Investigation of antenna diversity effect on BAN coordinator

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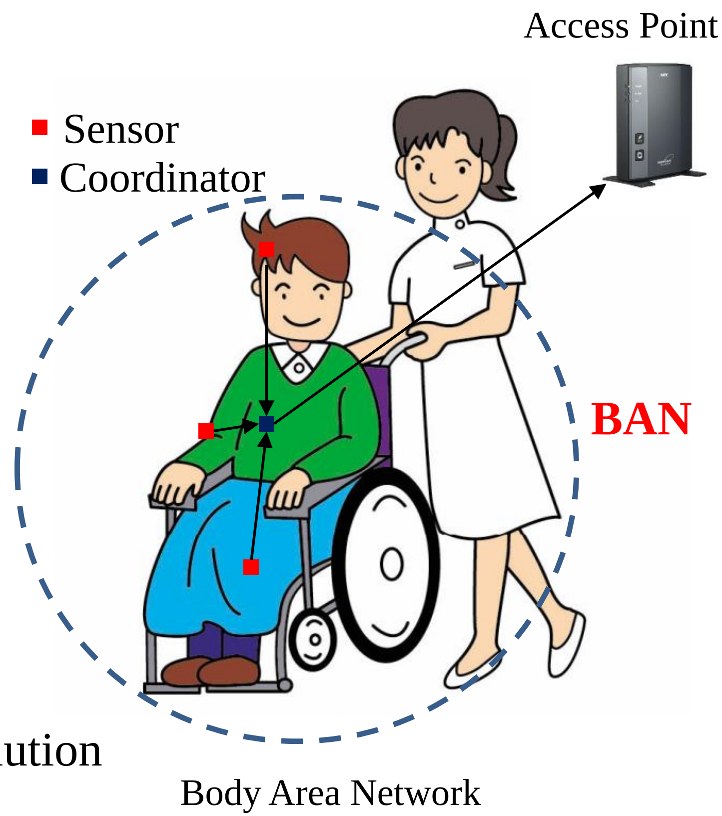
MCRG seminar

Background

- Body Area Network (BAN)
  - Communication between nodes located in, on or around the human body
  - Expected to find wide applications especially in medical/healthcare



- IEEE 802.15.6
  - Standards for BAN
  - UWB
    - Wideband system specification
    - Low power consumption
    - Long-term use by battery
    - RAKE reception utilizing high time resolution

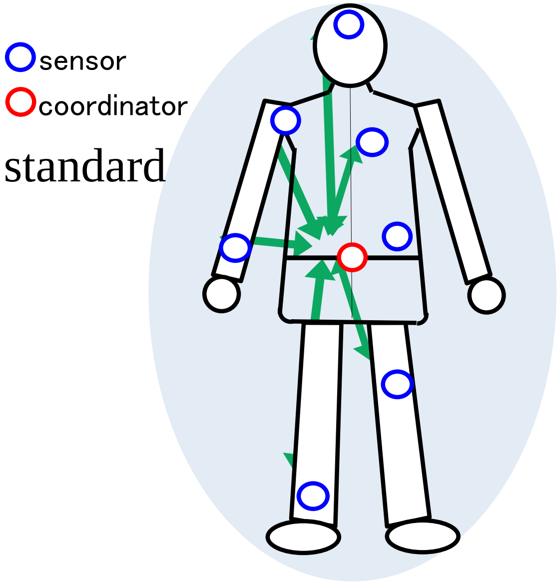
Background

- Vital data sensor and coordinator node
  - Sensor node
    - Collecting vital data
  - Coordinator node
    - Collecting vital data from sensor node
    - Degree of freedom in power consumption and volume for implementation
- Tasks
  - Continuous collection of vital data
    - Prevention of disruption of communication by shadowing of human body
      - Consideration of channel propagation affected by the body posture and movement
    - Construction of high reliable system
      - RAKE reception
      - Antenna diversity using multiple antennas
      - Regulation in power and volume

Objective

- Consider RAKE reception and antenna diversity for performance improvement
  - Consider RAKE reception utilizing specification of UWB
  - Consider antenna diversity using multiple antennas at coordinator node
    - Sensor node is regulated in power and its volume
    - Utilize degree of freedom of coordinator node

  - Assume the attaching position on the waist belt
    - Easy to communicate with all the sensors in IEEE standard
      - Located at center of the body
    - Low sense of discomfort for attachment
      - Possible to be used for monitoring in daily life



Investigate the effect of RAKE reception and antenna diversity

Contents

- Use outage probability as evaluation criteria
  - This research calculated analytical probability in the following situations

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Antenna diversity</td></tr>
<tr><td>Without</td><td>With</td></tr>
<tr><td rowspan="2">RAKE reception</td><td>Without</td><td>①</td><td>③</td></tr>
<tr><td>With</td><td>②</td><td>④</td></tr>
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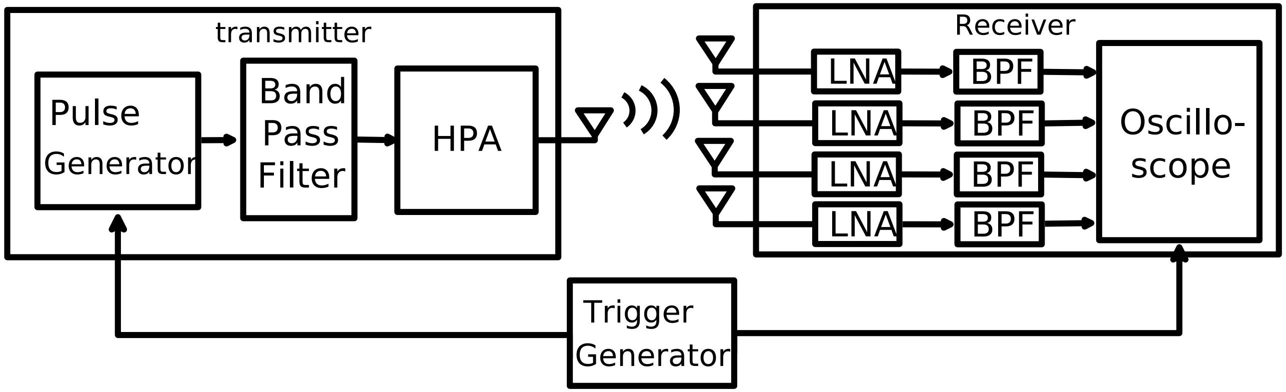
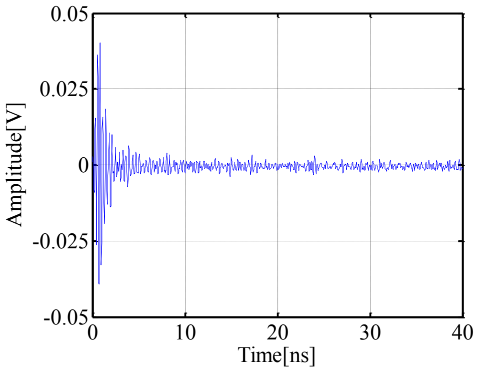
Measurement System



Measurement system



Transmit signal

Transmitter

- Pulse generator (PG)
- Band Pass Filter (BPF)
  - Frequency band:3.0-4.8 GHz
- High Power Amplifier (HPA)

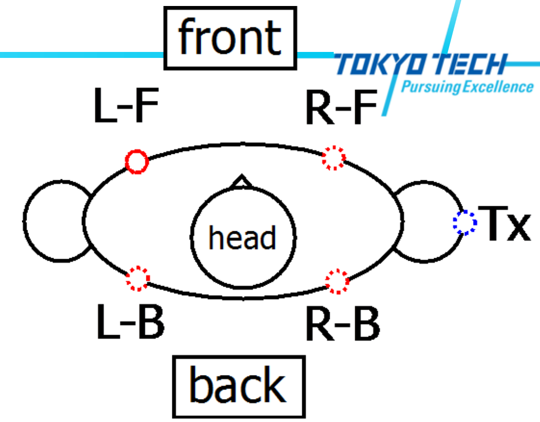
Receiver

- Low Noise Amplifier (LNA)
  - Gain : 40 dB
- Band Pass Filter (BPF)
  - Frequency band:3.0-4.8 GHz
- Digital storage Oscilloscope (DSO)
  - Sampling rate : 25 G samples/sec
  - 4 Ports

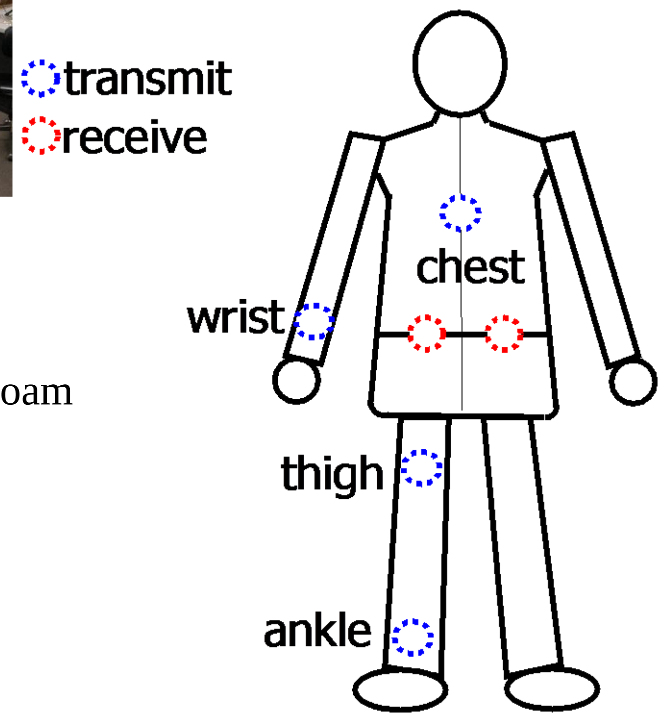
- Low band UWB (3.4～4.8GHz) is used as frequency band
- The data acquisition timing at the receiver was synchronized with the pulse repetition at transmitter by using common clock source

Measurement Setup

- Antenna position
  - Transmission : wrist, chest, thigh, ankle
    - Reception (4 antennas) : on the waist belt



Top view

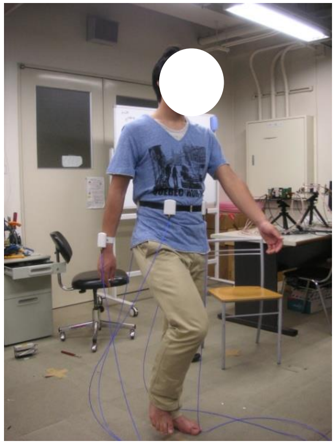


Front view

- Antenna
  - Skycross SMT-3TO10M-A (Omnidirectional antenna)
  - Attached 1cm away from body surface by polystyrene foam

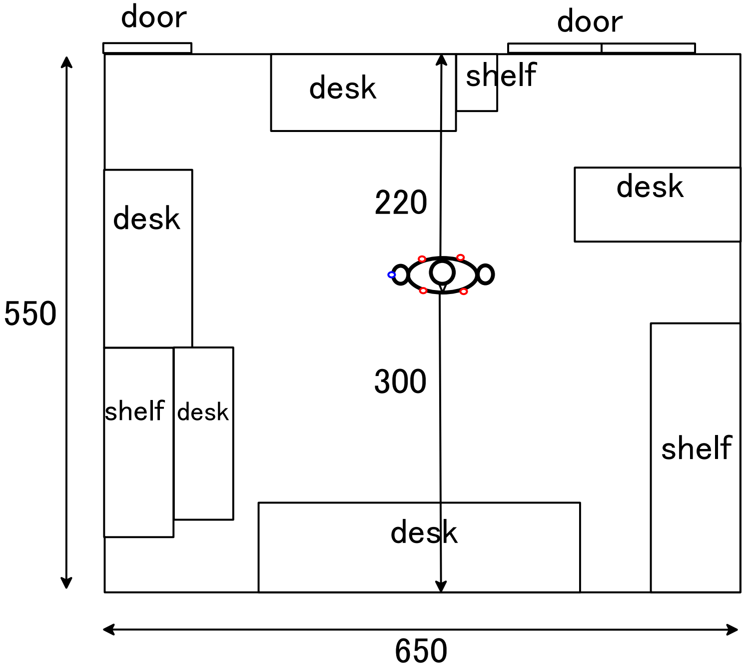
Measurement Setup

- Posture
  - Walk
  - Standing up and sitting down
- Subject (2 persons)
  - 165 cm, 68 kg
  - 180 cm, 65 kg



- Use the data including 2 persons and 2 postures statistically

- Place: Experiment room in Tokyo Tech
  - Regarded as office environment
  - Size : 5.5 m × 6.5 m
  - Ceiling height : 2.7 m ～3.3 m



Floor plan of the experiment room

System Evaluation

- Use outage probability as evaluation criteria
  - Outage probability can be obtained by path gain from experiment
  - Assume DBPSK as modulation scheme

Parameters in calculation

Parameter	Value
Bandwidth	499.2 MHz
Modulation scheme	DBPSK （Synchronous detection）
Packet size (N_b)	250 Bytes
Noise figure (NF)	12 dB
Implementation loss (Loss)	8 dB
Bit rate (BR)	487 kbps

Calculation Method

1. BER P_b

$$P_b = \mathrm{erfc}\left(\sqrt{\gamma_b}\right)$$

γ_b: SNR per bit

- SNR per bit: γ_b

$$\gamma_b = \frac{E_b}{N_0} = \frac{P_r}{BR} \cdot \frac{1}{N_0}$$

E_b: energy per bit
N_0: noise power spectrum density
BR: bit rate

- Receive power: P_r

$$P_{r\mathrm{dB}} = P_{t\mathrm{dB}} - NF - Loss + PG_{\mathrm{dB}}$$

P_t : transmit power
NF : noise figure
Loss : implementation loss
PG : path gain

- Noise power spectrum density : N_0

$$N_0 = k \cdot T$$

k : Boltzmann's constant (1.38×10^{-23}[J/K])
T : temperature（25℃、298K）

2. PER P_p

$$P_p = 1 - (1 - P_b)^{N_b}$$

N_b : Packet size

3. Outage probability P_{out}

$$P_{\mathrm{out}} = prob(\Gamma_p < P_p)$$

Γ_p : threshold （5% = 0.05）

Calculation Method of Path Gain

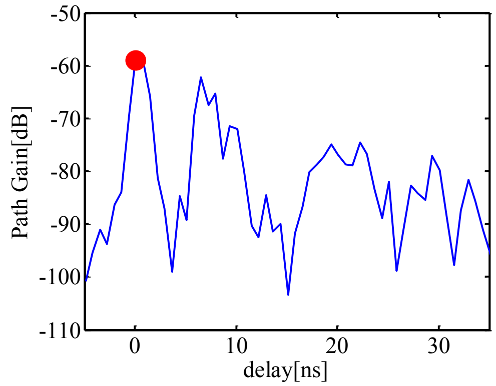
- Calculate path gain from impulse response measured in experiment

①Peak detection

- Obtain the peak of impulse response

$$PG^{peak} = -10\log_{10}\left(\max(|h(\tau)|^2)\right)$$

$h(\cdot)$: impulse response
τ : delay time

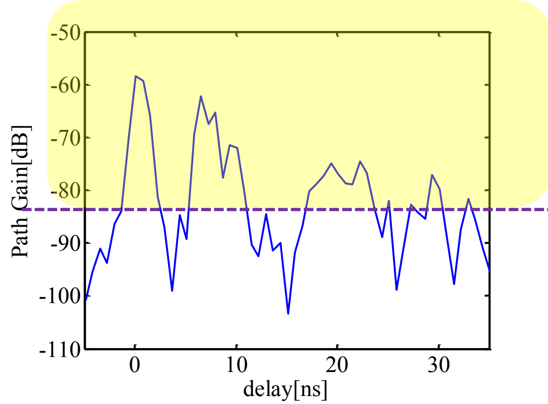


②Only use RAKE reception

- Sum all multipath components (All-RAKE reception)
- Sum each data which are above the threshold
- Threshold: -83.5 dB => Noise floor

$$PG^{ARake} = -10\log_{10}\left(\sum_\tau |h(\tau)|^2\right) \quad (h(\tau) \geq \alpha)$$

$h(\cdot)$: impulse response
τ : delay time
α : threshold



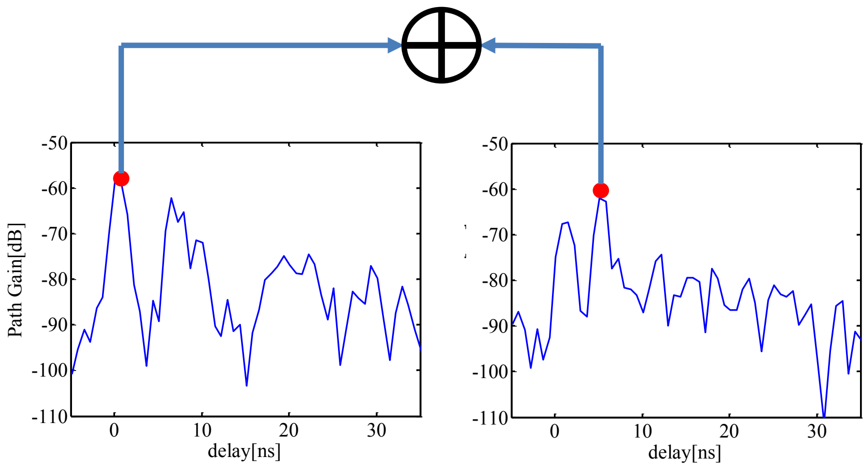
Calculation Method of Path Gain

③Only use antenna diversity

- Sum peak value at each antenna

$$PG^{Div} = -10\log_{10}\left(\sum_i\left(\max(|h_i(\tau)|^2)\right)\right)$$

$h_i(\cdot)$: impulse response at each antenna
τ : delay time
α : threshold
i : the number of antenna

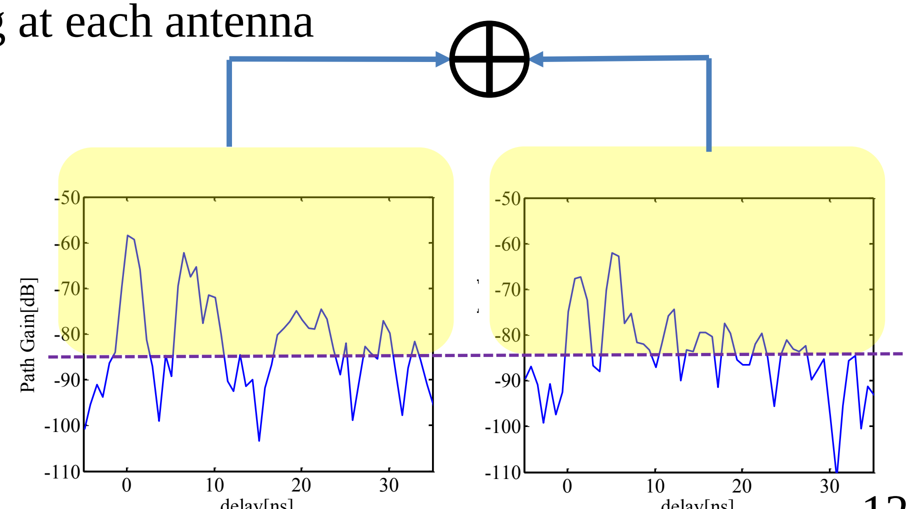


④ Use both RAKE reception and antenna diversity

- Sum result of RAKE combining at each antenna

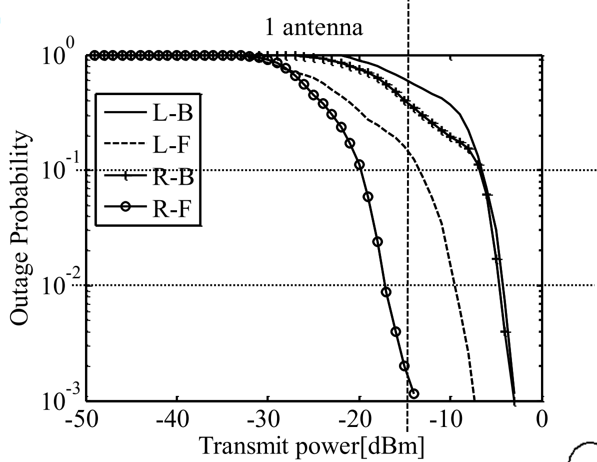
$$PG^{RAKE\text{-}Div} = -10\log_{10}\left(\sum_i\sum_\tau|h_i(\tau)|^2\right)$$

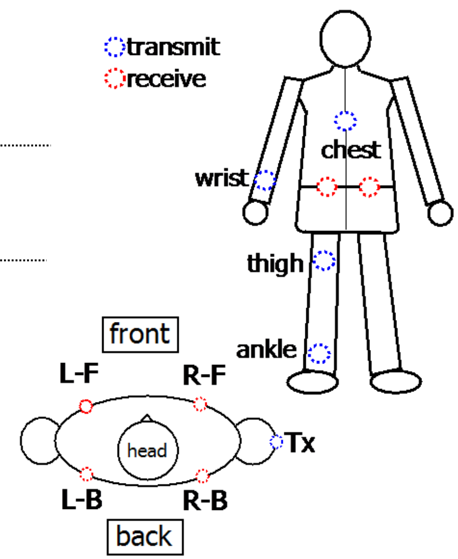
$h_i(\cdot)$: impulse response at each antenna
τ : delay time
α : threshold
i : the number of antenna

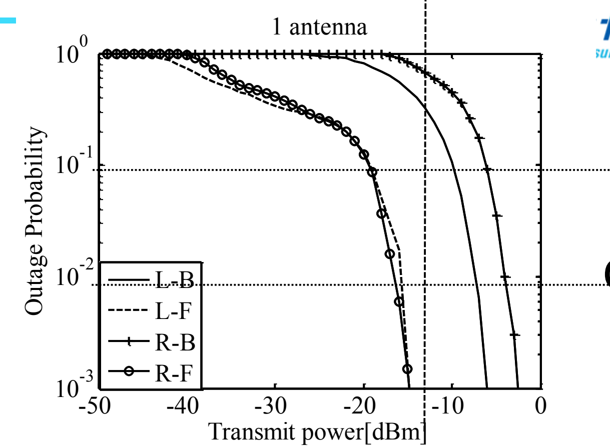


Peak Detection

Wrist

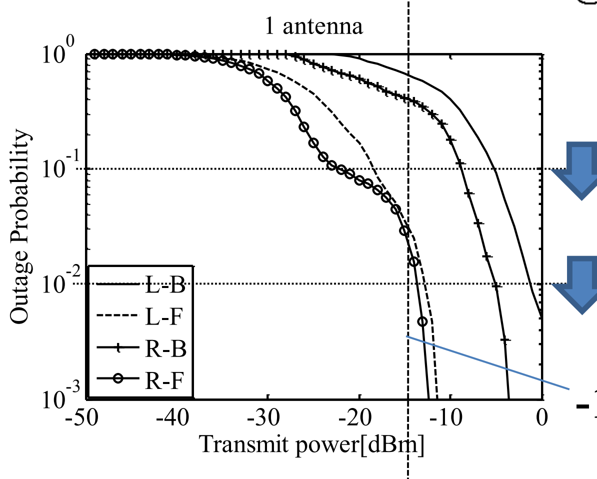






Chest

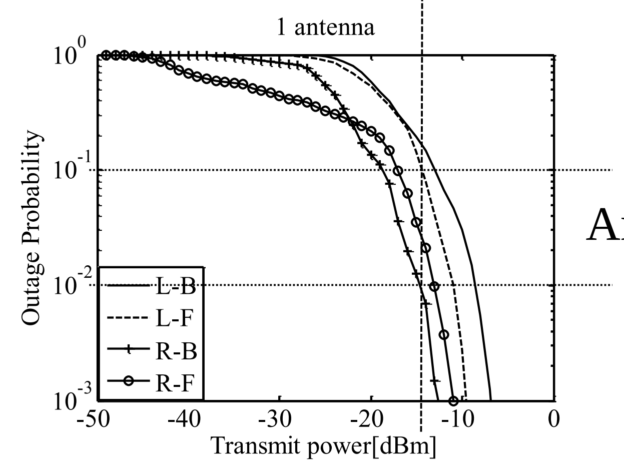
Thigh



less than 10%

less than 1%

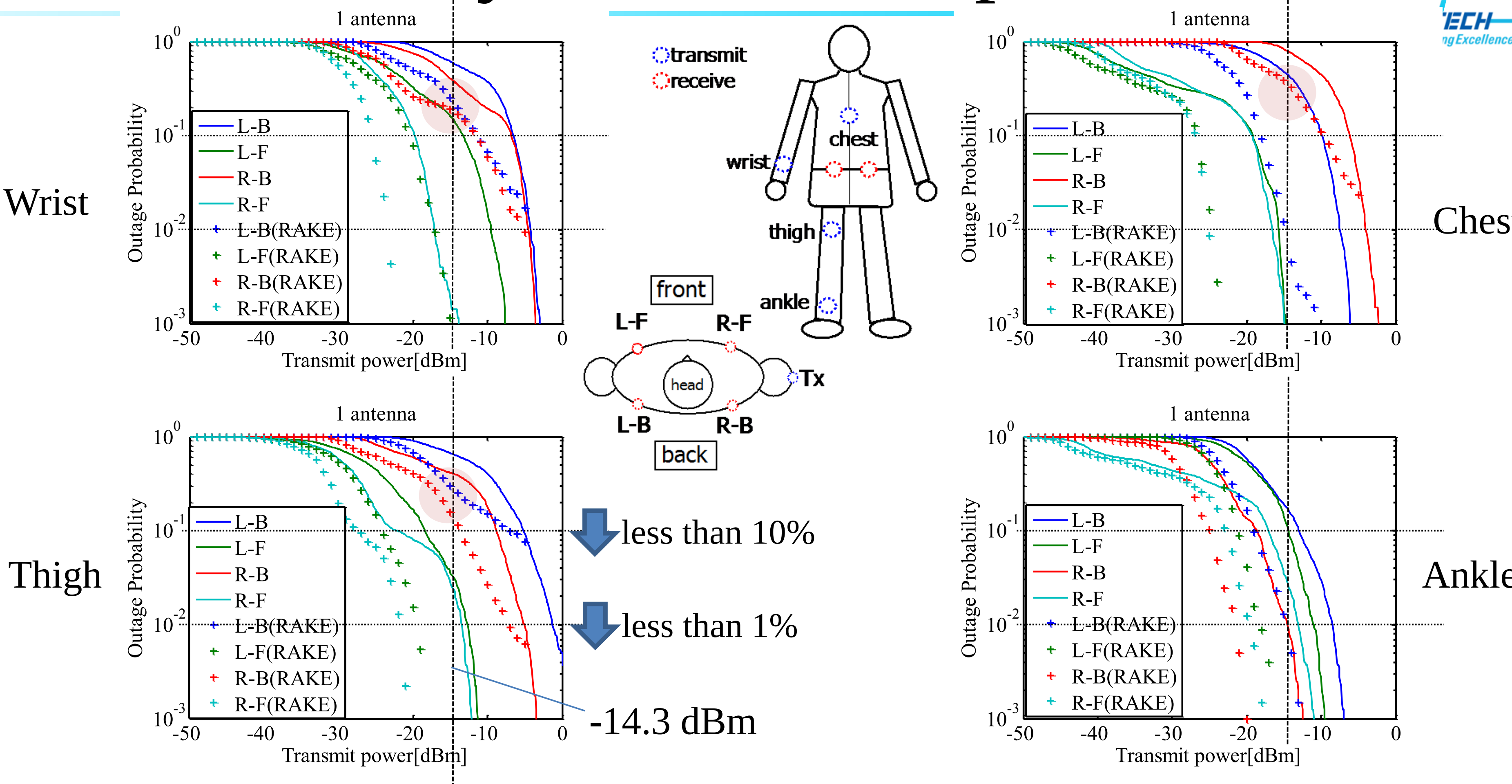
-14.3 dBm



Ankle

- Assume maximum EIRP of UWB (500 MHz : -14.1dBm)
  - For all transmit antenna positions, some antennas achieve less than 10 % probability
  - Right-Front antenna(R-F) achieve less than 10 % outage probability for all transmit antenna positions

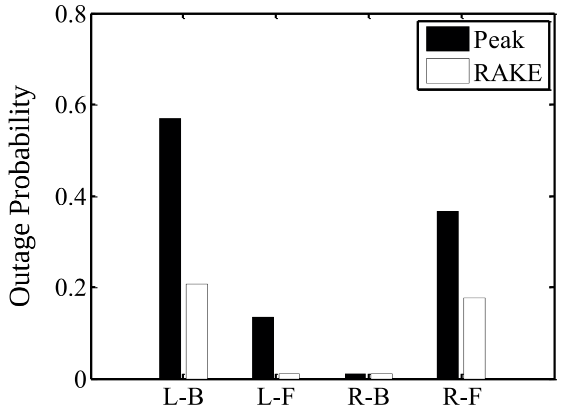
Only RAKE Reception

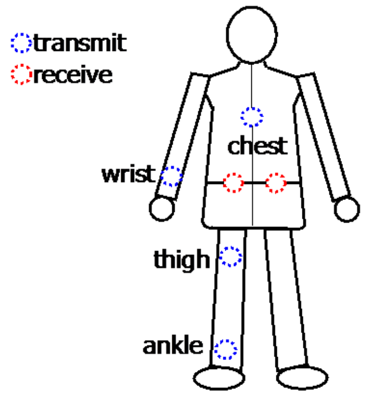


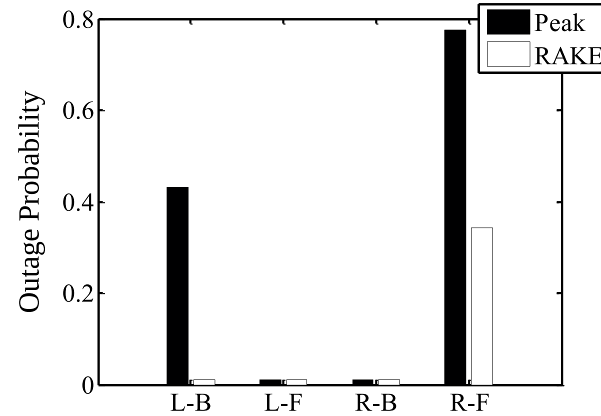
- Front side antenna (R-F, L-F) : less than 1% probability for all transmit antenna
- Left-Back antenna (L-B) : wrist and thigh cannot achieve 10% outage
- Right-Back antenna (R-B) : chest also cannot achive10% outage
  - Back side antennas are more affected by shadowing of human body

Only RAKE Reception

Wrist

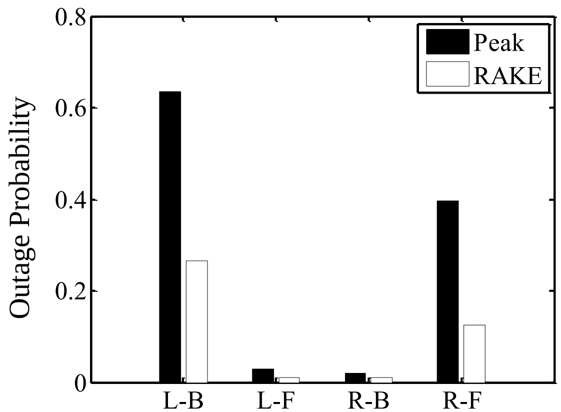


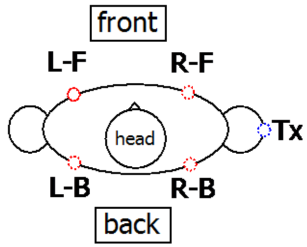


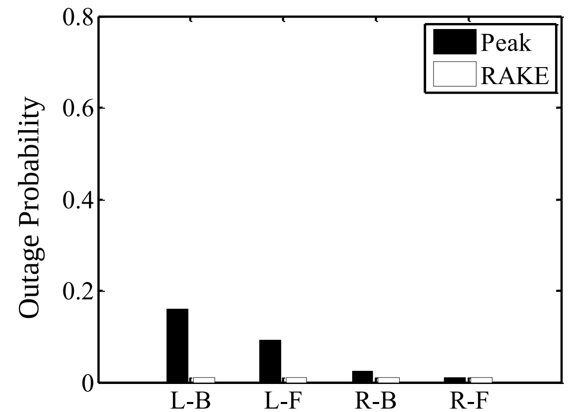


Chest

Thigh







Ankle

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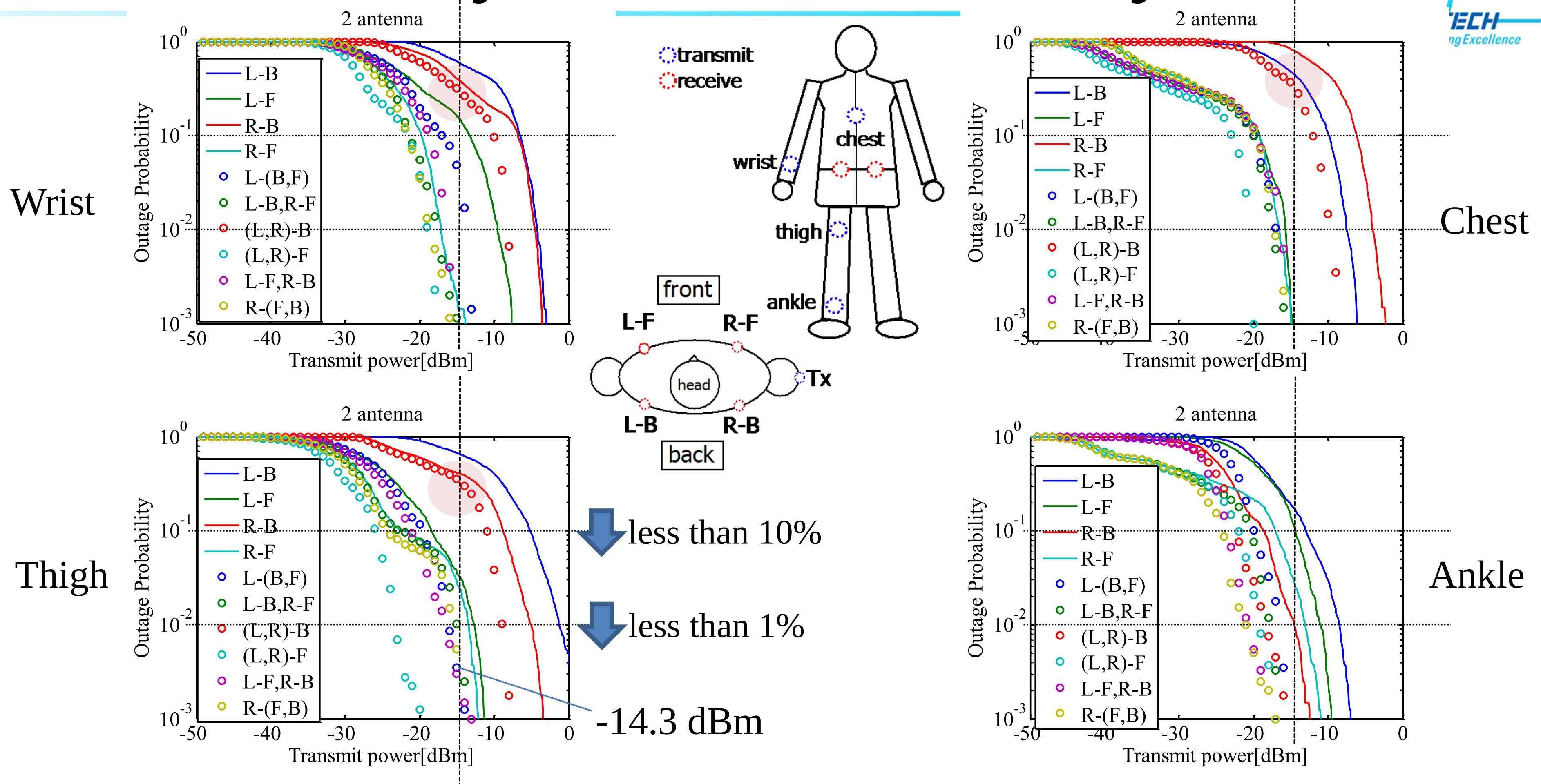
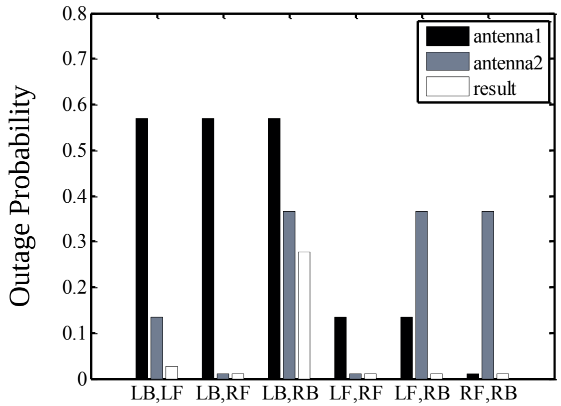
Only Antenna Diversity

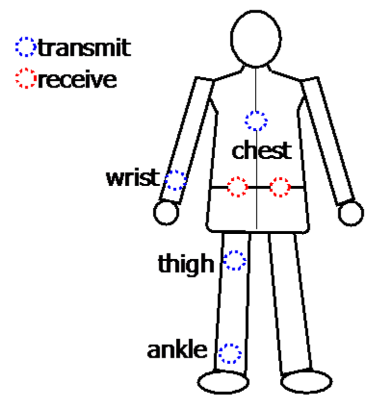


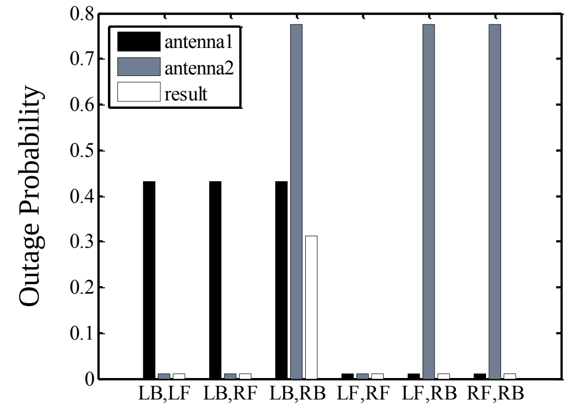
- 2 antennas case
  - Many pairs achieve less than 1% outage probability
  - The pair between back side (R-B, L-B) show little improvement

Only Antenna Diversity

Wrist

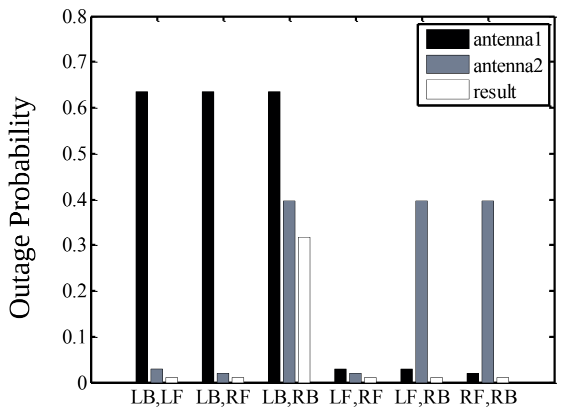


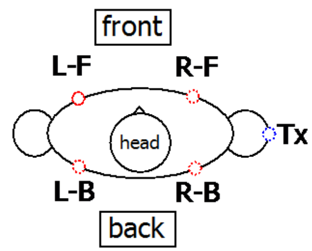


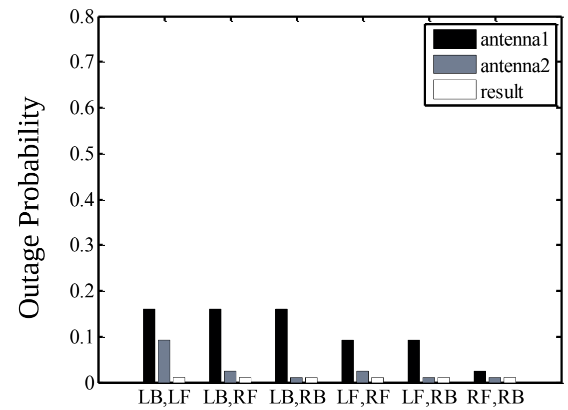


Chest

Thigh



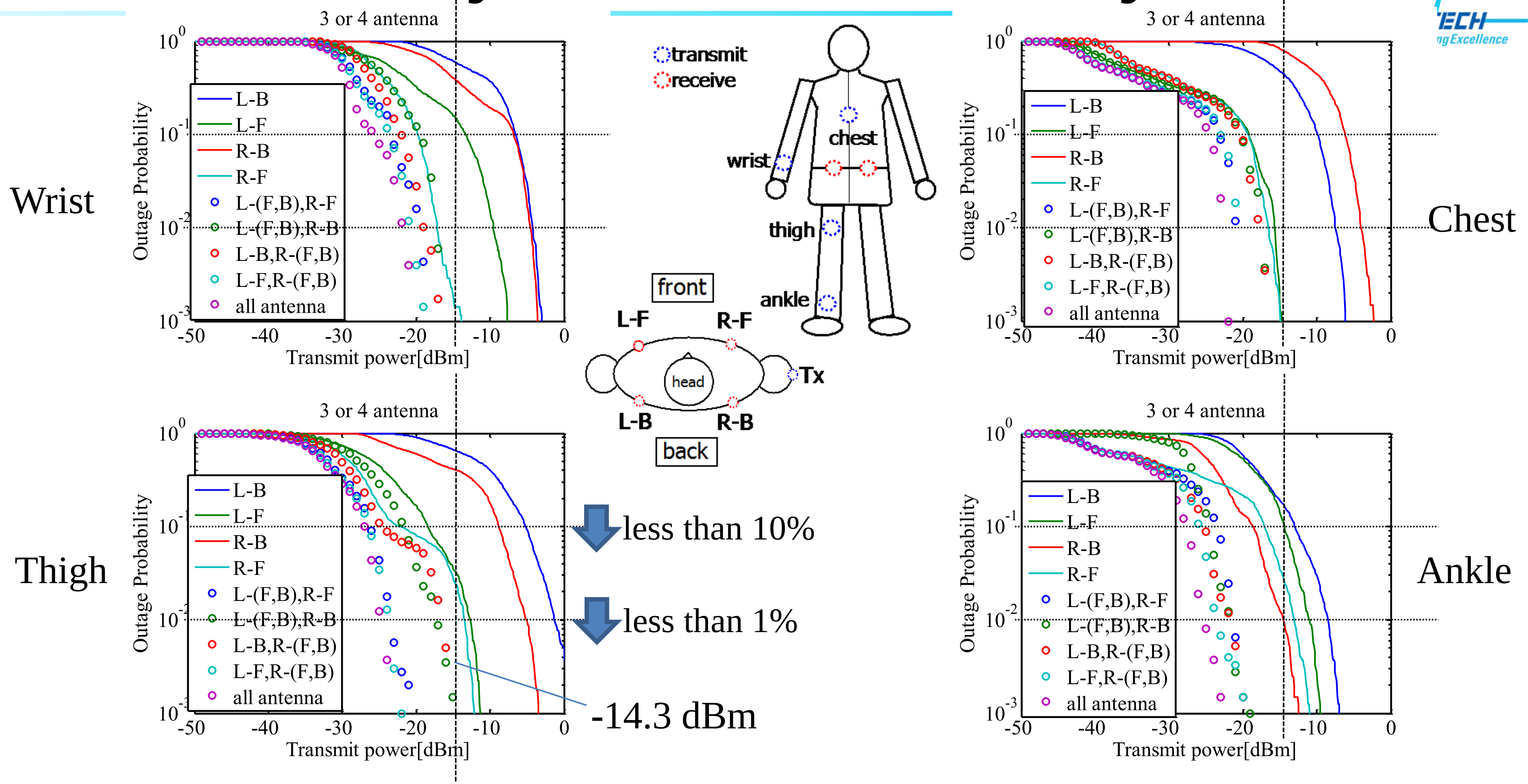




Ankle

- 2 antennas case
  - Many pairs achieve less than 1% outage probability
  - The pair between back side (R-B, L-B) show little improvement

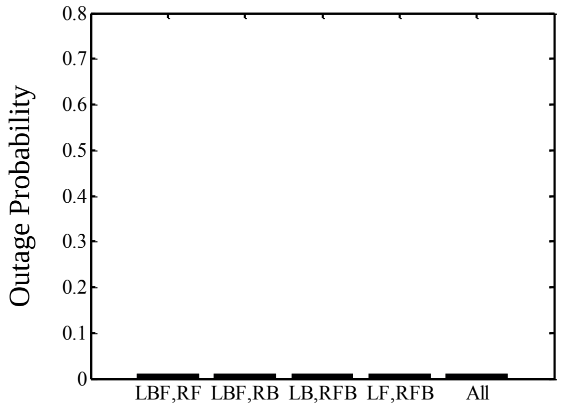
Only Antenna Diversity

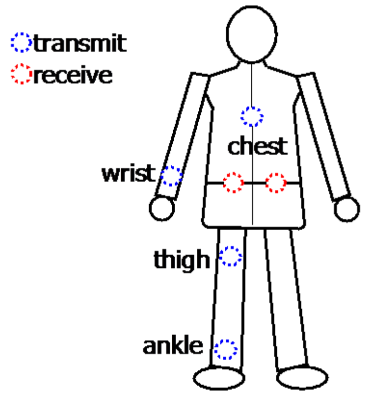


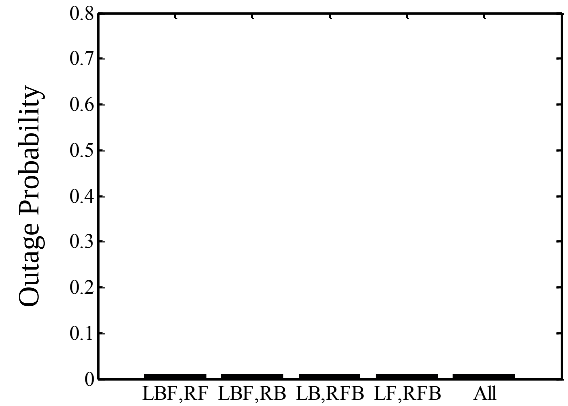
- 3 or 4 antennas case
  - More improvement compared by 2 antennas
  - All pairs can achieve less than 1 % outage probability

Only Antenna Diversity

Wrist

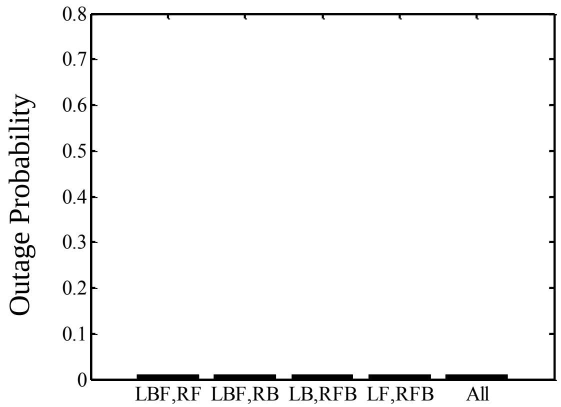


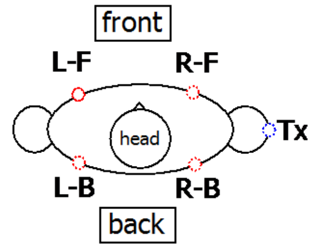


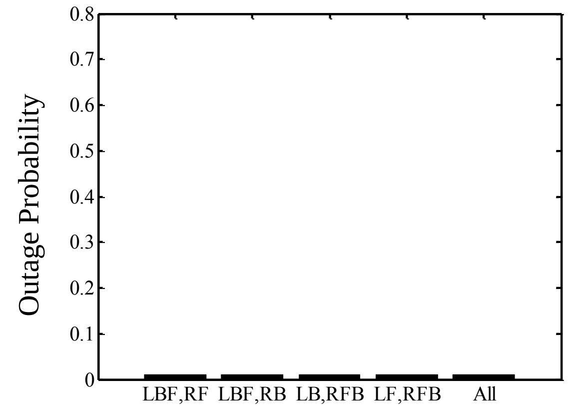


Chest

Thigh



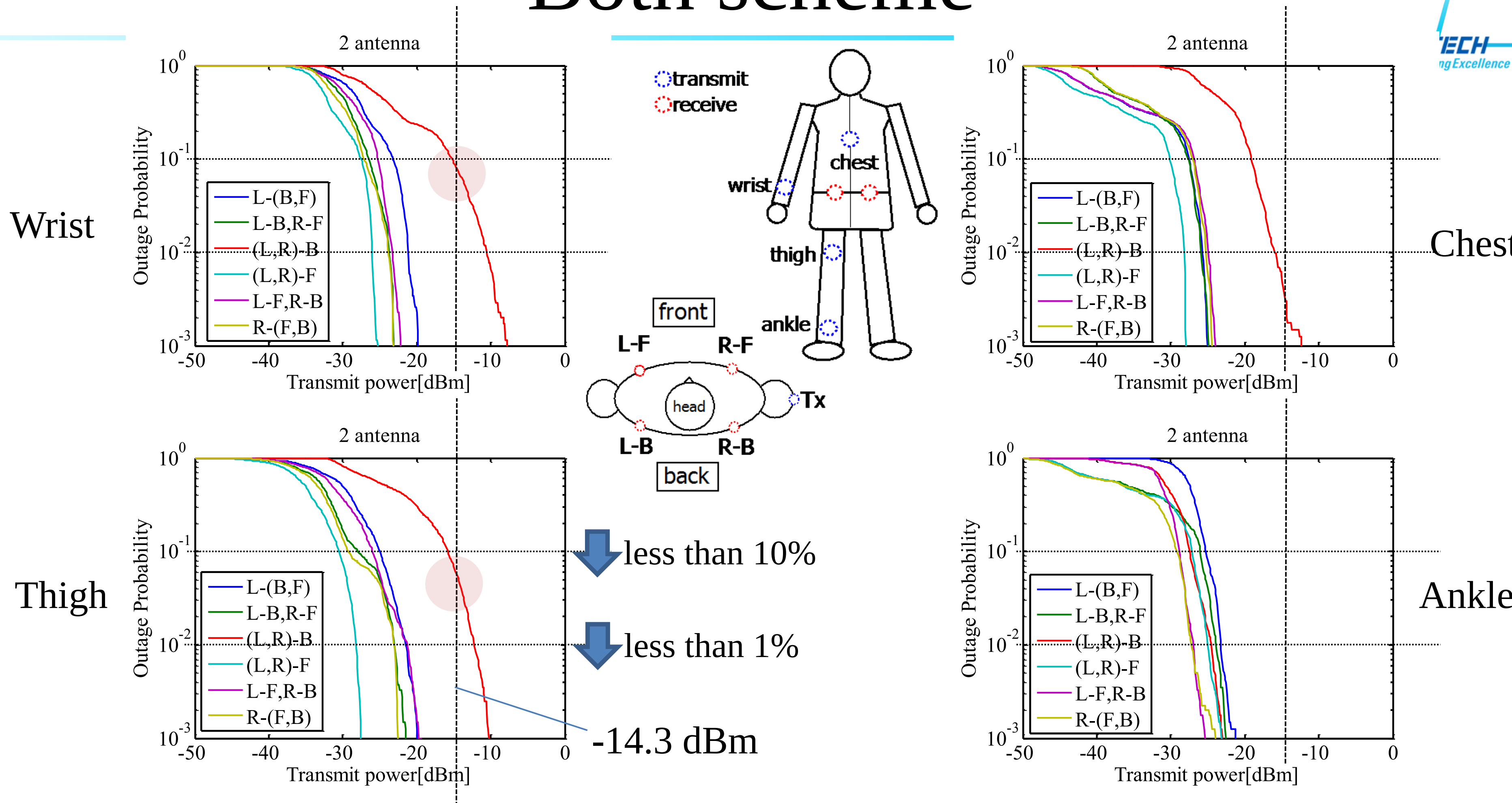




Ankle

- 3 or 4 antennas case
  - More improvement compared by 2 antennas
  - All pairs can achieve less than 1 % outage probability

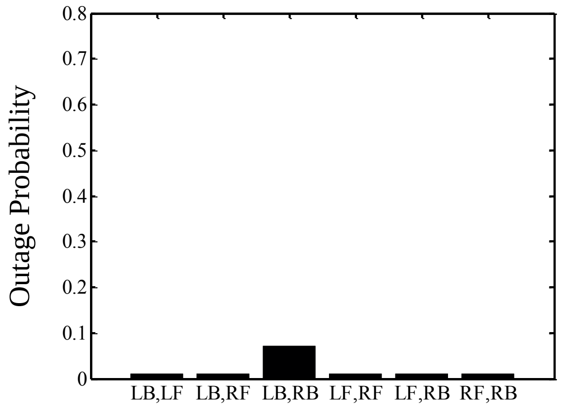
Both scheme

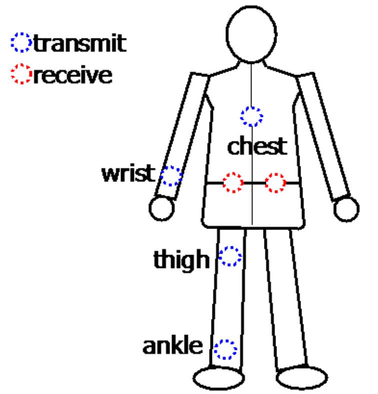


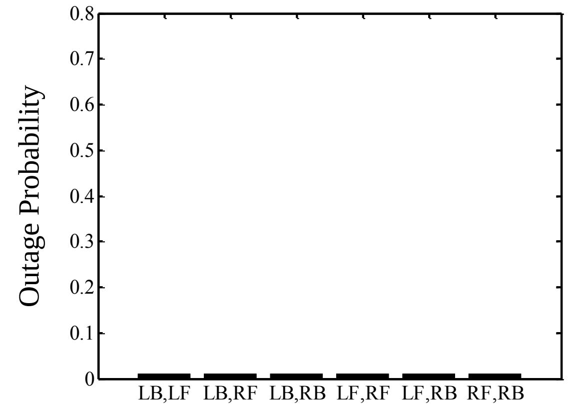
- 2 antennas case
  - Pair of back side antennas (R-B, L-B) has low performance improvement
    - Able to achieve less than 10%
  - Other combination can achieve less than 1%

Both scheme

Wrist

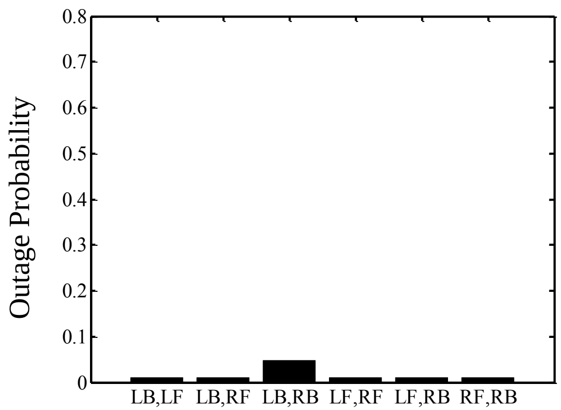


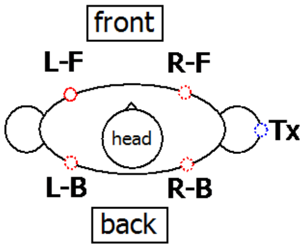


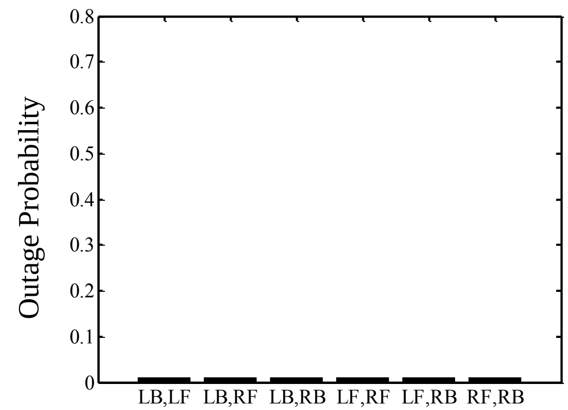


Chest

Thigh



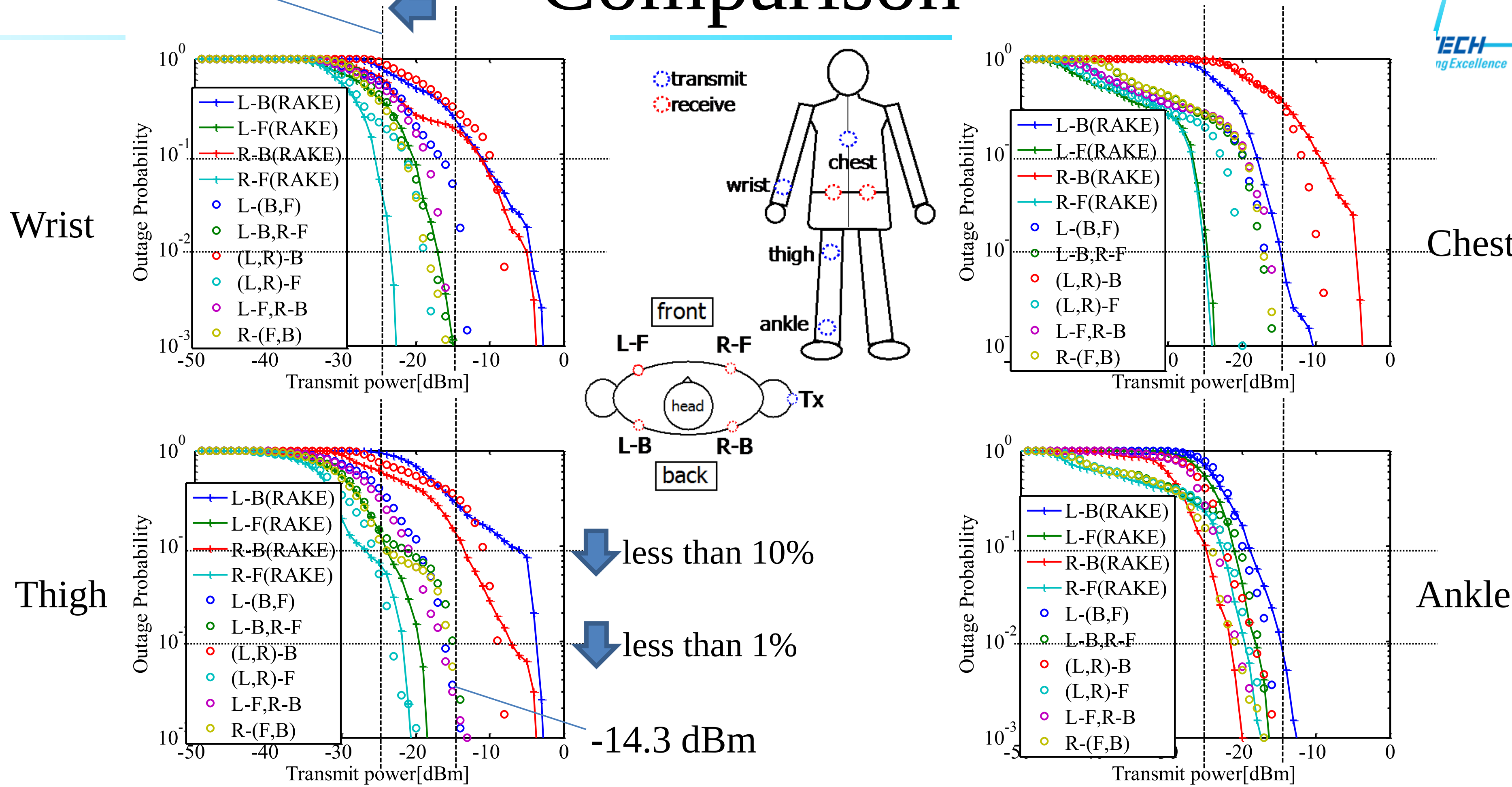




Ankle

- 2 antennas case
  - Pair of back side antennas (R-B, L-B) has low performance improvement
    - Able to achieve less than 10%
  - Other combination can achieve less than 1%

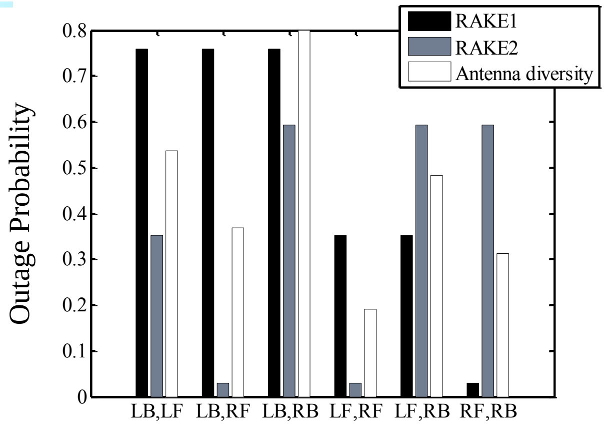
Comparison

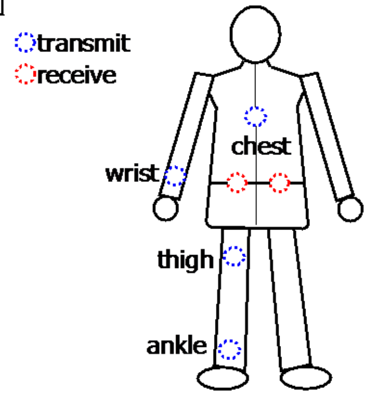


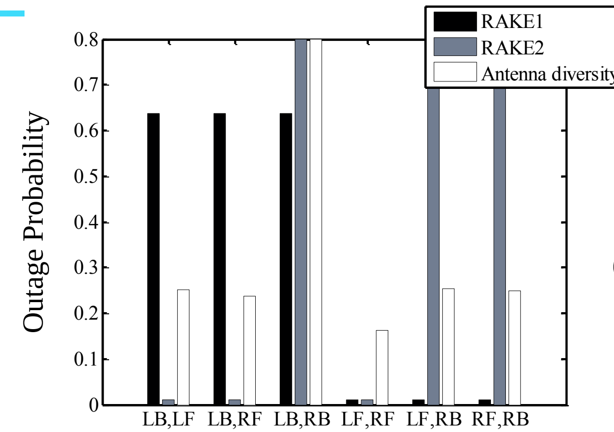
- Comparison between RAKE reception and antenna diversity (2 antennas)
  - Compare the result at **10 dB less** than maximum EIRP of UWB **(-24.1dBm)**
  - Wrist, chest, ankle : RAKE reception has higher performance improvement than antenna diversity
  - Thigh : RAKE reception and antenna diversity have same performance improvement

Comparison

Wrist

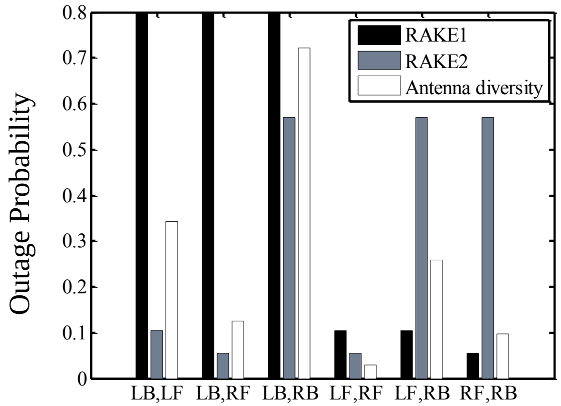


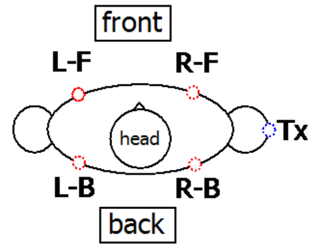


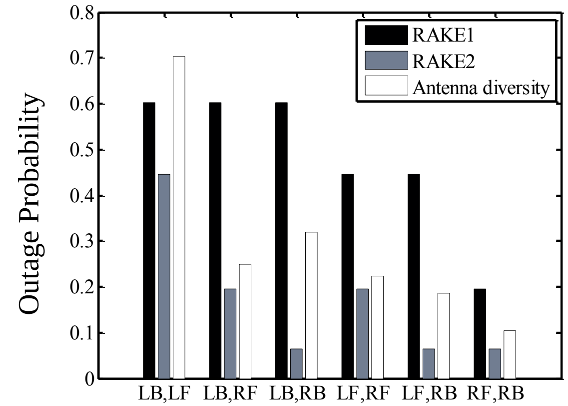


Chest

Thigh







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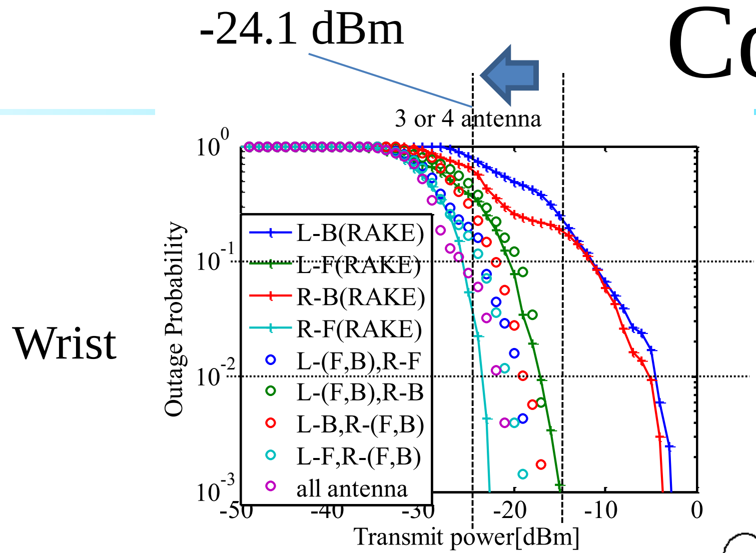
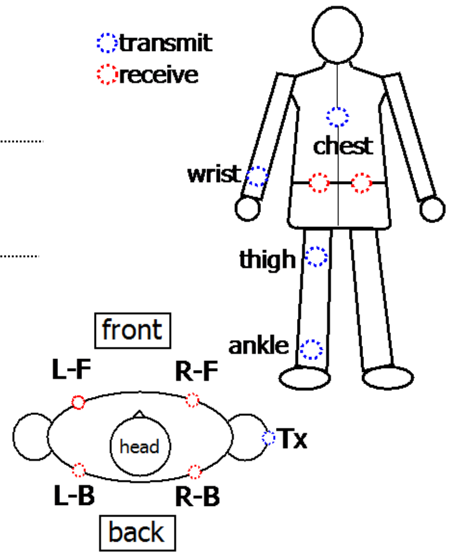
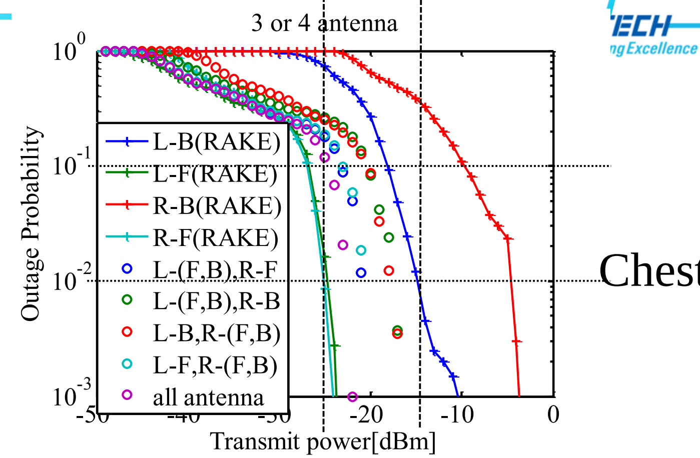
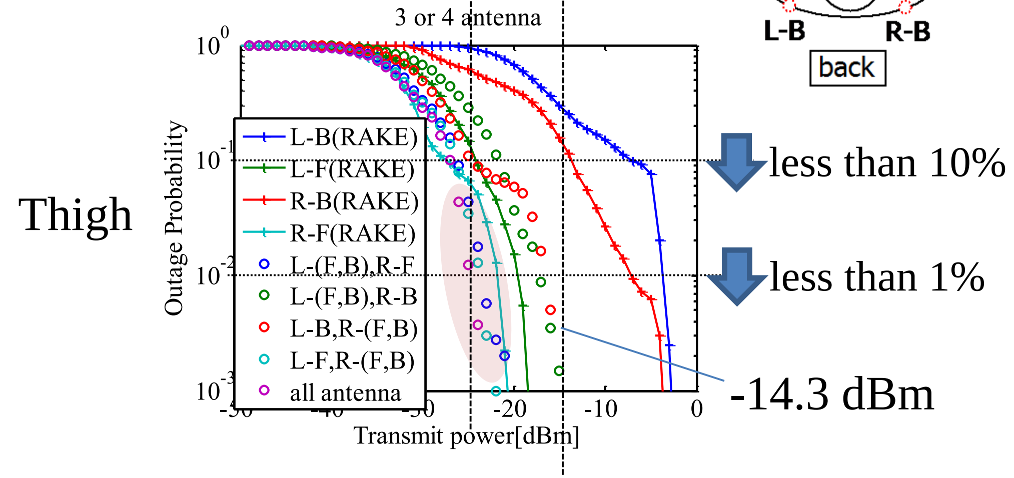
  - Thigh : RAKE reception and antenna diversity have same performance improvement

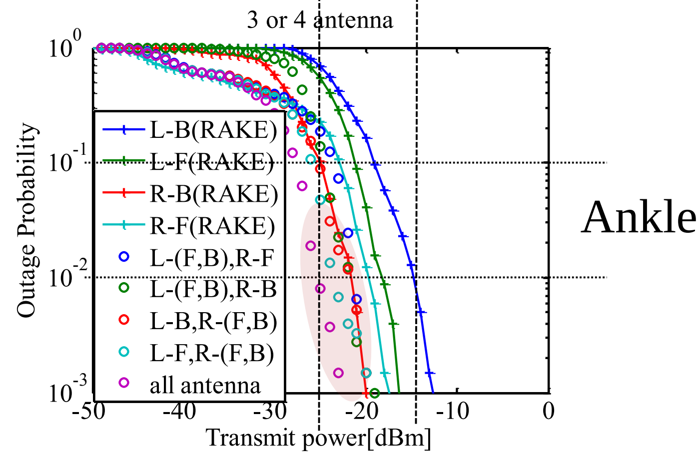
Comparison







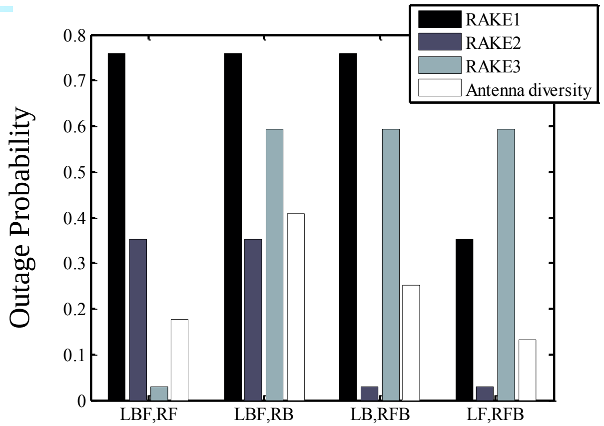


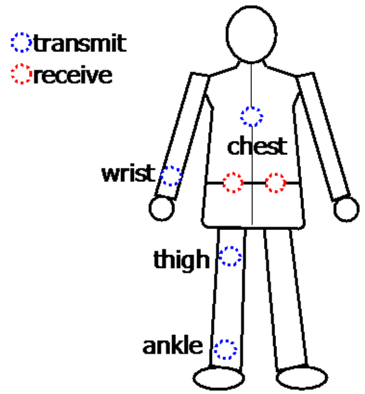


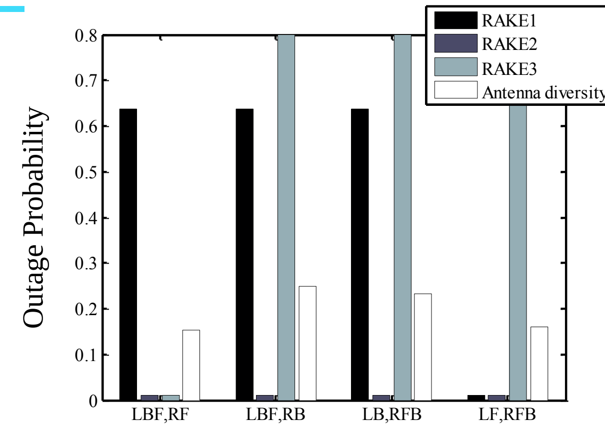
- Comparison between RAKE reception and antenna diversity (3 antennas)
  - Compare the result at **10 dB less** than maximum EIRP of UWB **(-24.1dBm)**
  - Wrist, chest : RAKE reception has higher performance improvement than antenna diversity
  - Thigh, ankle : antenna diversity has higher performance improvement than RAKE reception

Comparison

Wrist

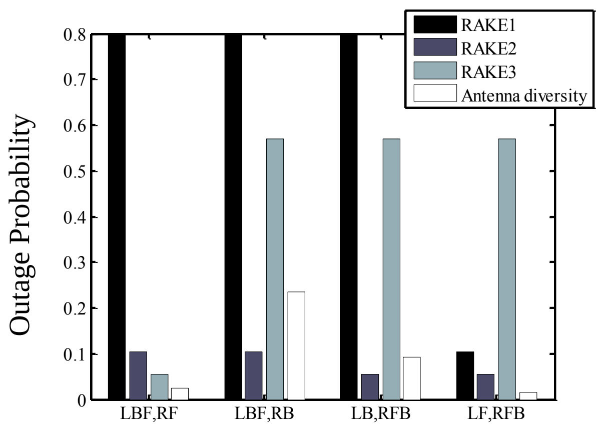


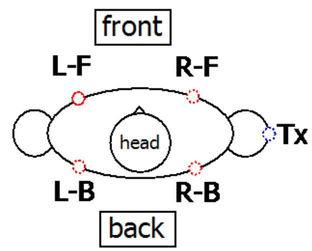


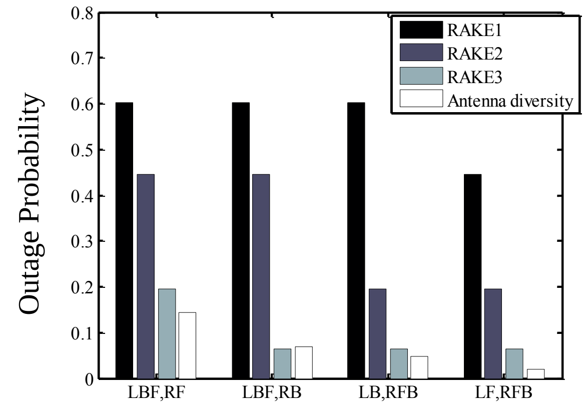


Chest

Thigh







Ankle

- Comparison between RAKE reception and antenna diversity (3 antennas)
  - Compare the result at **10 dB less** than maximum EIRP of UWB **(-24.1dBm)**
  - Wrist, chest : RAKE reception has higher performance improvement than antenna diversity
  - Thigh, ankle : antenna diversity has higher performance improvement than RAKE reception

Summary and Future Works

Summary

- Evaluated the effect of RAKE reception and antenna diversity at coordinator node

		Antenna diversity	
		Not use	Use
RAKE reception	Not use	• Only Right-Front antenna(R-F) can achieve less than 10 % outage probability for all transmit antenna	• 2 antennas : achieve less than 1 % except the pair of back side • More than 3 antennas : all pair can achieve less than 1 %
	Use	• Front side antenna (R-F, L-F) achieve less than 1% probability • Back side antenna (R-B, L-B) cannot achieve less than 10% for all	• In the case of 2 antennas, Pair of back side antennas(R-B, L-B) can also achieve less than 10 % probability

- Comparison between RAKE reception and antenna diversity
  - wrist, chest : RAKE reception > antenna diversity
  - thigh, ankle : RAKE reception < antenna diversity (more than 3 antennas)

Future works

- Expand to other situations

Thank you for listening!