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

Submission Title: [YNU PHY and MAC design for WBAN IEEE P802.15.6]

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Abstract: [We propose our specially designed PHY and MAC for wireless body area network (BAN) to satisfy various requirements for both medical and non-medical applications, which is uniqueness of IEEE802.15.6. In PHY, pulsed chirp UWB is proposed because of its total performance for WBAN. In particular, hybrid type of ARQ and FEC is proposed to satisfy both requirements of medical and non-medical applications in a sense of highly reliable and lower power consumption. In MAC, we propose a protocol for BAN considering effect to a human body, in particular, taking care of SAR (specific absorption ratio) of parts of BAN devices in and on a body. Although this proposal is not a full set of proposal corresponding to technical requirements for IEEE802.15.6, we hope this can contribute to improve system performance by harmonizing with others. This is a revised version of our proposal with a new positioning scheme in addition in March, 2009.]

Purpose: [Response to “TG6 Call for Proposals” (IEEE P802.15-08-0811-02-0006).]

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YNU PHY and MAC Design for WBAN IEEE P802.15.6

- Revision of Our Proposal in March, 2009 and additional scheme -

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Yokohama National University
1. Aim and Motivation

- The aim of this presentation is to introduce some technologies to enhance performance of a merged proposal.
- We propose our designed schemes for PHY and MAC of BAN so as to satisfy the different requirements for both medical and non-medical use of BAN such as reliability and safety for medical use and efficiency for non-medical use.
- Positioning or localization scheme for BAN nodes is also presented in addition different from the last presentation in March.

2. PHY

2.1 Pulsed Chirp UWB using hopping
2.2 Error controlling scheme using hybrid ARQ and FEC for medical and non medical uses, respectively

3. MAC

3.1 Protocol considering SAR or thermal influence to a body by switching cluster
3.2 Positioning or localization of BAN nodes
2. Physical Layer design:

Pulsed Chirp UWB with Hopping
2. Body Area Network: BAN

- **Body Area Network**
  - Networks composed of wireless communication inside and/or outside a human body

1. Monitoring vital signs such as ECG, EEG etc and remotely controlling medical equipments such as pace-maker with ICD, capsule endoscope
2. Assisting disability such as eyeglasses with camera, etc.
3. Fitness and Entertainment with body area games and cell phones etc.

:Wearable  :Implant

Example of implant device

- Implant WBAN
- Wearable WBAN
2.1 Direct Sequence UWB (DS-UWB) and Chirp on UWB (Co-UWB)

**DS-UWB system**

- Advantage: transmitting signal for DS-UWB using spreading sequence
- Down back: no tolerance to near-far problem due to no spreading gain

**Chirp on UWB (Co-UWB) system**

- Advantage: Easily sweeping frequency among ultra wideband
  Using different frequency band for multiple nodes, tolerance to near-far problem
- Down back: it is difficult to distinguish different BANs in case using the same frequency band
2.1 Pulsed Chirp UWB system

Aim: Improve immunity against narrow band and multi-user interference with combined chirp-on-UWB and DS-UWB

Chirp-on-UWB system + DS-UWB system

Using frequency sweeping, it is good performance against narrow band interference in case SIR is low. Using direct sequence, it is good performance against multi user interference in case SIR is high.

Proposed system: Pulsed Chirp UWB system; like IEEE802.15.4a with optional chirp pulse

This seems to be a merged proposal between NICT’s Part 1&2* in a sense of “Multi-Band Pulsed Chirp UWB with Frequency and Time Hopping”

Each pulse uses different sub-band for tolerance against narrow band interference

Transmitting signal uses spreading sequence to distinguish multiple nodes in BANs

*: NICT’s Part 1: Doc#IEEE802.25.09.0166-00-0006, NICT’s Part 2: Doc#IEEE802.25.09.0163-00-0006,

Submission No.7 <Ryuji Kohno, et.al., Yokohama National University>
2.1 Pulsed Chirp UWB system with single hopping for medical use

The system uses multiple sub-bands with OCC frequency hopping sequence to avoid both narrow band and multi-user interferences and DS with Gold sequence to indentify users.

This system seems to be a merged proposal between NICT’s Part 1&2 in a sense of “Multi-Band Pulsed Chirp UWB with Frequency and Time Hopping”

① Divide the bandwidth by applied length of sequence

② Define using frequency sub-band which adapts to each pulse by hopping sequence

③ Make direct sequence by using direct sequence with up and down chirp corresponding 0 and 1.

④ Data modulation is bi-phase
2.1 Pulsed Chirp UWB system with parallel hopping for non-medical use

Medical use → Utilize hopping sequence for improvement of interference immunity

Non-medical use → Utilize hopping sequence for multi-level modulation for satisfying demand of higher data rate

For medical use

- Use for identification of multiple BAN nodes
- For medical use: Use for identification of multiple BAN nodes

For non-medical use

- Use for higher data-rate transmission with multi-level modulation
- A non-medical user employs 3 parallel sub-bands to transmit data with 3 times higher date rate
2.1 System configuration for medical use

In case of No. of medical nodes = 3

Transmitter Configuration

Frame Clock → Hopping Sequence Generator → Frequency Synthesizer → UWB-Chirp Filter → Sequence delay

Medical node 1 data or Medical node 2 data or Medical node 3 data

Receiver Configuration

data → Sequence Correlator → Chirp Correlator

node 1 data or node 2 data or node 3 data

Hopping sequence information → Reference Signal
2.1 System configuration for non-medical use

In case of No. of non-medical nodes = 1

Transmitter Configuration

- Frame Clock
- Hopping Sequence Generator
- Frequency Synthesizer
- UWB-Chirp Filter
- Sequence delay

Receiver Configuration

- Data with 3 times higher data rate using 3 hopping sequences
- Sequence generator
- Chirp Correlator
- Reference Signal
- Sequence Correlator
- Hopping sequence information
- data
2.1 Wearable Wireless BAN channel model

Using channel model of IEEE802.15.4a final report

Characteristic

- frequency is 3.4~4.8GHz
- No energy penetrating through a body

Path loss model are defined according to distance around a body

Path loss formula

\[ P_{dB} = \gamma (d - d_0) + P_{0,dB} \]

\( \gamma \): units of dB/meter

\( d_0 \): reference distance

\( P_{0,dB} \): Power at the reference distance

Depending on transmitter and receiver position, the power of reflection wave is higher

Ex) Impulse response which is receiver’s position left arm

Diffracting wave around the body

Ground reflection
2.1 Simulation Model

• Simulation model
  • Multiple pico-nets (Multiple BANs) coexisting
  • Assuming multiple BANs are perfectly synchronized and channel propagation is known in ideal case
  • Undesired factor: multi-user interfering signals and AWGN

• Parameter of each system
  • Total frequency sub-bands used in all BANs is the same in each system
  • Bit rate and power consumption of 1 bit is the same
  • Number of multiple nodes is the same
### 2.1 Performance Evaluation

**Simulation Parameters**
Both medical and non-medical nodes and BANs are coexisting.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pulse shape</strong></td>
<td>Root raised cosine roll-off pulse (roll-off rate 0.6)</td>
</tr>
<tr>
<td><strong>Bit rate</strong></td>
<td>Medical: 1Mbps</td>
</tr>
<tr>
<td></td>
<td>Non-medical: 3Mbps</td>
</tr>
<tr>
<td><strong>Frequency Band</strong></td>
<td>3.2 - 4.8GHz</td>
</tr>
<tr>
<td><strong>Sampling interval</strong></td>
<td>0.08[ns]</td>
</tr>
<tr>
<td><strong>Using channel model</strong></td>
<td>IEEE 802.15.6 CM3</td>
</tr>
<tr>
<td><strong>No of coexisting BAN nodes for medical and non-medical use</strong></td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of UWB</th>
<th>Pulse Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS-UWB using Gold sequence with length 7</td>
<td>0.75ns</td>
</tr>
<tr>
<td>Proposed Pulsed Chirp UWB with FH and DS using RS code with length 8 as FH and Gold sequence with length 7 as DS</td>
<td>2.5ns~20ns</td>
</tr>
</tbody>
</table>
2.1 BER Performance Evaluation

Case of the number of coexisting nodes or BANs is 8 (Bit rate = 1Mbps)

Case of the number of coexisting nodes or BANs is 8 (Bit rate = 3Mbps)
2.1 Link budget

<table>
<thead>
<tr>
<th>parameter</th>
<th>Value (medical)</th>
<th>Value (non-medical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data rate (R)</td>
<td>1Mbps</td>
<td>3Mbps</td>
</tr>
<tr>
<td>Tx antenna gain (Gt)</td>
<td>0dBi</td>
<td>0dBi</td>
</tr>
<tr>
<td>Rx antenna gain (Gr)</td>
<td>0dBi</td>
<td>0dBi</td>
</tr>
<tr>
<td>Required (SIR) for BER &lt; 10^-3</td>
<td>-16</td>
<td>-9</td>
</tr>
<tr>
<td>Received SNR (dB)</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Path loss at 1m (dB)</td>
<td>60.98</td>
<td>60.98</td>
</tr>
</tbody>
</table>
2.1 Conclusions for Pulsed Chirp UWB

• We proposed pulsed chirp UWB with single and parallel frequency hopping for medical and non-medical use, respectively.

• The proposed pulsed chirp UWB with hopping sequence performs stable high interference immunity in various environments of coexisting medical and non-medical nodes or BANs.

• The proposed UWB may be a merged proposal between NICT’s Part 1&2 in a sense of “Multi-Band Pulsed Chirp UWB with Frequency and Time Hopping”
2.2 Error Controlling Scheme in Physical Layer Design:
Combination between Hybrid ARQ for Medical Use and FEC for Non-Medical Use
2.2 Demand of medical and non medical system

**Medical**
- Robust against interference
- High reliability and security

**Non-medical**
- Efficiency with High rate
- Continuous data streaming

**Aim**: Design an error-controlling scheme for BAN appropriate for both medical and non-medical uses

- **Coding for higher reliability**
  - Information bit
  - More Redundant bits
  - Degradation of throughput according to more redundancy for high error-correcting capability

- **Multi-level modulation for high speed**
  - Shorter Euclidian distance among signal points
  - Increase of error rate according to higher efficiency

**Solution**: Choose decoding scheme between hybrid ARQ and simple FEC for medical and non-medical uses, respectively in reception while the same modulation and coding are used for both medical and non-medical uses in transmission
2.2 Several types of Error controlling method

- **FEC**
  (Forward Error Correction)
  Error detection or error correction by adding redundant bit without retransmission

- **ARQ**
  (Automatic Repeat reQuest)
  If packet error is detected, it is retransmitted.

**FEC+ARQ is Hybrid ARQ**

Error detection and correction is performed in decoding at reception and if the error is detected and cannot be corrected, retransmission is requested until correctly received.

- **Type 1 of hybrid ARQ**: Retransmit same data
- **Type 2 of hybrid ARQ**: Retransmit other data

**Incremental Redundancy method**: Retransmit redundant bit

- **Modulation**: BPSK
- **Channel**: AWGN

high throughput communication
2.2 Code Configuration (Interleaving)

Packet data

Generate Redundant code

Packet data

Generate

Packet data

Generate

Packet data

Generate

Redundant code data

1

2

3

4

5
2.2 Proposed combined hybrid ARQ and FCC for error-control satisfying different requirements for medical and non-medical applications

Choose decoding scheme either hybrid ARQ or simple FEC according to medical or non-medical use while transmitting signals are the same in transmission device.

- Requirement for Medical use: Accept a certain level of delay for improvement of quality.
- Requirement for Non-medical use: Decrease delay in moderate quality.

**Proposed method**

For Medical use: Hybrid ARQ
For Non-medical use: FEC only

Use Super orthogonal convolutional code or Concatenated code according as a purpose.
2.2 Flowchart of proposed error-controlling scheme

(1) Make a block with k bits by dividing binary data stream

\[
\begin{array}{cccccc}
1 & 2 & \cdots & k & k+1 & \cdots \\
& & & & & \\
1 & 2 & \cdots & B
\end{array}
\]

(1) Add CRC code to detect errors

Convolutional Coding

(2) B blocks of data are added with CRC and encoded with a coderate \( R_0 \) of convolutional code.

\[
L = n \times B
\]

(2) Initial packet \( L_1 \)
(both Medical and Non-Medical uses)

(3) Make the first transmitting block \( L_1 \) and retransmitting redundant block \( L_2, L_3 \) for medial use.

\[
L_1 = L_{\max} / R_1 \quad \text{and} \quad L_{2,3} = L_{\max} - L_1
\]

(3) Retransmission packet \( L_2, L_3 \)
(Medical use only)
2.2 Reason for Retransmission

2-PPM (2-level Pulse position modulation)

- Attenuation
- Distortion and delay

Avoid the interference by expanding time duration $T_d$
2.2 Time Duration Td

Short duration Td: Increase errors due to ISI
Long duration Td: Increase errors due to Noise
2.2 Performance Evaluation for Proposed Error-Controlling Scheme

<table>
<thead>
<tr>
<th>Simulation Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel</td>
</tr>
<tr>
<td>Modulation</td>
</tr>
<tr>
<td>Code</td>
</tr>
<tr>
<td>Block number length</td>
</tr>
<tr>
<td>Decode</td>
</tr>
<tr>
<td>Limit of number of retransmission</td>
</tr>
<tr>
<td>UWB pulse</td>
</tr>
<tr>
<td>Pulse width</td>
</tr>
<tr>
<td>Symbol duration</td>
</tr>
</tbody>
</table>
2.2 Evaluation of Bit Error Rate and Throughput

- Medical use: BER = 10^-6
- Non medical use: BER = 10^-3

- Medical use: Max 1Mbps
- Non medical use: Max 10Mbps
2.2 Another Hybrid ARQ method (1)

**Chase Combining method : Retransmit same bit**

$I = I_1 \ldots I_K$ : data (k bits)

$X = X_1 \ldots X_N$ : codeword (coderate $K/N$)

$Y^1 = Y_1 \ldots Y_N , w_1$

$Y^L = Y_1 \ldots Y_N , w_L$

The weights in AWGN channel are

$$w_j = \frac{1}{\sigma_j^2} \quad (j = 1,2,\ldots,L)$$

Which are used for soft-decision decoding in retransmission

<table>
<thead>
<tr>
<th>Data (+CRC)</th>
<th>K=2000 bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error Detection</td>
<td>CRC 24bits</td>
</tr>
<tr>
<td>Code rate</td>
<td>$1/2$</td>
</tr>
<tr>
<td>Decoding</td>
<td>Hard decision Viterbi decoding, Syndrome decoding</td>
</tr>
<tr>
<td>Decoding Error Probability ($p'$)</td>
<td>$p' = 10^{-4}$</td>
</tr>
<tr>
<td>Channel</td>
<td>AWGN</td>
</tr>
</tbody>
</table>

Max ratio combination → need large size of buffer

Max ratio combination → need channel information

Construct Data $K$ bits by encoding

$w_1 \ldots w_L$ are weights for maximum ration combination

$\frac{\text{NUMBER OF PACKET TRANSMISSIONS}}{\text{CHANNEL ERROR PROBABILITY}(p)}$

- Blue line: CAPACITY LIMIT
- Green line: $K=7$ CONVOLUTIONAL
- Orange line: $K=5$ CONVOLUTIONAL
- Pink line: $(7, 3)$ RS $t=2$

$<$Ryuji Kohno, et.al., Yokohama National University$>$
2.2 Another Hybrid ARQ method (2)

**Invertible coding**: Retransmitted data packet or redundant packet

Effective for fading channels and jamming

Hybrid ARQ using Invertible code which can decode with only redundant bits. It can be easily performed using RS code with a code rate $\frac{1}{2}$.

If decoding is failed, retransmission is requested.
2.2 Conclusions of Error Controlling scheme for BAN

- We proposed the error controlling scheme to choose hybrid ARQ and FEC only corresponding to medical use and non-medical use, respectively while transmitted signals have the same channel coding for both medical and non-medical uses.
- The proposed scheme could satisfy the demand of both medical and non-medical simultaneously.
- We can choose a super orthogonal convolutional code with much lower code rate but much higher error-correcting capability as well as the same concatenated code between RS code and convolutional code as IEEE802.15.4a in option.
3. MAC Layer design:

3.1 Protocol considering SAR or thermal influence to a body by switching cluster
3.1 Background of MAC design

Integration of medical field and wireless communication technology

• Implementation of network on-body and in-body, in particular implant BAN inside a body

\textbf{Ex}) • Capsule Endoscope

• Cardiac pacemaker etc...\newline

✓ Smaller devices
✓ Longer-lasting batteries

• Wireless communication devices (nodes) will be able to form a sensor network inside a human body.
3.1 Motivation
Focus on thermal influence for a body due to implanted devices

- Problem of wireless communication inside a human body
  - Thermal Influence for a body by electromagnetic wave exposure and circuit heat in a sense of SAR factor

Radiation absorption → Increase of the cell’s temperature

- Objective
  Propose a MAC protocol minimizing thermal influence to a human body using a certain thermal propagation model of a body,
3.1 Network Structure of Implant BAN

Cluster-based communication protocol

- This protocol is more energy efficient than a tree-based protocol.
- Particular nodes (cluster leader) perform long range communication with a receiver outside a body.

Switching of cluster leader

- In order to disperse the thermal influence to a body, we switch the access controlling task among multiple FFD (full function device) nodes that are cluster leaders so as to suppress increase of temperature of human tissues.

**FFD**: Full Function Device

**RFD**: Reduced Function Device

System model
3.1 Thermal Propagation Modeling

1. Electromagnetic Wave Exposure

SAR (Specific Absorption Rate) \[ SAR = \frac{\sigma}{\rho} E^2 [W/kg] \]

\( \sigma \): electrical conductivity of the tissue [S/m]
\( \rho \): density of tissue [kg/m\(^3\)]
\( E \): RMS induced electric field [V/m]

\[ \Delta T = \frac{V \times A}{\rho \times C} \]

\( V \): voltage of leader node [V]
\( A \): current of leader node [A]
\( C \): specific heat of tissue [J/kgK]

Biologic thermal transport equation

\[ \rho c \frac{\partial T}{\partial t} = \kappa \nabla^2 T - \rho \rho_b c_b F (T - T_b) + \rho SAR + \frac{VA}{\rho c} \]

Parameters of blood

\( \kappa \): thermal conductivity of tissue [W/mK]
\( \rho_b \): density of blood [kg/m\(^3\)]
\( c_b \): specific heat of blood [J/kgK]
\( F \): function depending on tissue properties

2. Circuit Heat

Indicator of thermal influence by electromagnetic wave exposure
3.1 Specific Absorption

1. Standards for Peak SAR

• We consider about FCC standard in America that is most strict standards than other countries.

• FCC standard
  \[ \text{SAR (per 1g)} < 1.6[W/Kg] \]

• Our value in muscle is \(0.845[W/Kg]\) that satisfy FCC standards.

• These standards are based on exposure from sources outside the body but we consider sources inside the body.
• So the value of SAR might have to be lower than the standards.
3.1 Temperature Characteristic

- Surrounding medium of the leader is muscle.
- Consider the temperature in the leader position.
- The more it narrows the switch time, the more the temperature lowers.
3.1 Aim of Proposed MAC protocol

Problem of collecting the information

Communication in the cluster

Collecting the information from each RFD node results in inefficiency.

The leader is affected by thermal influence during longer time and thermal influence increase.

Thermal influence is significantly dependent on the processing time when the cluster leader receives the information from each RFD node.
3.1 Access Procedure of Proposed Protocol

**Fundamental access procedure**

![Diagram of access procedure]

**Backoff time**: a term of carrier sense

\[
\text{Backoff time : Backoff } \times \text{ slot time}
\]

\[
\text{Backoff : integral number randomly generated in the interval } [0, \text{ CW}]
\]

\[
\text{CW} : (CW_{\text{min}} + 1) \cdot 2^n - 1
\]
3.1 Adaptive Controlling Back-off Time Algorithm

The proposed Algorithm

\[ CW_{min} = \alpha \cdot M \]

Backoff Coefficient Table

<table>
<thead>
<tr>
<th>( \alpha )</th>
<th>( M ) (The number of RFD node)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>( M &lt; 35 )</td>
</tr>
<tr>
<td>30</td>
<td>( M \geq 35 )</td>
</tr>
</tbody>
</table>

Objective of our algorithm

- Derive an appropriate range of backoff time corresponding to the number of RFD nodes to transmit data most efficiently under the restriction of max temperature of human tissues.
- Optimum back-off coefficient \( \alpha \) to minimize processing time according to the number of RFD nodes has been pre-calculated and saved.
3.1 Flowchart of Proposed Protocol

**Leader node**
- Allot a unique address for each RFD node

**Sleep**
- Broadcast data (back_off time)
- Broadcast information (wake_up)
- Receive sensing data
- Transmit sensing data (to receiver outside the body)

**Cycle**
- Yes: Broadcast information (sleep) & leader switch
- No: End the default cycle??

**RFD node**
- Belong to a cluster (Receive address)

**Sensing**
- Receive data (back_off time)
- Receive information (wake_up)
- Transmit sensing data

**Sleep**
- Yes
- No: Receive information (sleep)??
3.1 Performance Evaluation

Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data-rate</td>
<td>250kbps</td>
</tr>
<tr>
<td>payload</td>
<td>500bits</td>
</tr>
<tr>
<td>DATA time</td>
<td>2480μs</td>
</tr>
<tr>
<td>Slot time</td>
<td>144μs</td>
</tr>
<tr>
<td>DIFS time</td>
<td>192μs</td>
</tr>
<tr>
<td>SIFS time</td>
<td>400μs</td>
</tr>
<tr>
<td>ACK time</td>
<td>352μs</td>
</tr>
<tr>
<td>Switching interval</td>
<td>10cycles</td>
</tr>
<tr>
<td>Number of packets</td>
<td>50packets</td>
</tr>
<tr>
<td>RFD nodes</td>
<td>5~40</td>
</tr>
</tbody>
</table>

Assumption

- Assume that range attenuation and packet error are ignored.

- Number of packets

- Data size to transmit of each RFD node in a cycle

※extract a referential treatise
3.1 Performance Evaluation

Simultation parameters

<table>
<thead>
<tr>
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<th>Value</th>
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<tbody>
<tr>
<td>Data-rate</td>
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</tbody>
</table>

Assumption

We assume that range attenuation and packet error are ignored.

※ extract a referential treatise
3.1 Thermal Influence Evaluation

The temperature of leader is saturated after a time caused by cooling effect of blood flow.

✔ Proposed protocol can control the thermal influence better than the existing protocols.
3.1 Conclusions of MAC Protocol Considering Thermal Influence to a Body

• We have proposed a novel protocol to minimize thermal influence to a body by switching cluster leaders.

• This protocol may be applicable to any MAC protocol of BAN as a unique approach considering medical purpose of BAN in a sense of SAR.
3.2 Positioning or Localization of BAN Nodes in the presence of Non Line of Sights Propagation
3.2 Motivation and Objective

• Positioning or Localization system
  – Using an inherent property of UWB, we propose a positioning or localization scheme for BAN.
  – In order to estimate the position of BAN nodes, we focus on Time of Arrival (TOA) positioning method using measurement of distance by UWB.
  – Position information is used to divide the cluster for MAC layer design.
  – It is desirable to reduce the processing quantity for low power consumption.
3.2 Assumed environment

• By communicating with each node, distance between nodes is estimated.
• Each position of node is estimated by the distance.
3.2 Positioning Algorithm of TOA Method

– NEWTON algorithm
  • (high-speed convergence and a small processing quantity)

- Compute distance by Observed time

\[ \Delta R_i = c \cdot t_i \]

- Initial value configuration: \((x_0, y_0)\)

\[ R_i^0 = \sqrt{(X_i - x_0)^2 + (Y_i - y_0)^2} \]

- Residual matrix from estimation value, linearization

\[ R_i = \frac{\partial R_i}{\partial x} \Delta x + \frac{\partial R_i}{\partial y} \Delta y \]

- Computing of gradient

\[
\frac{\partial R_i}{\partial x} = -\frac{(X_i - x_0)}{\sqrt{(X_i - x_0)^2 + (Y_i - y_0)^2}} \quad \frac{\partial R_i}{\partial y} = -\frac{(Y_i - y_0)}{\sqrt{(X_i - x_0)^2 + (Y_i - y_0)^2}}
\]
3.2 Positioning Algorithm of TOA Method

- adjust matrix: \( \Delta(X, Y) \)

\[
\Delta(X, Y) = \begin{bmatrix} \Delta X \ \
\Delta Y \end{bmatrix}^T
\]

- Residual matrix: \( \Delta R \)

\[
\Delta R = \begin{bmatrix} \Delta R_1 & \Delta R_2 & \ldots & \Delta R_n \end{bmatrix}^T
\]

- Computing of gradient matrix \( G \)

\[
G = \begin{bmatrix}
\frac{\partial R_1}{\partial x} & \frac{\partial R_1}{\partial y} \\
\frac{\partial R_2}{\partial x} & \frac{\partial R_2}{\partial y} \\
\vdots & \vdots \\
\frac{\partial R_n}{\partial x} & \frac{\partial R_n}{\partial y}
\end{bmatrix}
\]

- Computing of the Least square solution

\[
\Delta(X, Y) = \left(G^TG\right)^{-1}G^T\Delta R \quad \rightarrow \quad \text{Addition to } (x_0, y_0) \text{, and repeat}
\]
3.2 Mitigation of Influence of Non Line of Sight (NLOS) Paths

• A barrier or undesired object between transmission and reception nodes makes arrival time longer due to indirect path with non-arrival of direction wave.

• This effect of non line of sight (NLOS) leads to degradation of positioning accuracy.

• Using temporarily estimated position of all nodes, NLOS paths can be selected and removed or mitigated in a list of available paths for more accurate positioning.
3.2 Mitigation of NLOS Paths influence

Estimated position by all nodes: \[ [X, Y]_{temp} = [X_{temp}, Y_{temp}] \]

NLOS influenced value: \[ \Delta L_i = \Delta R_i - \sqrt{(X_i - X_{temp})^2 + (Y_i - Y_{temp})^2} \]

- Remove largest NLOS path node as worst influenced node of NLOS paths.

- Excluding removed NLOS path node, positioning process is performed by information of other LOS nodes.

- These processes are repeated at \( Nd \) times, where \( Nd \) is the number of removed nodes.
3.2 Simulation Results

<table>
<thead>
<tr>
<th>Field</th>
<th>10x10 [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node number</td>
<td>9</td>
</tr>
<tr>
<td>Deleted number</td>
<td>1, 2, 3, 4</td>
</tr>
<tr>
<td>Nd</td>
<td></td>
</tr>
<tr>
<td>Trial number</td>
<td>50000</td>
</tr>
<tr>
<td>Distance</td>
<td>0.2[m] (Gaussian)</td>
</tr>
<tr>
<td>measurement</td>
<td></td>
</tr>
<tr>
<td>error</td>
<td></td>
</tr>
<tr>
<td>Node position</td>
<td>0.2[m] (Gaussian)</td>
</tr>
<tr>
<td>error</td>
<td></td>
</tr>
<tr>
<td>Average NLOS</td>
<td>2 [m] (Exponential)</td>
</tr>
<tr>
<td>Delay</td>
<td></td>
</tr>
</tbody>
</table>
3.2 Simulation Results

Optimal \( Nd \) is determined by each NLOS rate, distance measurement error, node position error or node number.

Table:

<table>
<thead>
<tr>
<th>Field</th>
<th>10x10 [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node number</td>
<td>9</td>
</tr>
<tr>
<td>Deleted number ( Nd )</td>
<td>1,2,3,4</td>
</tr>
<tr>
<td>Trial number</td>
<td>50000</td>
</tr>
<tr>
<td>Distance measurement error</td>
<td>0.2[m] (Gaussian)</td>
</tr>
<tr>
<td>Node position error</td>
<td>0.2[m] (Gaussian)</td>
</tr>
<tr>
<td>NLOS rate</td>
<td>0.3</td>
</tr>
</tbody>
</table>
3.2 Decrease of Processing Complexity

• Number of computation on node information (approximation number)
  – All search algorithm … 2500 times
  – Partial Filter algorithm … 400 times
  – NEWTON algorithm … 10 times

• NEWTON algorithm is effective to reduce processing complexity and power consumption.
3.2 Concluding Remarks of BAN Nodes Positioning or Localization

- We proposed an optional function of BAN standard as the positioning system robust against performance degradation due to non line of sight (NLOS) propagation paths.

- We focused on NEWTON algorithm (TOA) in perspective of low consumption but we have published many other alternative choices applicable for BAN node localization.

- NLOS influence in accuracy of positioning can be mitigated by removing NLOS path nodes.
4. Concluding Remarks

• We have proposed some useful technologies in PHY and MAC of BAN satisfying requirement of both medical and non-medical uses considering trade-off between reliability and efficiency.

• For PHY, a pulsed chirp UWB using hopping and combined hybrid ARQ and FEC for medical and non-medical uses have been proposed.

• For MAC, a control scheme of thermal influence by switching cluster leaders has been proposed.

• In addition of our proposal in March, a positioning or localization scheme of BAN nodes has been introduced using UWB inherent property.

• This presentation could be useful to make a complete standard of BAN more attractive for both medical and non-medical uses by introducing these key schemes applicable to BAN.
Reference


3. Haruka Suzuki, Ryuji Kohno, “Error-Controlling Scheme for UWB Wireless Communications for both Medical and Non-Medical Uses,” IEICE Technical Conference on Medical ICT, Tokyo (Japan), April 23, 2009


