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
Use outage probability as evaluation criteria

- This research calculated analytical probability in the following situations

<table>
<thead>
<tr>
<th>RAKE reception</th>
<th>Antenna diversity</th>
<th>Without</th>
<th>With</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without</td>
<td>①</td>
<td>③</td>
<td></td>
</tr>
<tr>
<td>With</td>
<td>②</td>
<td>④</td>
<td></td>
</tr>
</tbody>
</table>
Measurement System

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

➢ 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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>499.2 MHz</td>
</tr>
<tr>
<td>Modulation scheme</td>
<td>DBPSK (Synchronous detection)</td>
</tr>
<tr>
<td>Packet size ($N_b$)</td>
<td>250 Bytes</td>
</tr>
<tr>
<td>Noise figure (NF)</td>
<td>12 dB</td>
</tr>
<tr>
<td>Implementation loss (Loss)</td>
<td>8 dB</td>
</tr>
<tr>
<td>Bit rate (BR)</td>
<td>487 kbps</td>
</tr>
</tbody>
</table>
Calculation Method

1. BER $P_b$

   \[ P_b = \text{erfc}(\sqrt{\gamma_b}) \]

   - SNR per bit: $\gamma_b$
     \[ \gamma_b = \frac{E_b}{N_0} = \frac{P_r}{BR} \cdot \frac{1}{N_0} \]

   - Receive power: $P_r$
     \[ P_{rdB} = P_{tdB} - NF - Loss + PG_{dB} \]

   - Noise power spectrum density: $N_0$
     \[ N_0 = k \cdot T \]

   $\gamma_b$: SNR per bit
   $E_b$: energy per bit
   $N_0$: noise power spectrum density
   $BR$: bit rate
   $P_t$: transmit power
   $NF$: noise figure
   Loss: implementation loss
   $PG$: path gain
   $k$: Boltzmann's constant ($1.38 \times 10^{-23}[\text{J/K}]$)
   $T$: temperature (25℃, 298K)

2. PER $P_p$

   \[ P_p = 1 - (1 - P_b)^{N_b} \]

   $N_b$: Packet size

3. Outage probability $P_{out}$

   \[ P_{out} = \text{prob}(\Gamma_p < P_p) \]

   $\Gamma_p$: threshold ($5\% = 0.05$)
Calculation Method of Path Gain

- Calculate path gain from impulse response measured in experiment

1. Peak detection
   - Obtain the peak of impulse response
   \[ PG_{\text{peak}} = -10 \log_{10}(\max(|h(\tau)|^2)) \]
   \[ h(\cdot) : \text{impulse response} \]
   \[ \tau \text{ : delay time} \]

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

\[ PG_{\text{RAKE}} = -10 \log_{10}(\sum_\tau |h(\tau)|^2) \]
\[ (h(\tau) \geq \alpha) \]
\[ h(\cdot) : \text{impulse response} \]
\[ \tau \text{ : delay time} \]
\[ \alpha \text{ : threshold} \]
Calculation Method of Path Gain

③ Only use antenna diversity
- Sum peak value at each antenna

\[
PG_{\text{Div}} = -10 \log_{10} \left( \sum_i \max(|h_i(\tau)|^2) \right)
\]

- \(h_i(\cdot)\): impulse response at each antenna
- \(\tau\): delay time
- \(\alpha\): threshold
- \(i\): the number of antenna

④ Use both RAKE reception and antenna diversity
- Sum result of RAKE combining at each antenna

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

- \(h_i(\cdot)\): impulse response at each antenna
- \(\tau\): delay time
- \(\alpha\): threshold
- \(i\): the number of antenna
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
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 achieve 10% outage

- Back side antennas are more affected by shadowing of human body
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 achieve 10% outage
  - Back side antennas are more affected by shadowing of human body
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
• 2 antennas case
  
  ❖ Many pairs achieve less than 1% outage probability
  
  ❖ The pair between back side (R-B, L-B) show little improvement
3 or 4 antennas case

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

- 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 between RAKE reception and antenna diversity (2 antennas)

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

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

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

- 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!