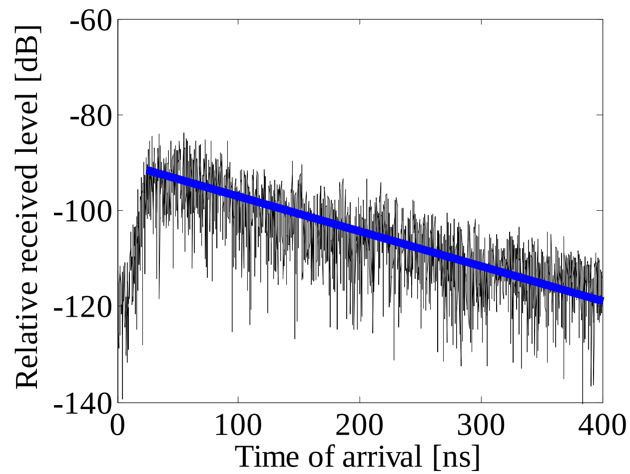
Example of AP – WD Channel in Office [5]



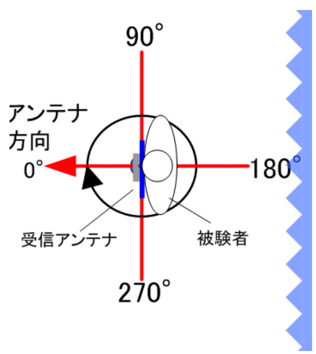
AP: 0 deg（LOS）



AP: 90 deg (Soft NLOS)

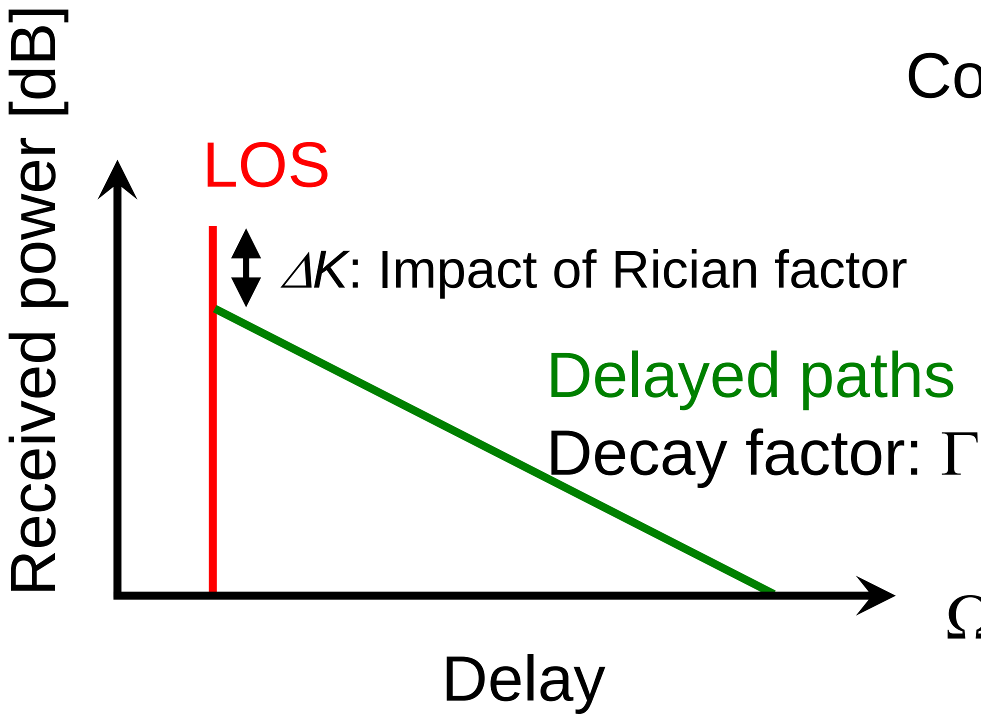


AP: 180 deg (NLOS)



- Exponential decay of multipath component
- Direct path detected in LOS
- Multipath from side walls in Soft NLOS
- Rich in delay paths (30 dB/400 ns)

Example of AP – WD Channel in Office [5]



Complex impulse response

$$h(t) = \sum_{m=0}^{\infty} \alpha_m \delta(t - \tau_m)$$

$$\overline{|\alpha_m|^2} = \Omega_0 e^{-\tau_m/\Gamma - k[1-\delta(m)]}$$

$$\angle \alpha_m \propto \mathrm{Uniform}[0, 2\pi)$$

Ω_0 : determined by path loss

Exponential decay model considering Rician factor

Issues of BAN Channel Modeling

Impulse response

- Stochastic model is less applicable for shorter range.
  - Difficulty in generalization due to large variation for individual cases
- Size and motion of human body may be taken into account for the BAN channel modeling instead of pure stochastic modeling.

Contents

- Introduction to body area network (BAN)
- Channel models for BAN
  - Specific features and modeling strategy
  - **Preliminary results**

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

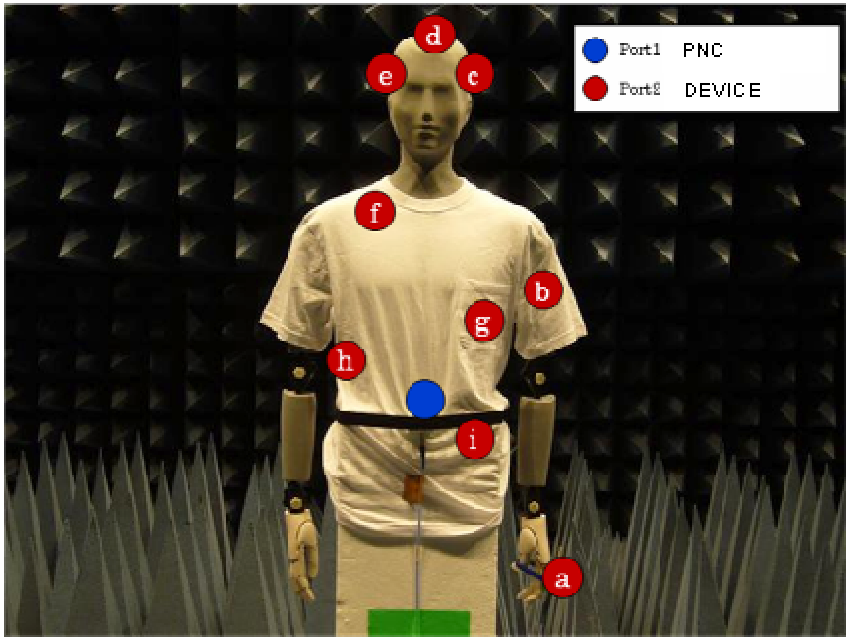
- Frequency bands and antennas

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

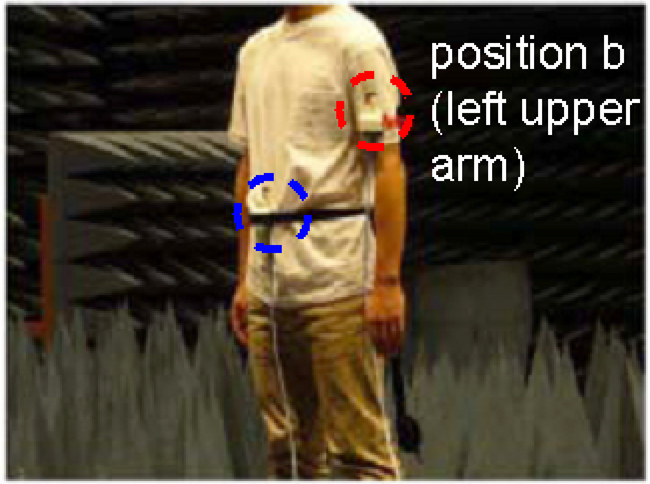
- Human body
  - male, height = 171 cm, weight = 63 kg

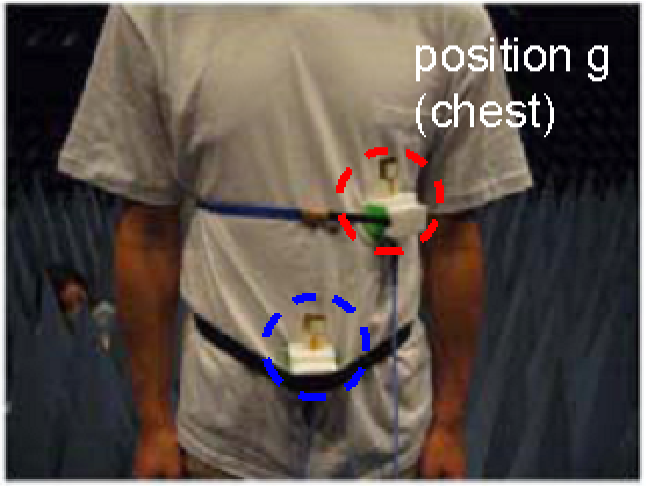
Measurement setup

- Measurement positions



a	left wrist	f	shoulder
b	left upper arm	g	chest
c	left ear	h	right rib
d	head	i	left waist
e	right ear		





Measurement setup

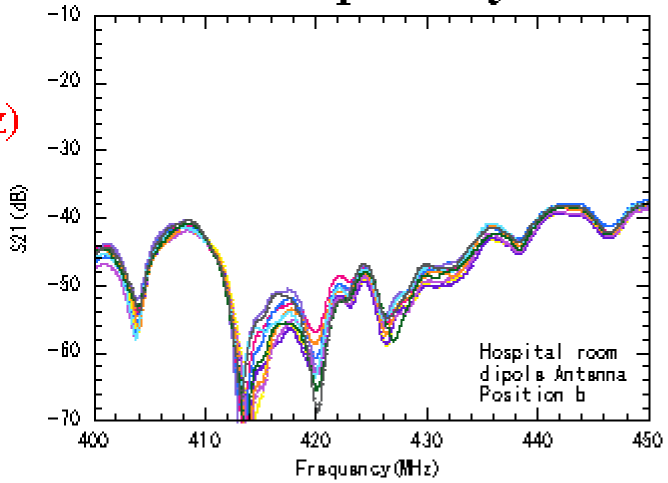
- Measurement environments
  1. Hospital room (Size: 7.0 m x 9.0 m x 2.5 m)

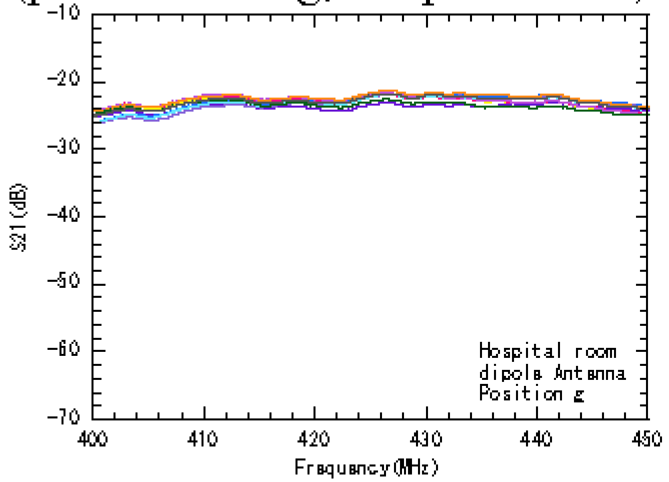
  2. Anechoic chamber
     – without reflections from the floor

Measurement results

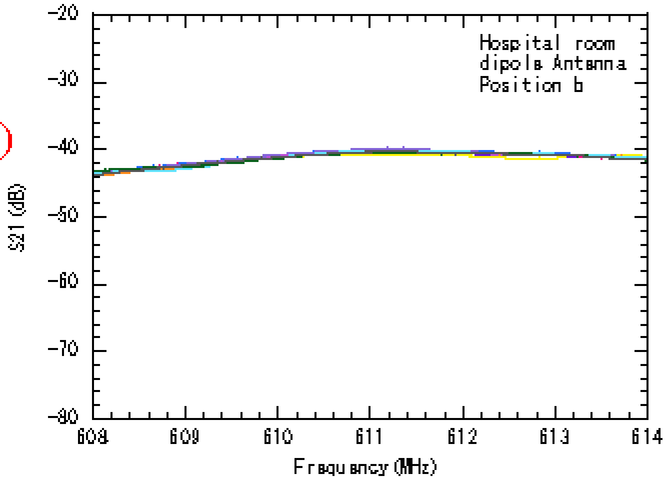
- S21 for each frequency band (position b & g, hospital room)

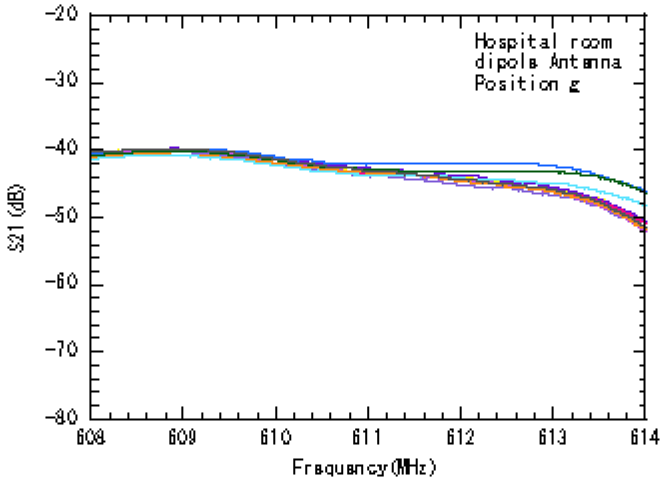
400 MHz
(400-450MHz)
(10 samples)





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



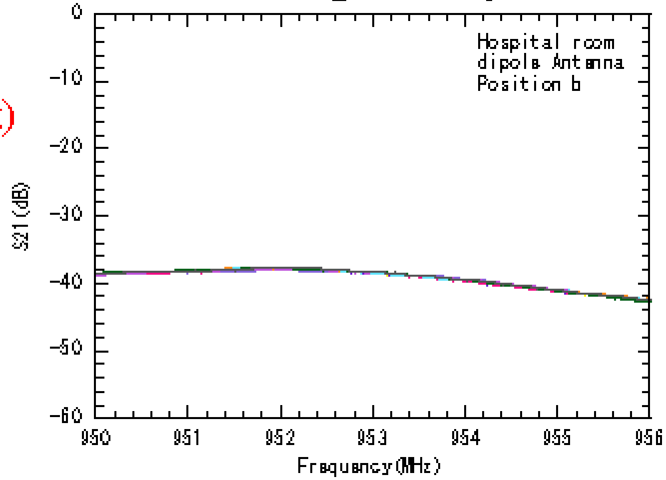


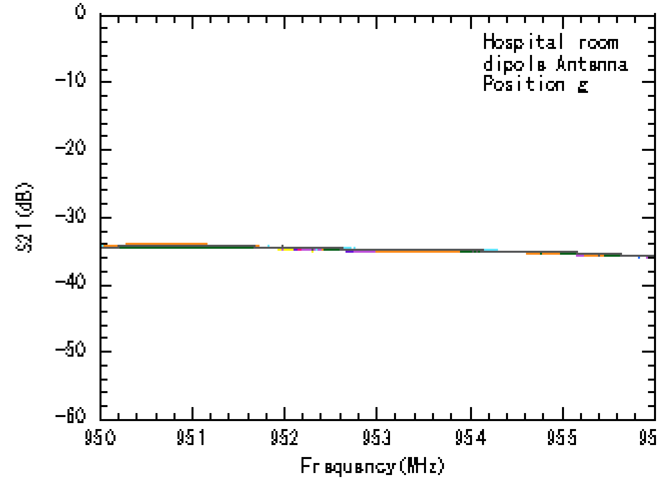
Measurement results

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

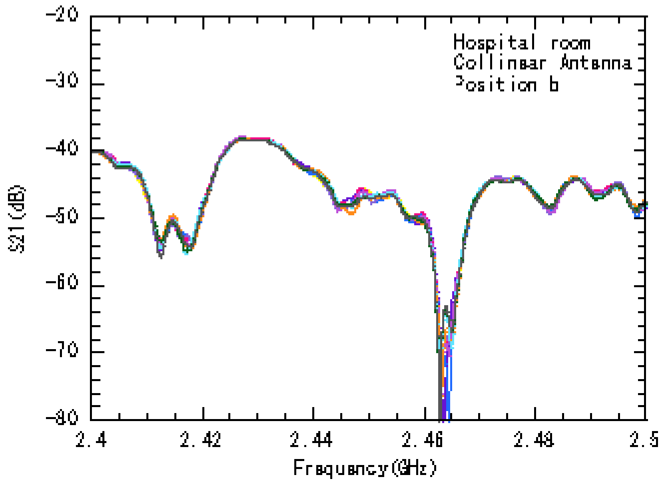
900 MHz
(950-956MHz)

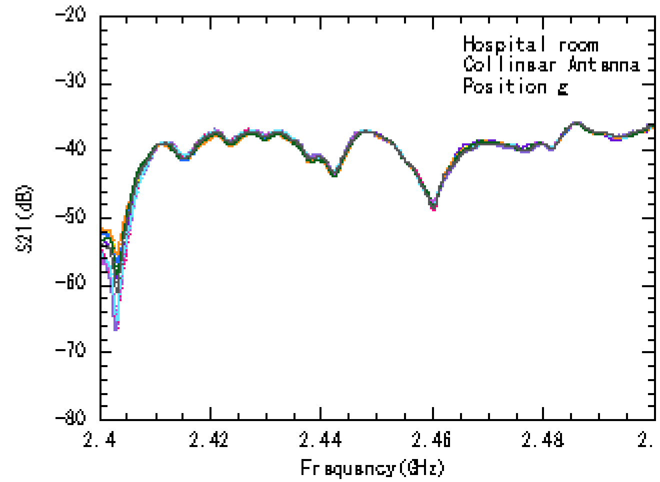
(10 samples)





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

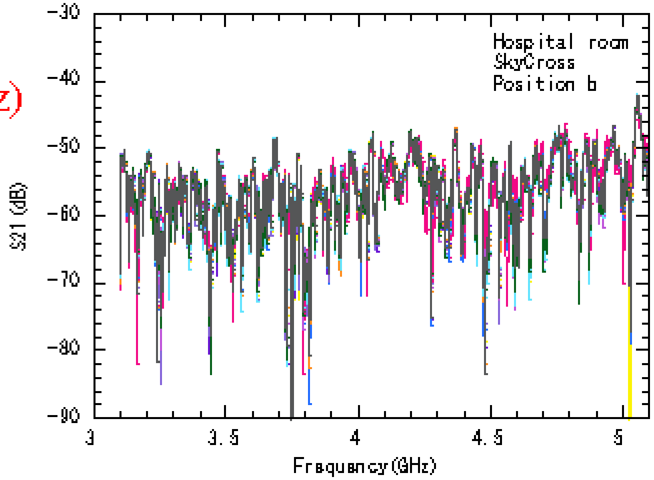


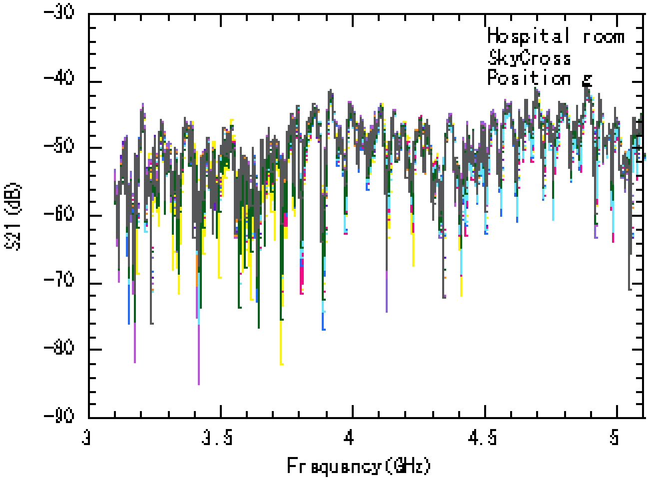


Measurement results

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

UWB
(3.1-5.1GHz)
(10 samples)

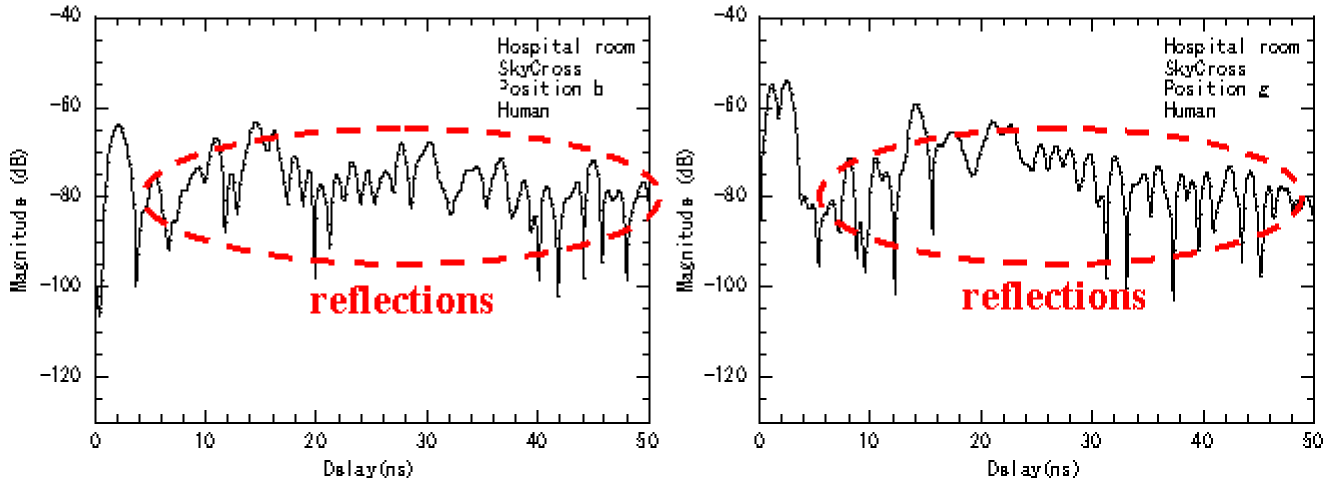




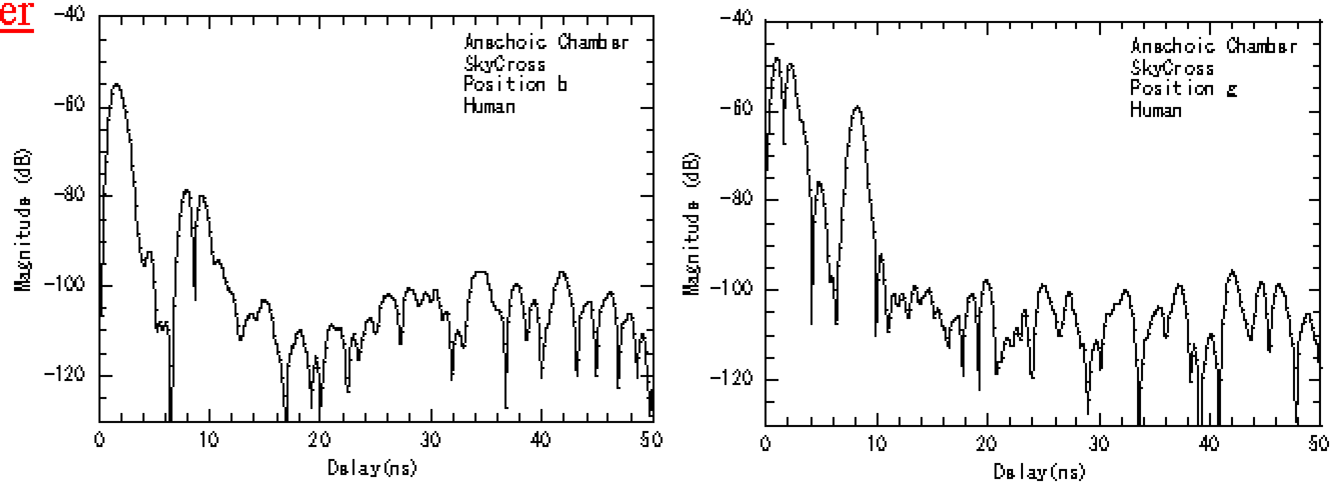
Measurement results

- 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 $[0, 2\pi)$
- 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

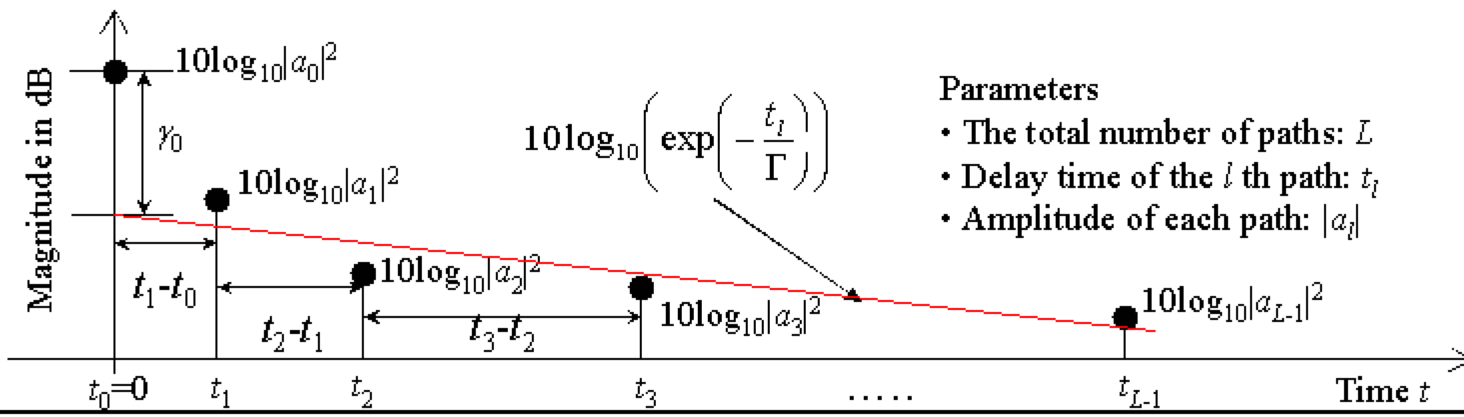
$$10\log_{10}|a_l|^2 = \begin{cases} 0 & l = 0 \\ \gamma_0 + 10\log_{10}\left(\exp\left(-\frac{t_l}{\Gamma}\right)\right) + S & l \neq 0 \end{cases}$$

- 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



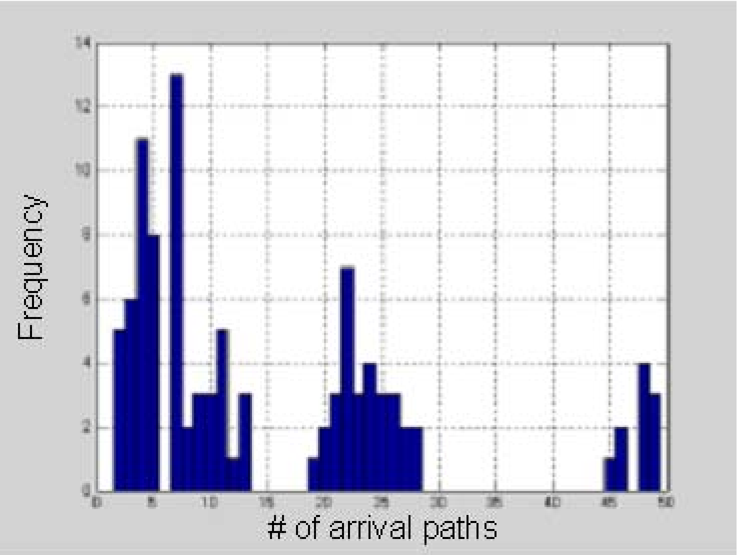
Parameters
- The total number of paths: L
- Delay time of the l th path: t_l
- Amplitude of each path: $|a_l|$

WBAN channel model - power profile model -

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

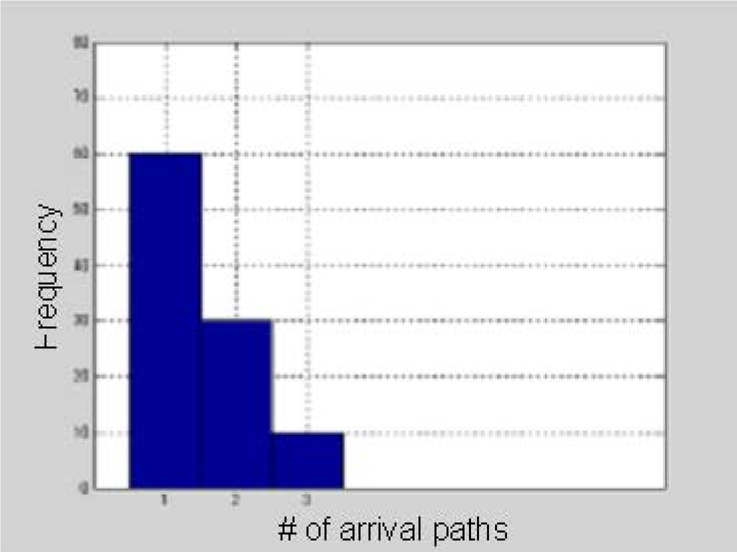
Hospital room

parameters	value
$\overline{L}$	15.6



Anechoic chamber

parameters	value
$\overline{L}$	1.5



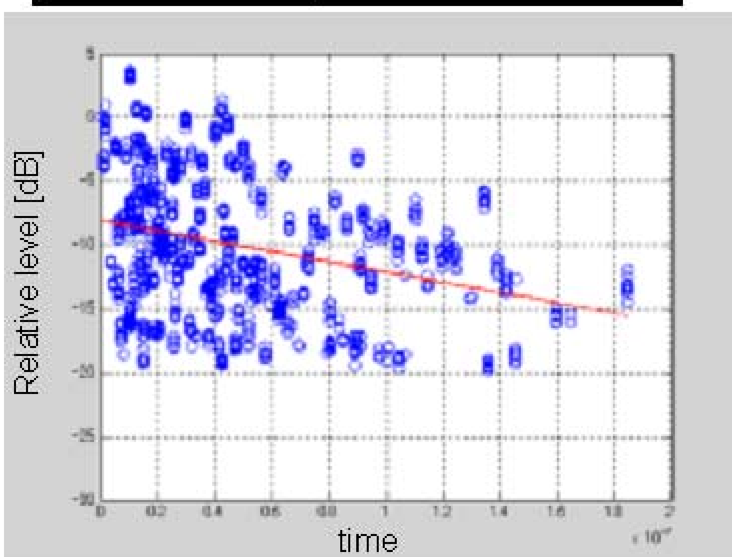
WBAN channel model - power profile model -

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

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

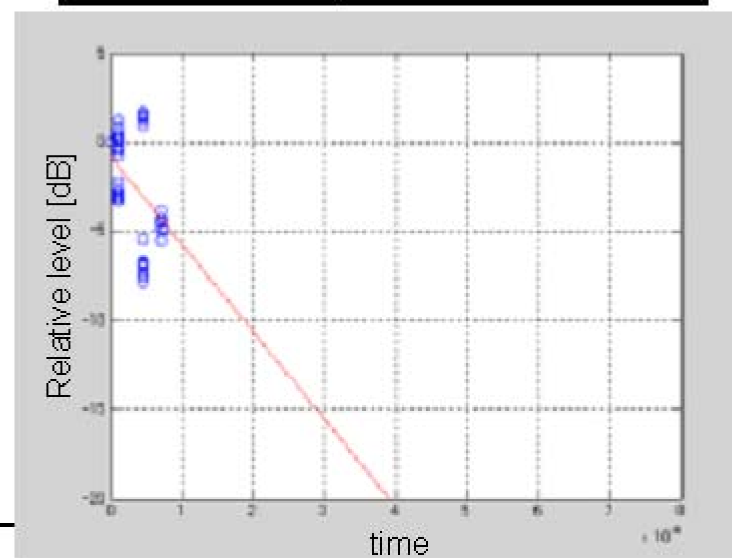
Hospital room

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



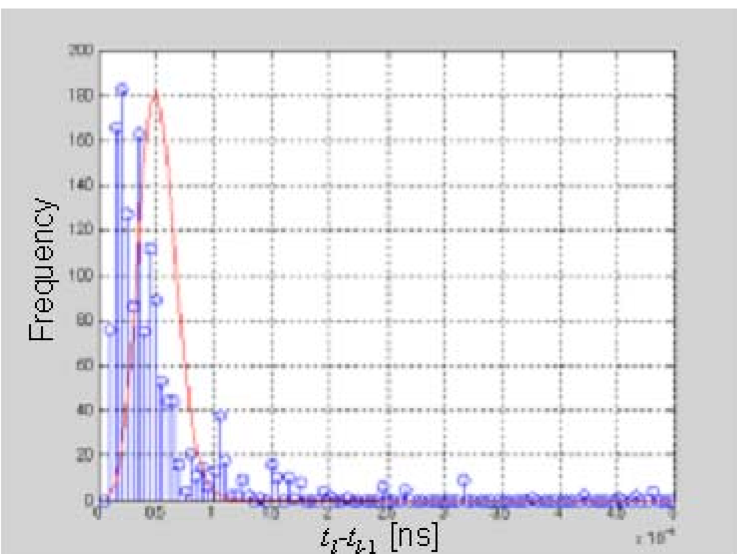
WBAN channel model - power profile model -

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

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

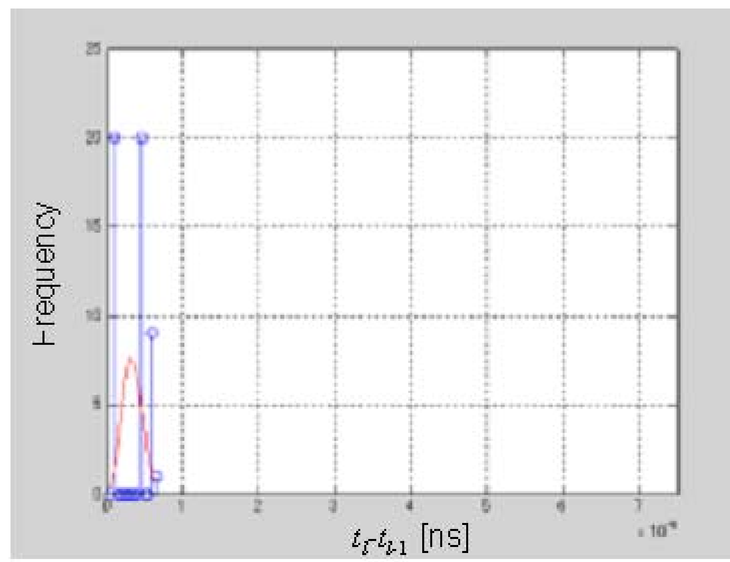
Hospital room

parameters	value
λ	5.17 ns



Anechoic chamber

parameters	value
λ	6.82 ns

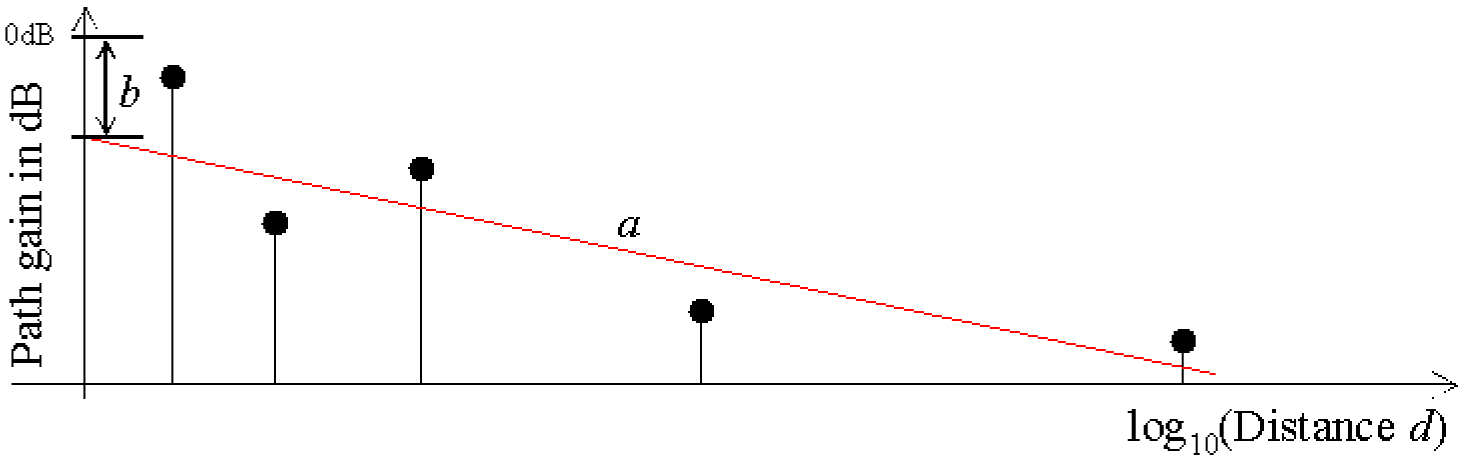


WBAN channel model - path gain model -

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

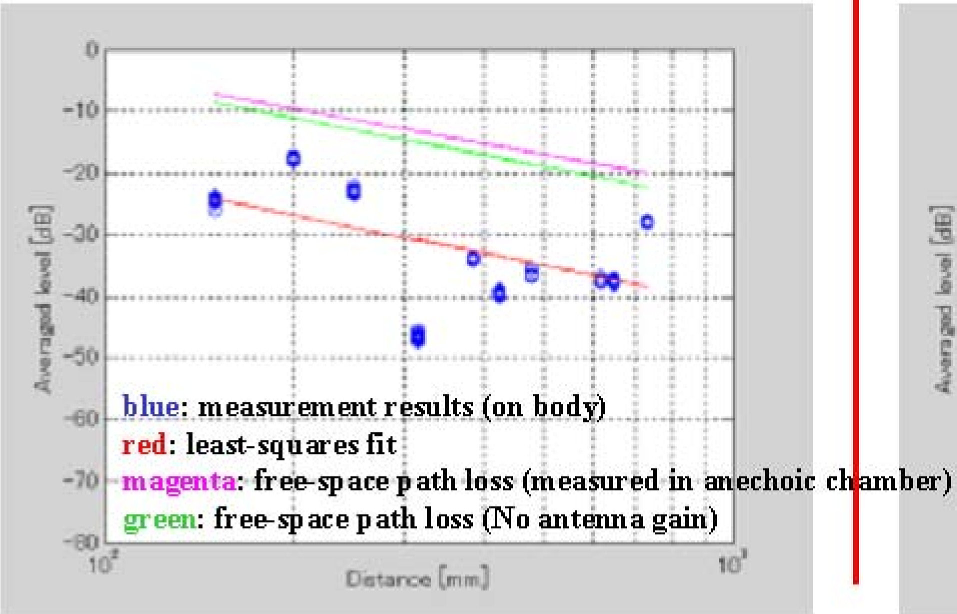


Path gain model 400 MHz

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

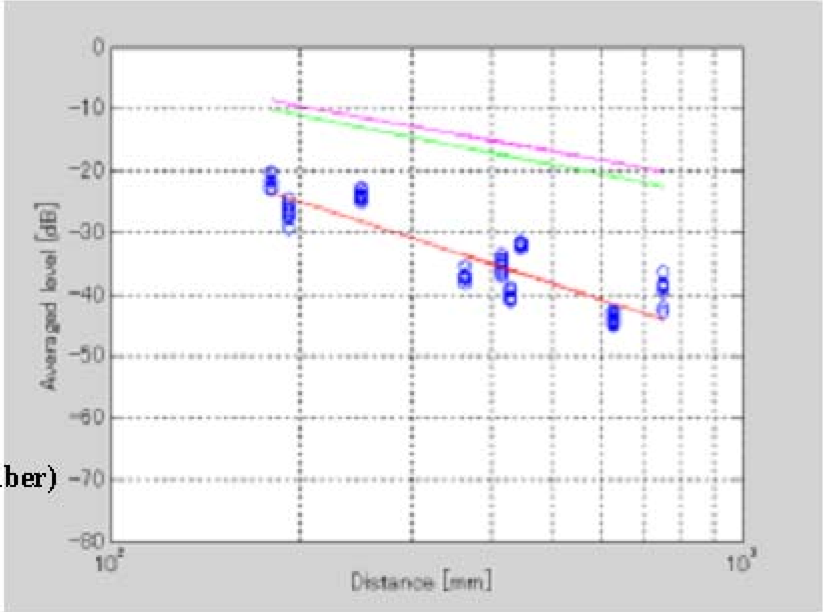
Hospital room

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

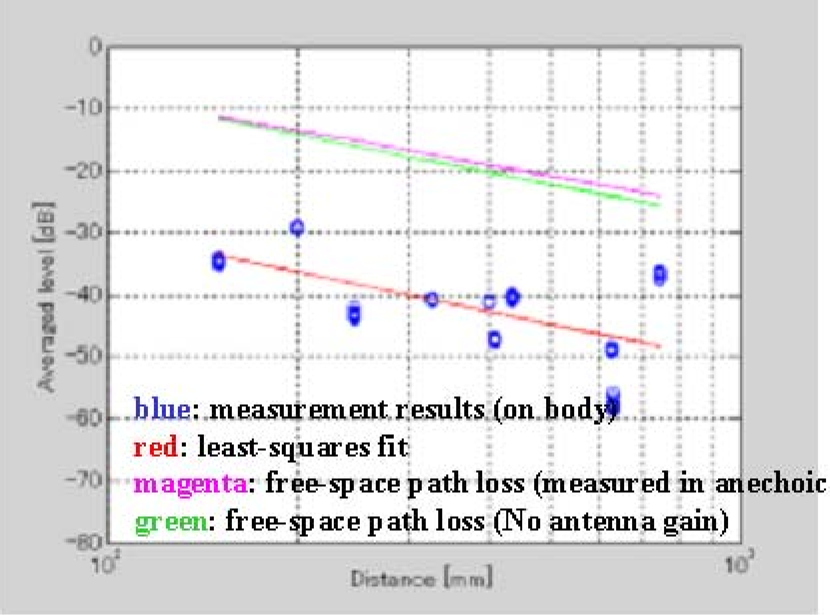


Path gain model 600 MHz

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

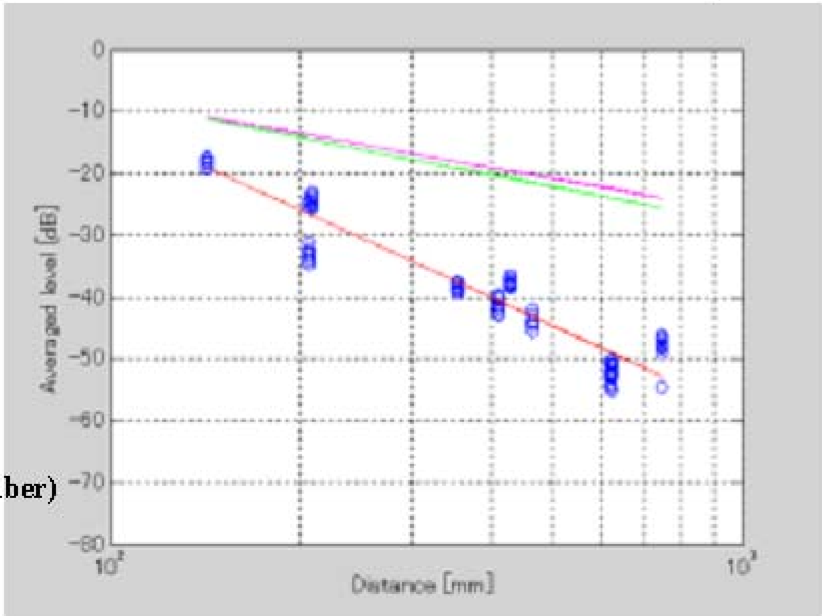
Hospital room

Parameters	value
a	-19.8
b	9.2
σ_N	5.4



Anechoic chamber

Parameters	value
a	-46.9
b	81.9
σ_N	3.2

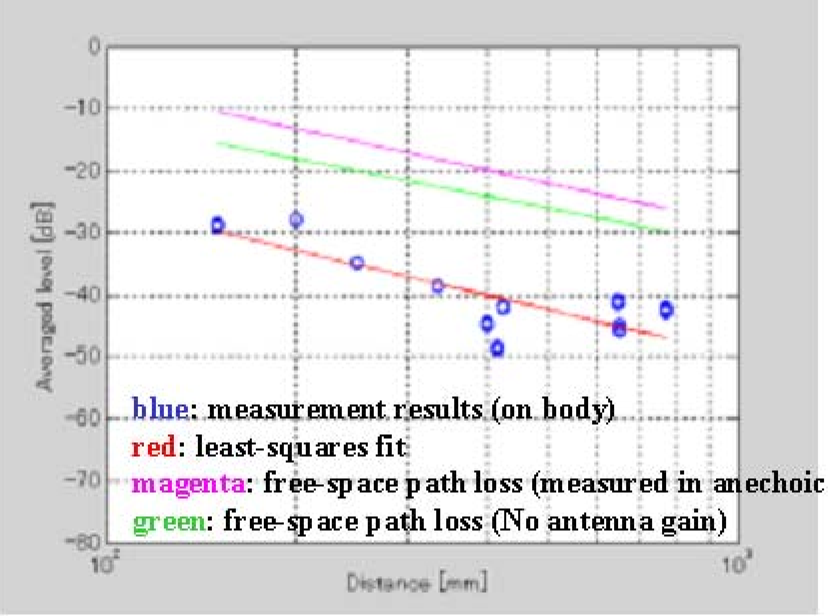


Path gain model 900 MHz

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

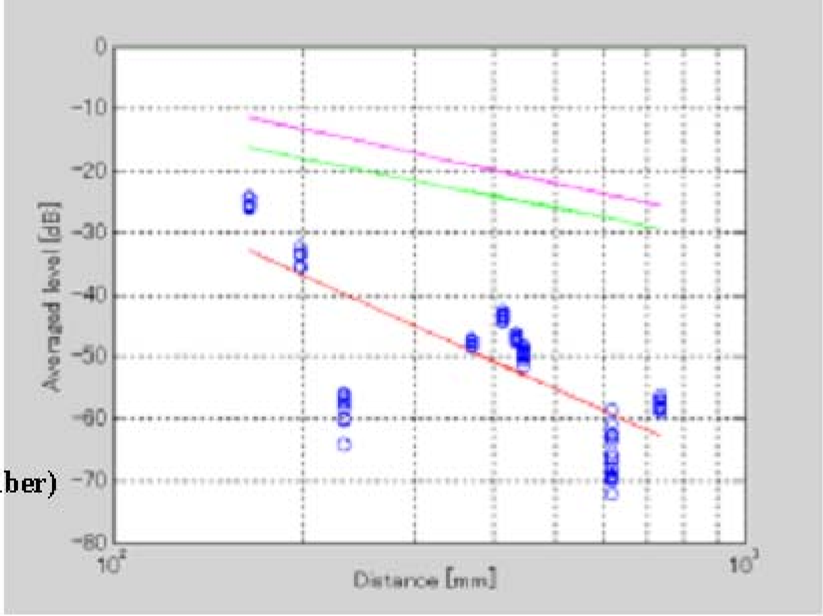
Hospital room

Parameters	value
a	-23.3
b	20.7
σ_N	4.1



Anechoic chamber

Parameters	value
a	-45.8
b	68.6
σ_N	8.1

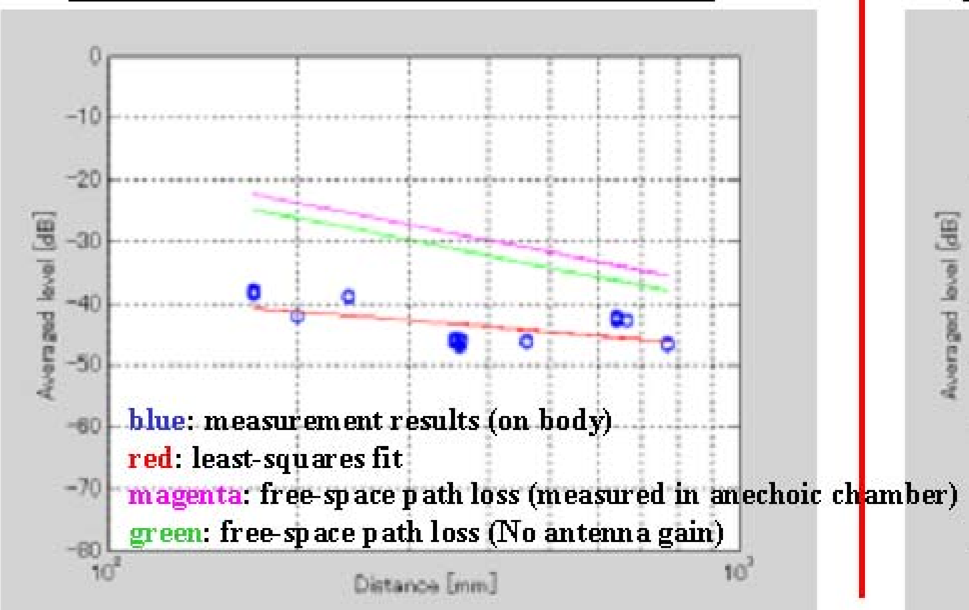


Path gain model 2.4 GHz

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

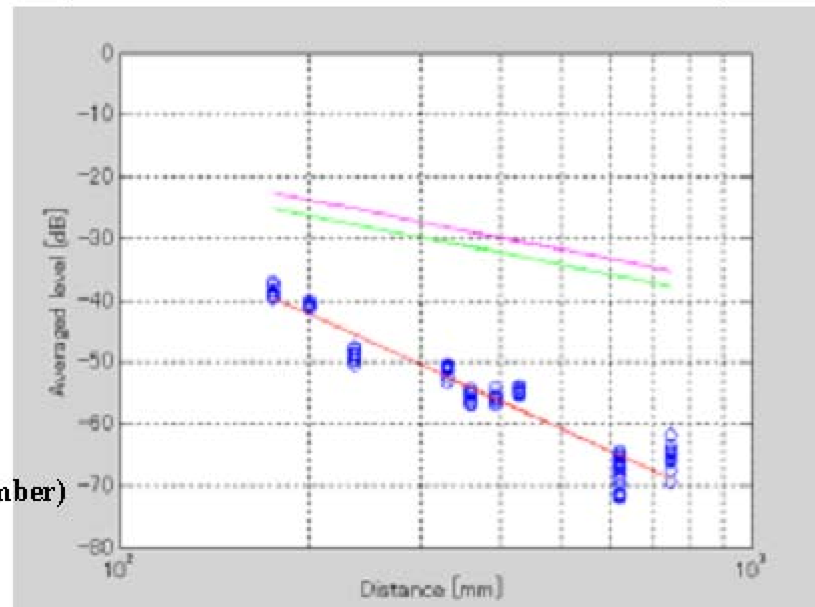
Hospital room

Parameters	value
a	-8.6
b	-20.3
σ_N	2.0



Anechoic chamber

Parameters	value
a	-46.1
b	63.7
σ_N	2.6

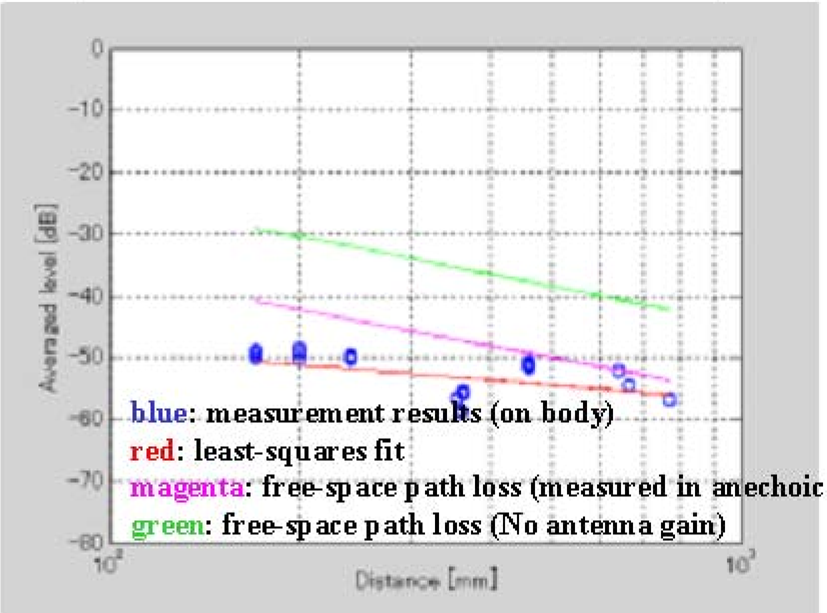


Path gain model UWB

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

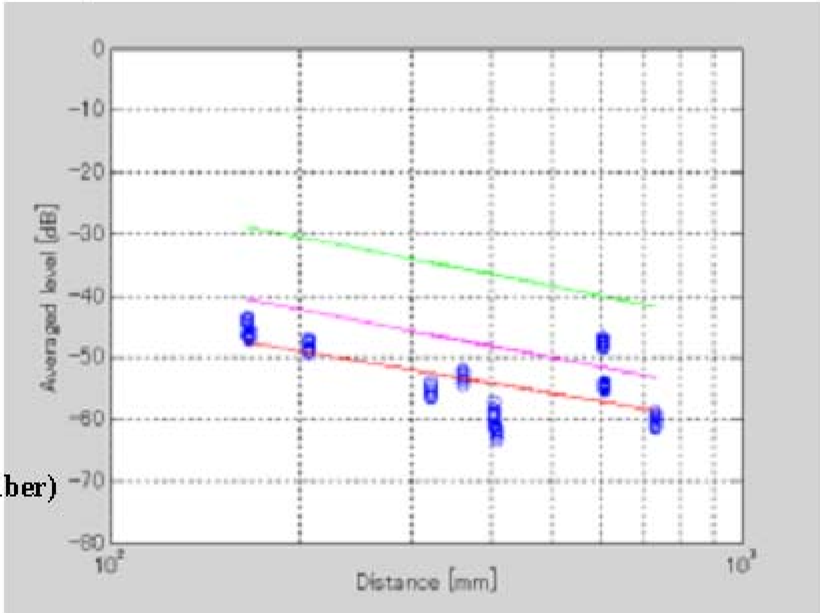
Hospital room

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

Conclusions

Body Area Network for Medical and Healthcare Applications

- Introduction to body area network (BAN)
  - Applications
  - New standard – IEEE 802.15.6
  - Regulatory
- Channel models for BAN
  - Specific features and Modeling strategy
  - Preliminary results

Future Issues

- Antenna design strategy
  - Integration and miniaturization
  - Impedance matching
  - Body loss reduction
  - SAR reduction
  - Directivity

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2. “Project Authorization Request for P802.15.6 (draft),” IEEE P802.15-07-0575-09-0ban.
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4. “TG6 Objectives and Agenda March 2008,” IEEE P802.15-08-0101-05-0006.
5. H. Sawada et.al., “Review of Body Area Network Channel Model", 2007 IEICE General Conf., BS-9-3, March 2007.