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

Submission Title: [YNU's 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 cheap UWB is proposed because of its total performance for WBAN. Inparticular, hybrid type of ARQ and FEC is proposed to staisfy 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.]

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

YNU's PHY and MAC Design for WBAN IEEE P802.15.6

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Yokohama National University

1. Motivation

BAN for both medical and non medical systems must satisfy different requirements such as reliability and safety for a human body, and efficiency so on.

In order to design PHY and MAC of BAN satisfying the different requirements as follows,

1. PHY
   1.1 Pulsed Cheap UWB using sequence
   1.2 Error correction scheme for medical and non medical uses
2. MAC
   2.1 Protocol considering thermal influence to a body by switching cluster

2. Physical Layer design
Pulse design

2. Body Area Network

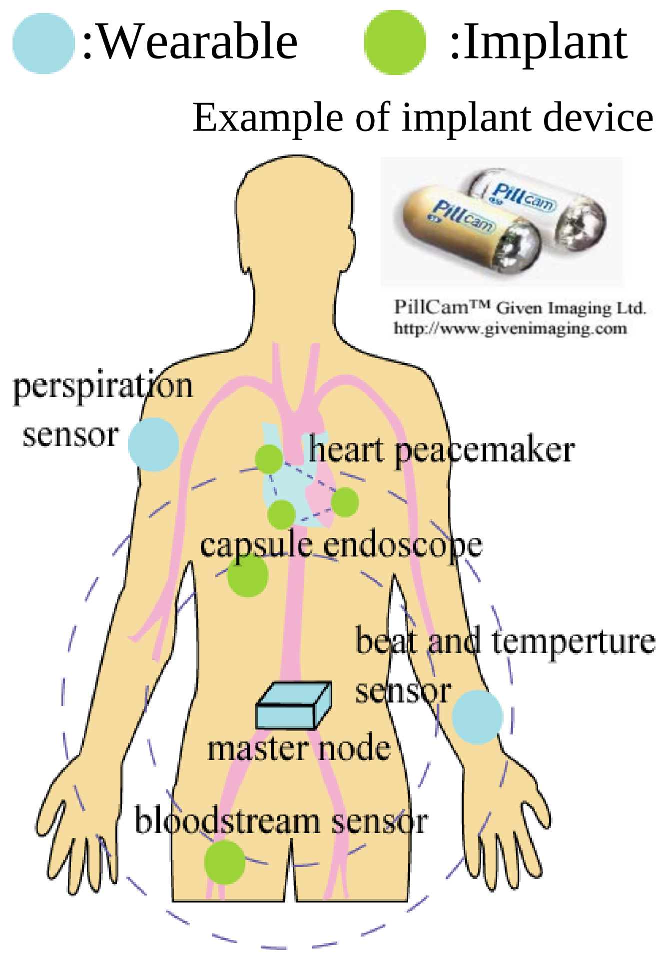
•Body Area Network

Networks composed of wireless communication inside or outside the human body

Implant WBAN

Wearable WBAN

Measure parameter of vital signs
Helped handicapped
etc.



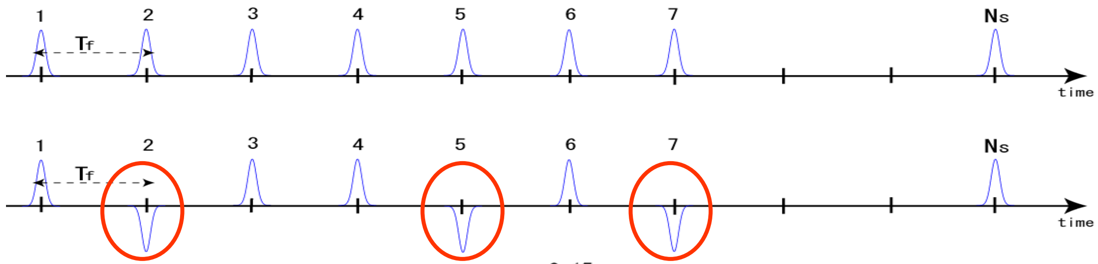
2. Direct Sequence UWB (DS-UWB) and Chirp on UWB (Co-UWB)

DS-UWB system

Characteristic

- merit : the transmitted signal for DS-UWB using the spreading sequence
- demerit : no tolerance to near-far problem

We can distinguish many users



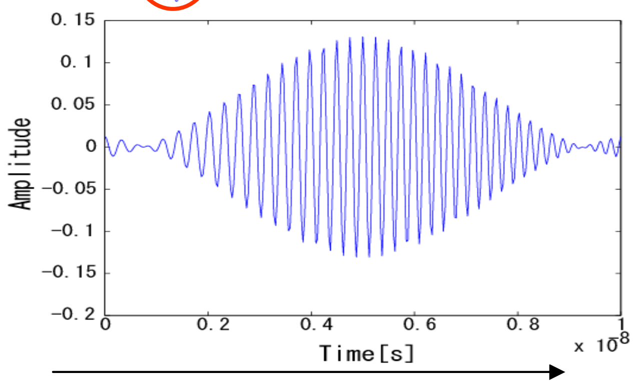
Chirp on UWB(Co-UWB) system

Characteristic

- merit : frequency ranges in between pulse width to time

Using different frequency band each user, tolerance to near-far problem

- demerit : it is difficult to distinguish user A from user B using the same frequency band



low frequency high

2.Pulsed Chirp UWB system

Aim: Independent on circumstance, proposing good performance system

Chirp-on-UWB system

Dividing using frequency,
it is good performance when
SIR is low(near-far problem)

DS-UWB system

Using direct sequence,
It is good performance when
SIR is high

Proposed system

Each pulse use different frequency band(tolerance to near-far problem)

+

Transmitted signal use spreading sequence
(we can distinguish many users)

2. Pulsed Chirp UWB system for Medical use

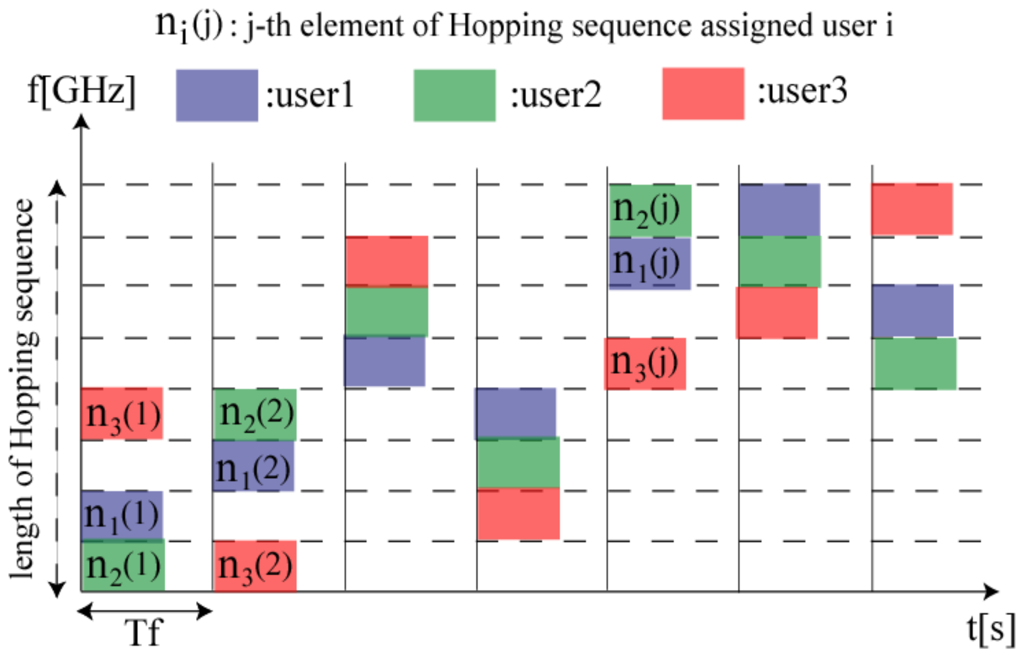
We defined using frequency sub-bands by hopping sequence

Use RS (Reed-Solomon) sequence or
OCC (One Coincidence) sequence

① Divide the bandwidth by applied length of sequence

② Define using frequency sub-band which adapt to each Pulse by Hopping sequence

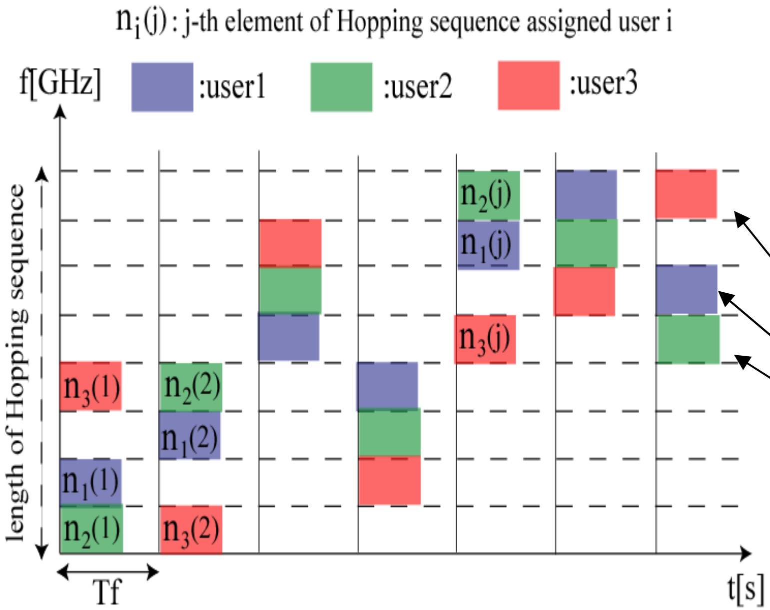
③ Make direct sequence by using gold sequence



2. Pulsed chirp UWB system for Non medical use

Medical use→Utilize Hopping sequence for improvement of performance

Non medical use : Necessity of high speed communication
Utilize hopping sequence for multi-value modulation



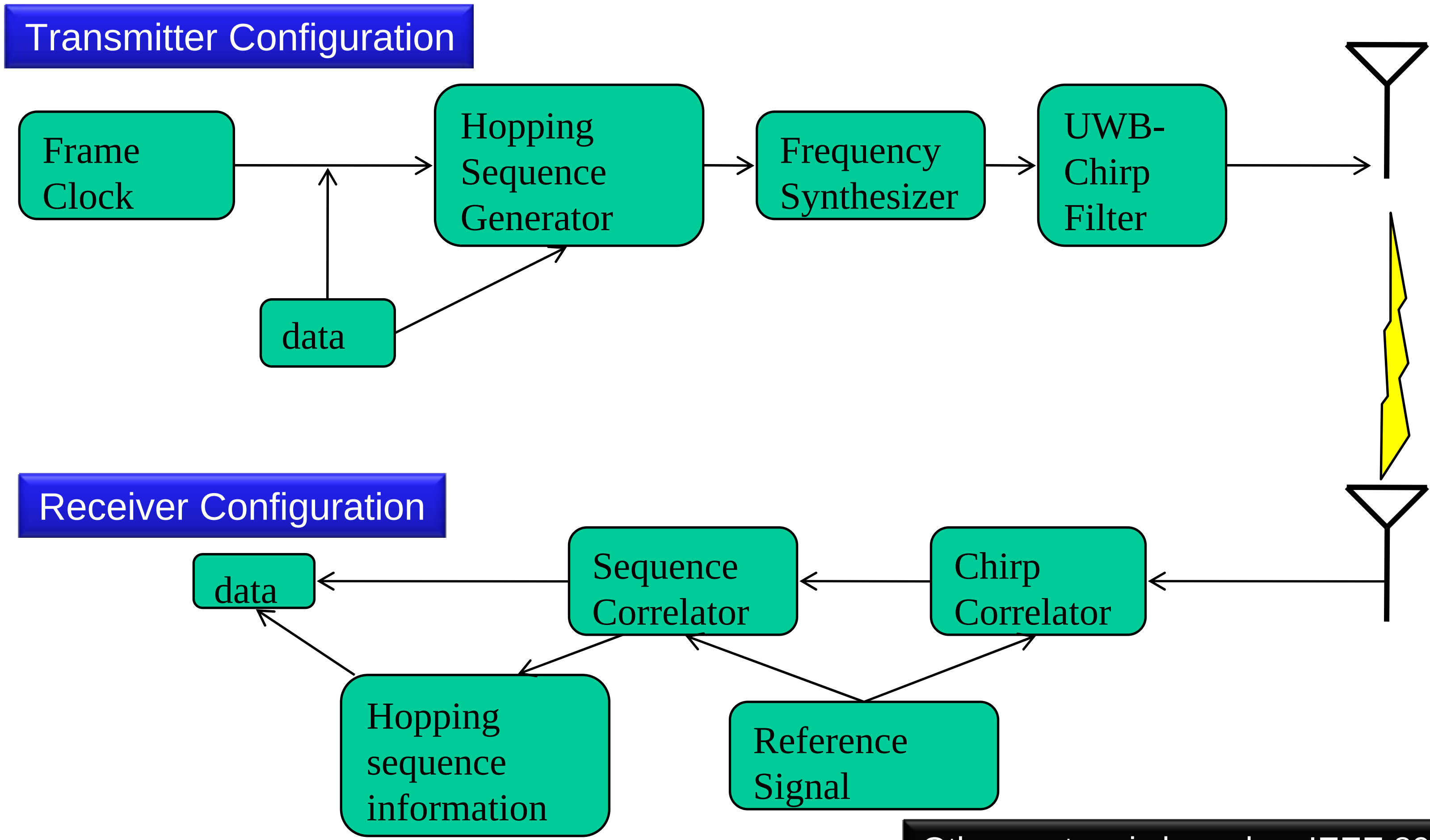
Hopping sequence

Medical use : User identification
Non Medical use : multi-value modulation

Consider RS sequence

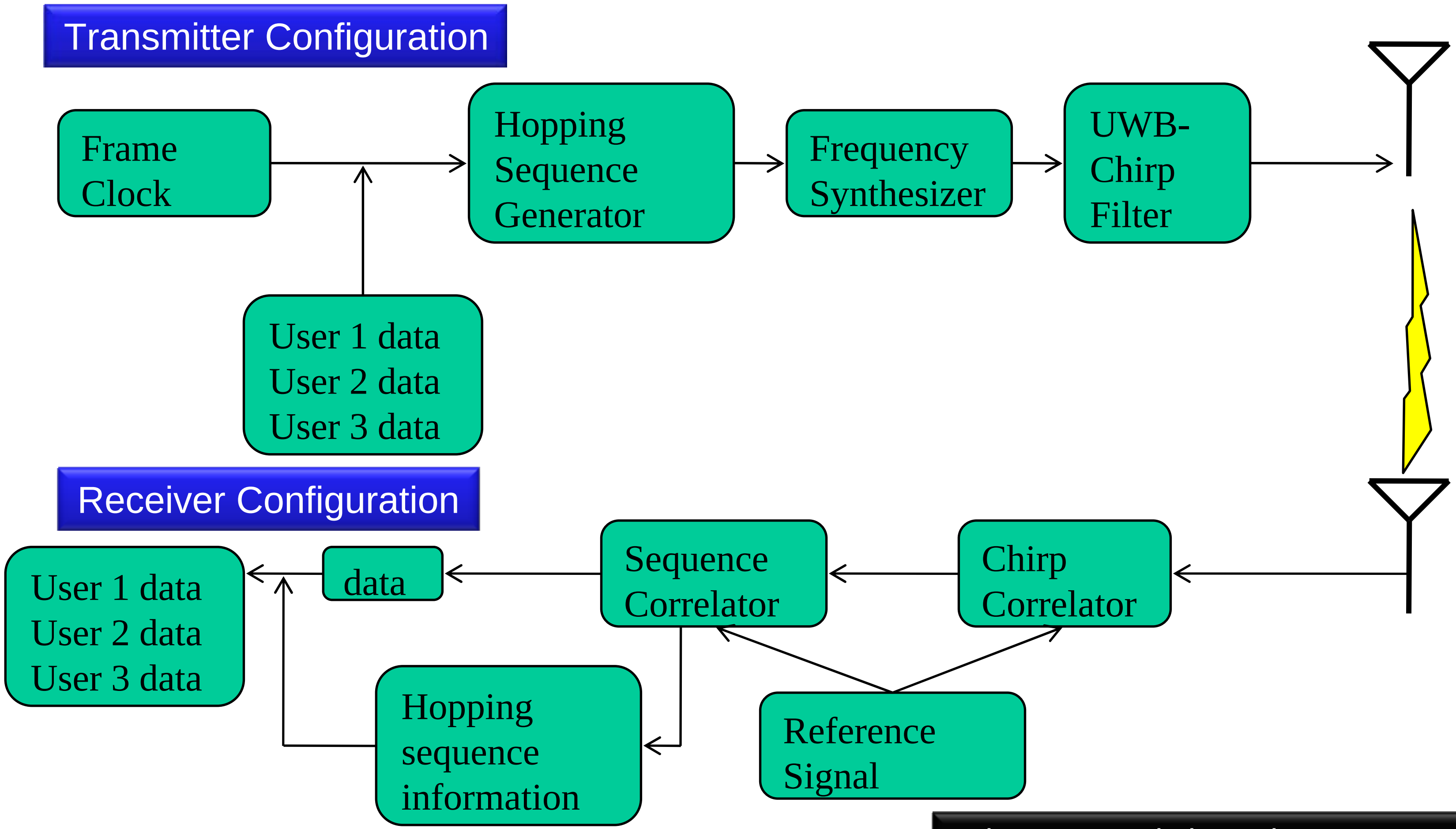
Represent data by each hopping sequence

2. System Configuration Non-medical



Other system is based on IEEE 802.15.4a

2. System Configuration Medical



Other system is based on IEEE 802.15.4a

2. Wearable Wireless BAN channel model

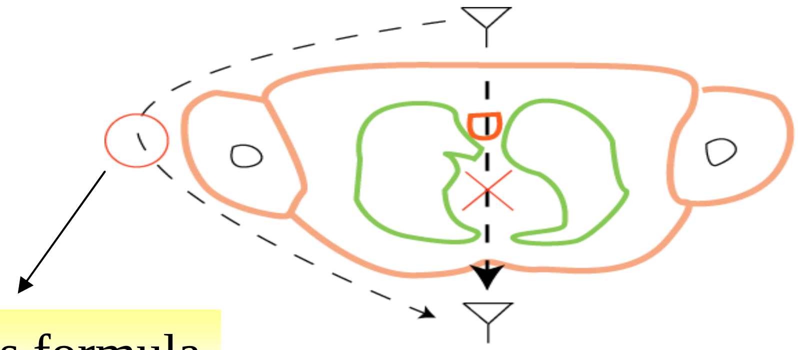
Use channel model which is IEEE802.15.4a channel model-final report

Characteristic

- frequency is 2~6GHz

→ No energy penetrating through the body

Path loss model are defined as the distance around the perimeter of the body



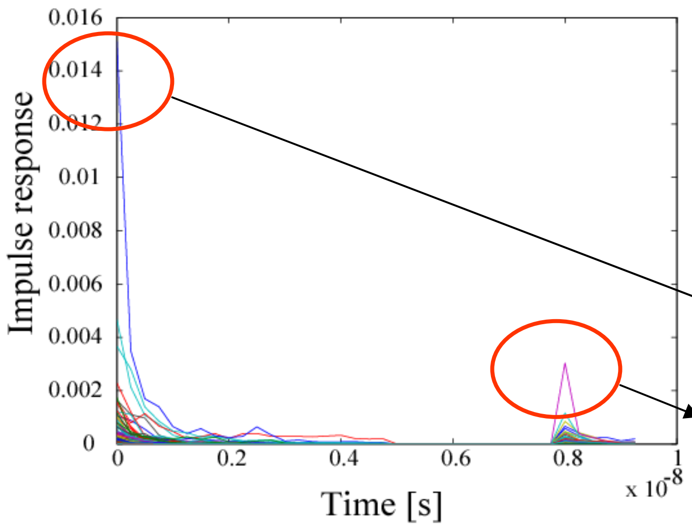
Path loss formula

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

12

γ: units of dB/meter d_0:reference distance

$P_{0,dB}$:Power at the reference distance



Diffracting wave around the body

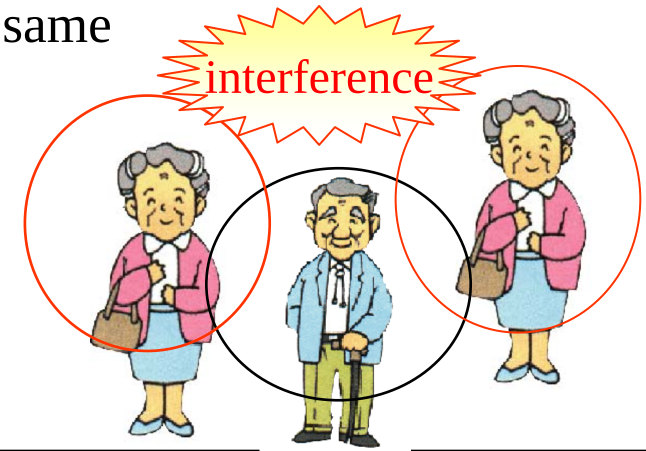
Ground reflection

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

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

2. Simulation Model

- Simulation model
  - Multi pico-net interference problem
  - It is perfectly synchronized and channel known
  - Interference wave arrive in the time which is 1bit transmitted in accordance with uniform distribution
  - Interference factor : interference wave + AWGN
- Parameter of each system
  - Frequency bands which are used Wearable WBAN is the same in each system
  - Bit rate and power consumption of 1bit is the same
  - Number of multi user is the same



2. Performance Evaluation

Simulation Parameters

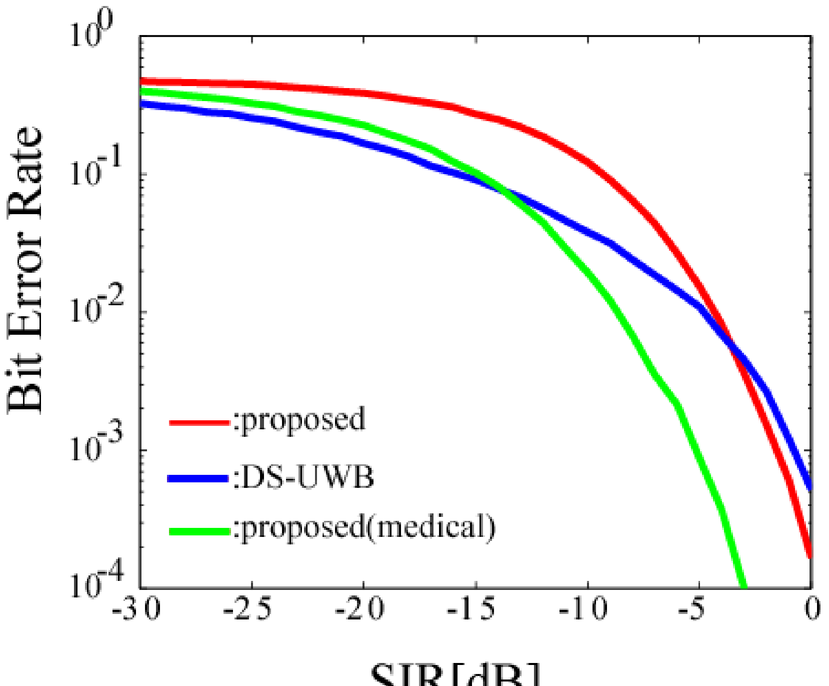
Simulation Situation

Pico-net number: 10
There are some medical systems and some non medical systems

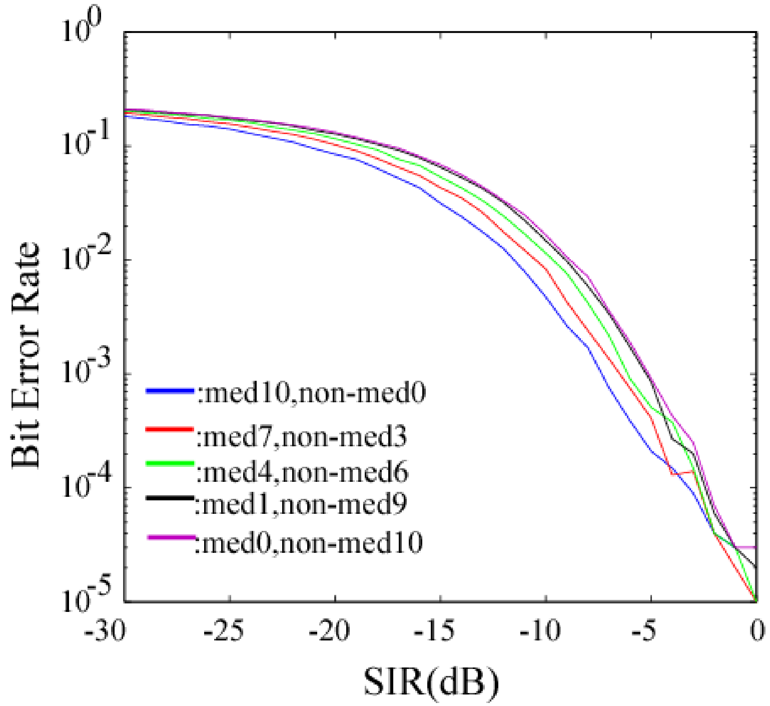
Pulse shape	Root raised cosine roll-off pulse(roll-off rate 0.6)
Bit rate	10Mbps (Non medical : 30Mbps)
Sampling interval	0.03125[ns]
Transmission device position	Front of stomach
Reception device position	arm
Interference Pico-net number	10

2. Performance Evaluation

Result



Interference user number 8



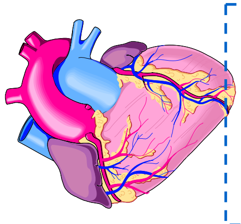
Case of Existing
some Medical and non medical systems

2. Conclusions of pulse design

- We compared conventional methods of UWB IR with proposed system of pulsed chirp with and without frequency hopping
- Both proposed methods with and without hopping sequence are superior to conventional methods

3. Physical Layer design
Error correction design

3. Demand of medical and non medical system



Medical

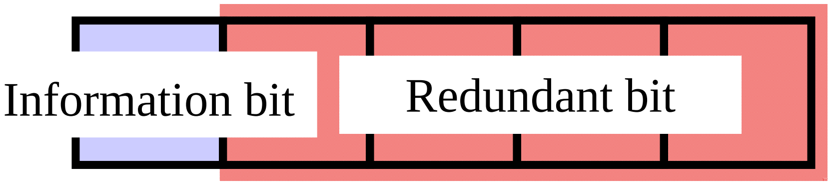
- Robust against interference
- High reliability

Non-medical

- High speed

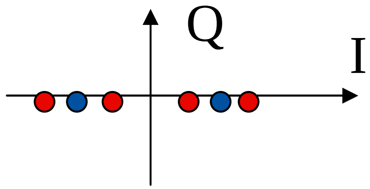
Aim : Consider BAN suitable for both medical and non medical

- **Cording for high reliability**



→Degradation of throughput

- **multi-value modulation for high speed**



Shorten Euclidian distance by multiple from 1 bit ( )to 2 bit ( )

→Increase of error rate

Solution :

Switch error correction method under same modulation and same coding according as medical or non-medical

3. Several type of Error correction method

FEC (forward error correction)

Error detection or error correction by adding redundant bit

ARQ (automatic repeat request)

If packet error is detected, it is retransmitted.

FEC+ARQ

Hybrid ARQ

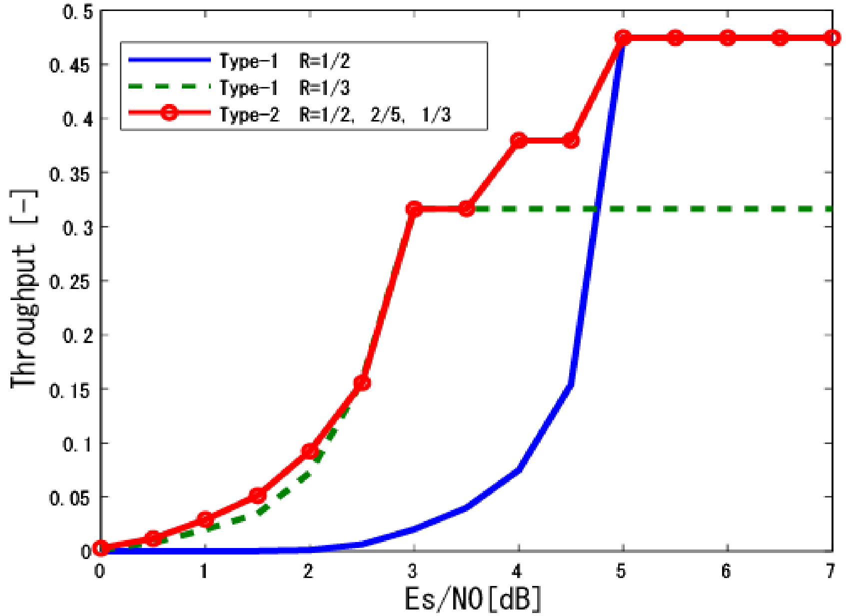
Error correction is performed and if the error cannot be corrected, data is retransmitted.

- type 1 : Retransmit same data

  Example) Chase Combine method

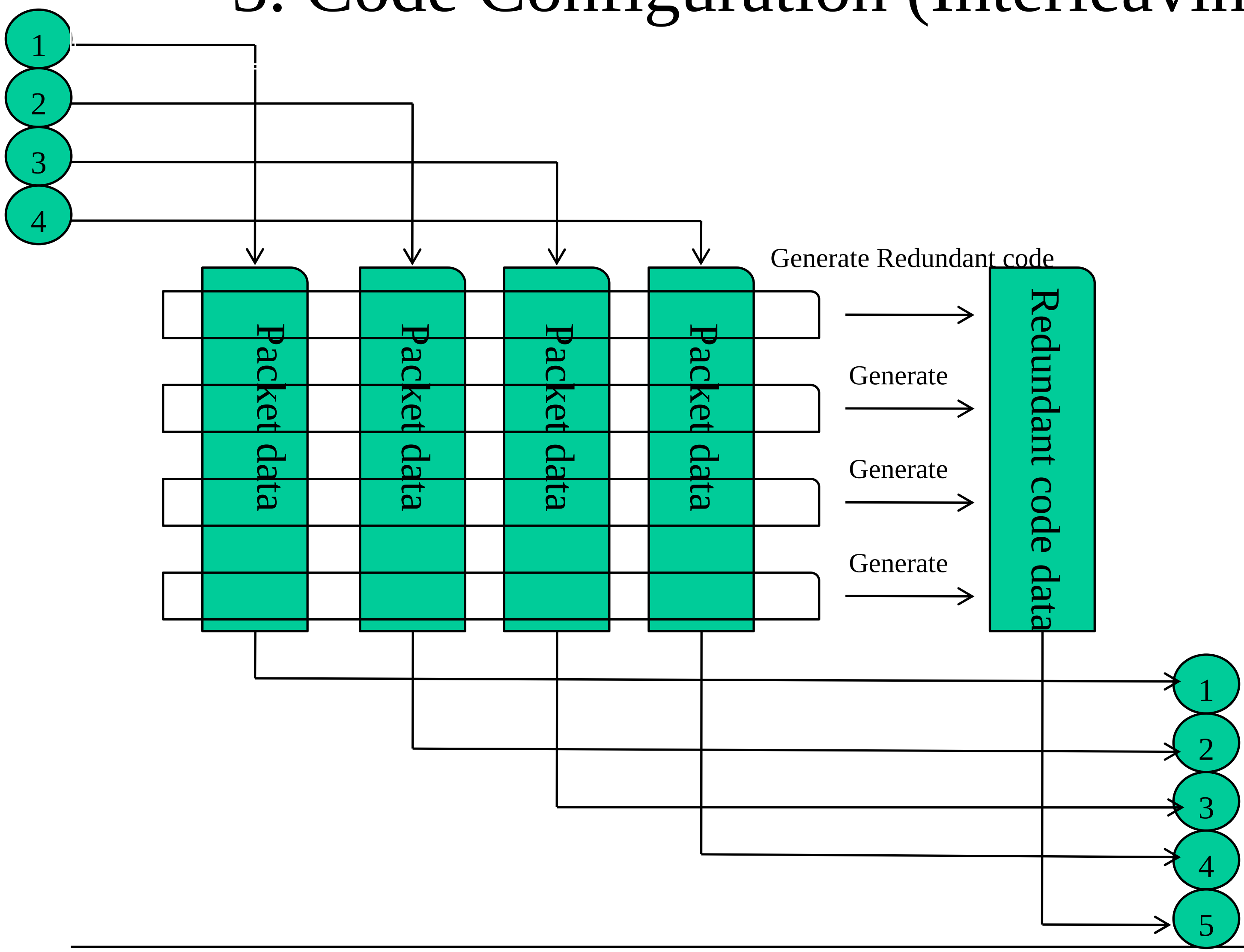
- type 2 : Retransmit other data

Incremental Redundancy method : Retransmit redundant bit



Modulation	BPSK
Noise	AWGN

3. Code Configuration (Interleaving)



3. Error correction suitable medical and non medical

Switch error correction method according as demand in same transmission device

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

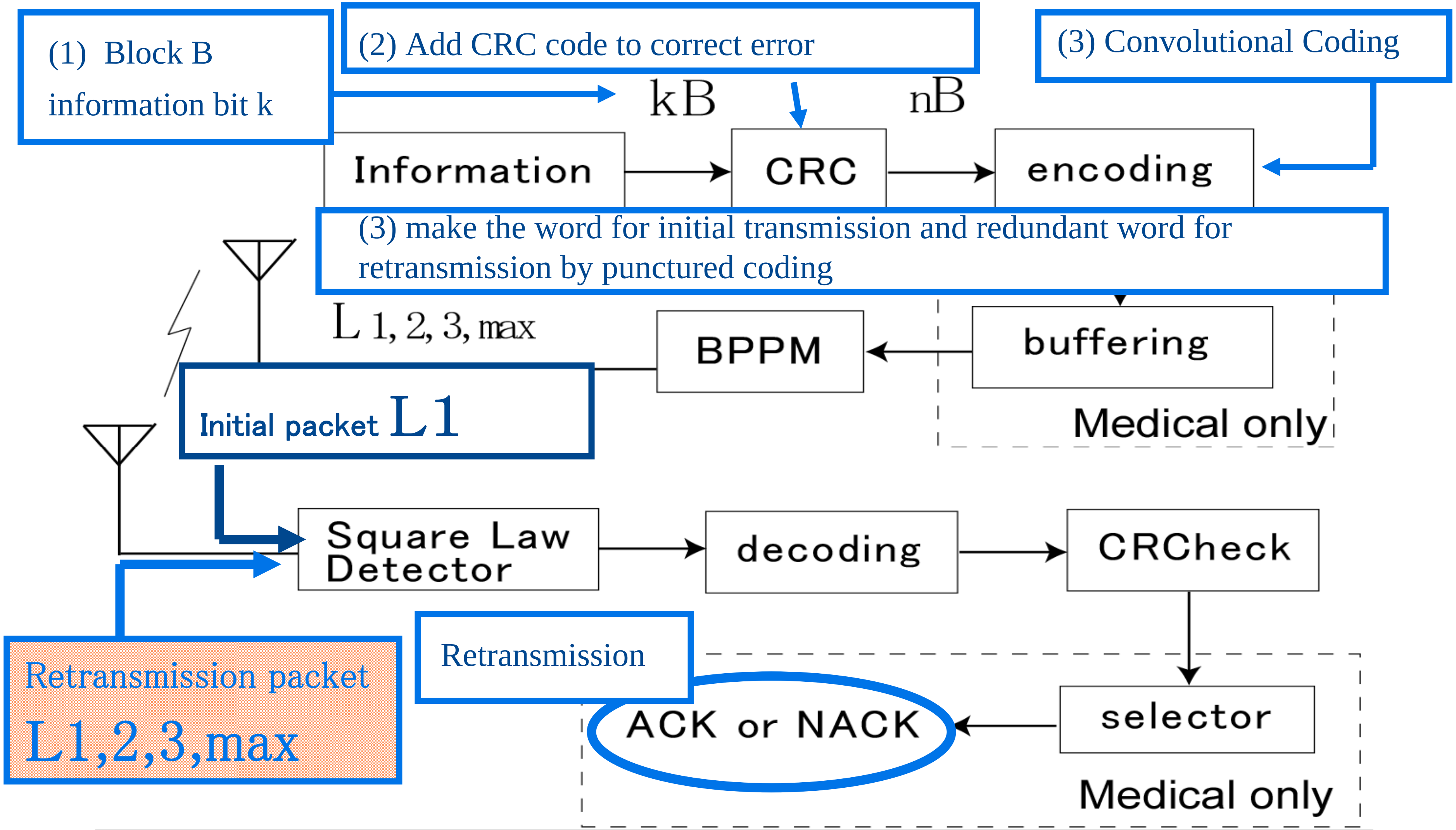
↓

Proposed method

Medical use: Hybrid ARQ
Non medical use: FEC only

Use **Super orthogonal convolutional code** or **Concatenated code** according as purpose

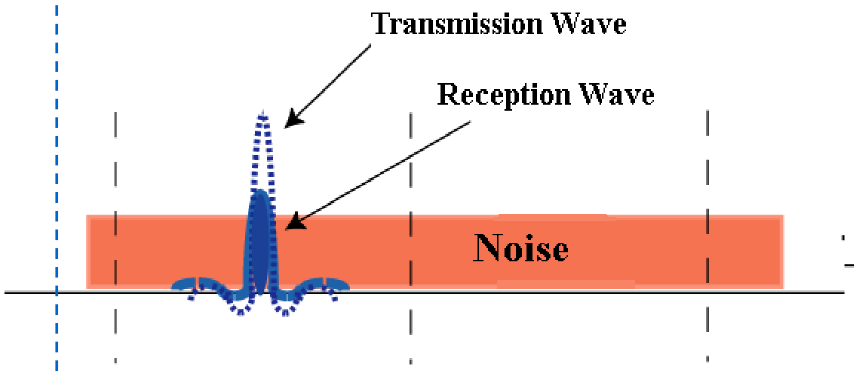
3. Proposed system Flowchart



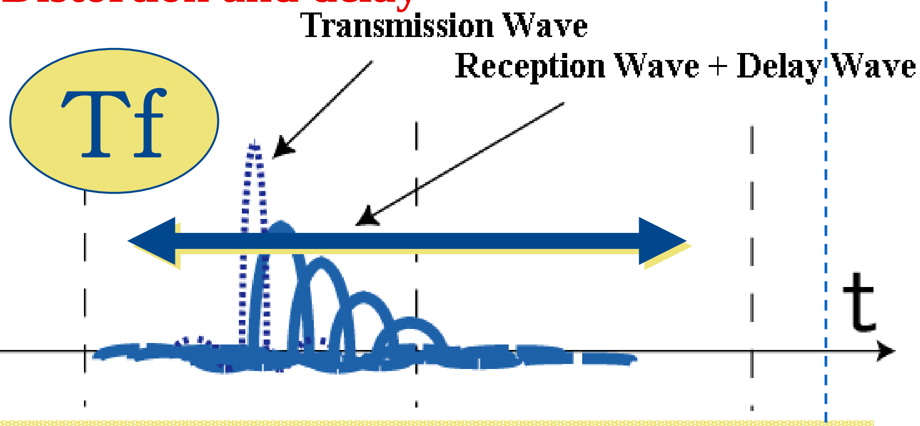
3. Reason for Retransmission

2-PPM (2-value Pulse position modulation)

- **Attenuation**



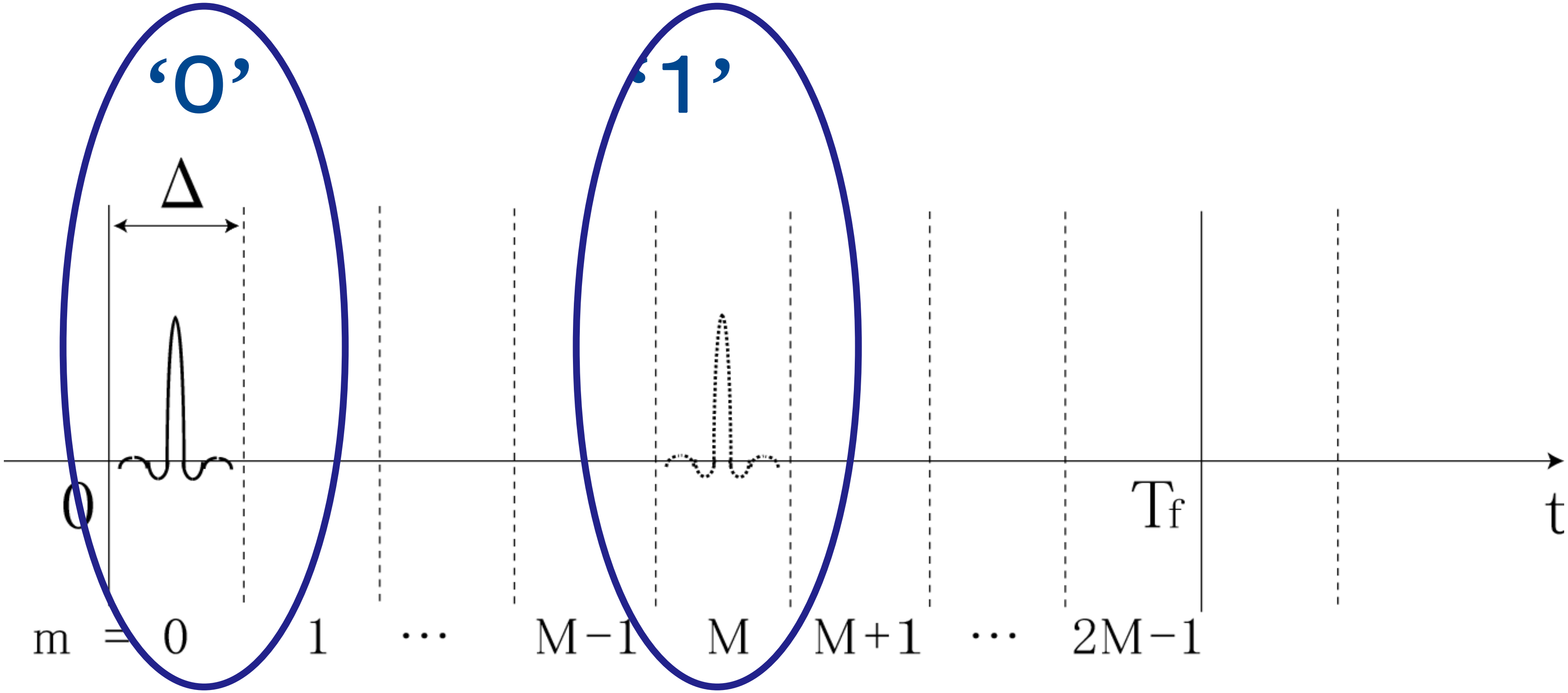
- **Distortion and delay**



Error by ISI(Inter symbol interference)

Avoid the interference by expanding Tf

3. Time Flame Tf



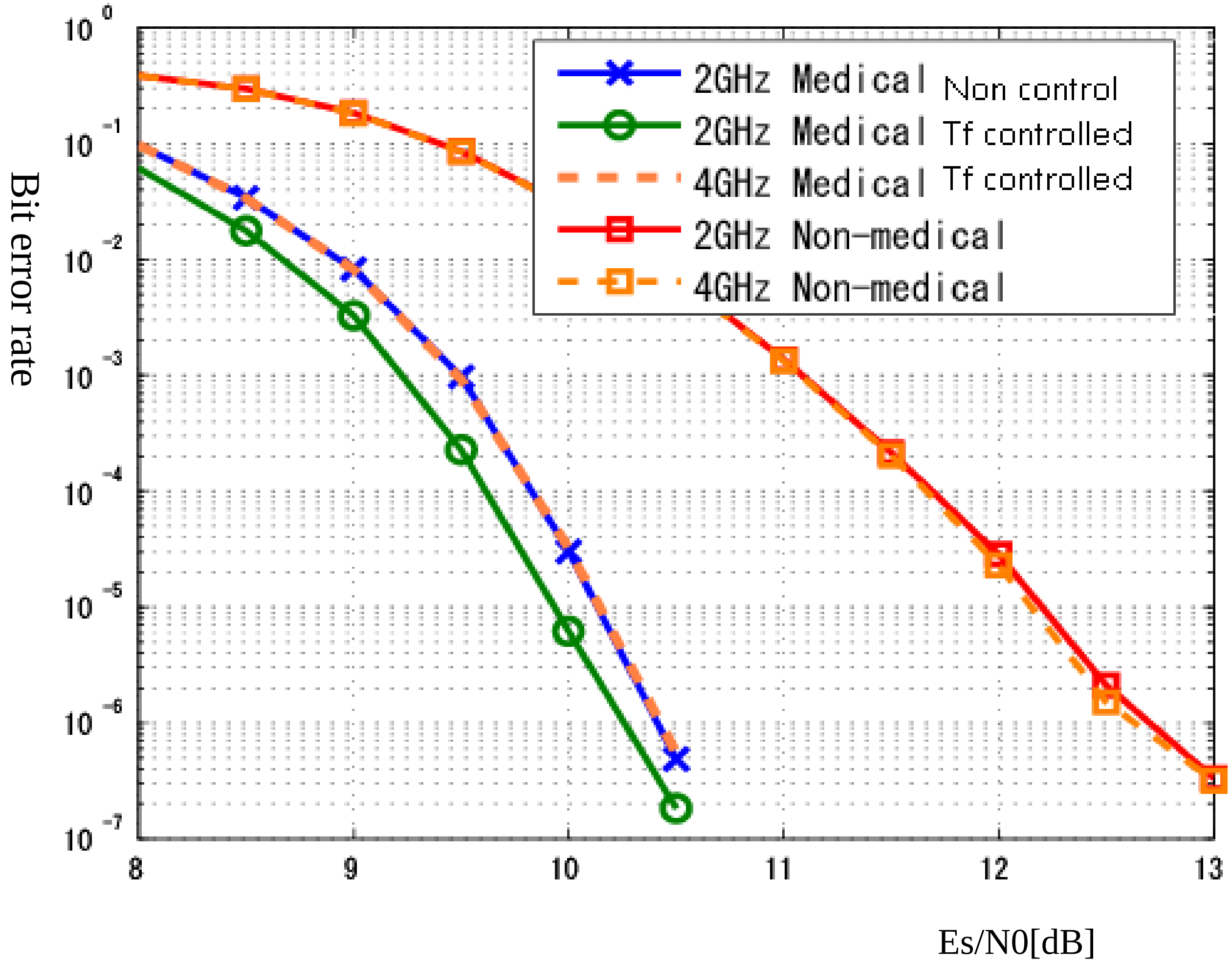
Short Tf : Interference of ISI
Long Tf : Interference of Noise

3. Performance Evaluation
simulation Parameters

Cannel	Two-wave model considering inside body
Modulation	2PPM, Squared detection(soft decision)
Code	Coding rate 1/3 RCPC Code CRC16
Block number length	300 bit , 10 block
Decode	Hard decision Vitabi decode
Retransmission limit	4
UWB pulse	Gaussian mono pulse
Bandwidth	0-2 GHz, 0-4 GHz

3. Performance Evaluation

Evaluation of Bit Error Rate

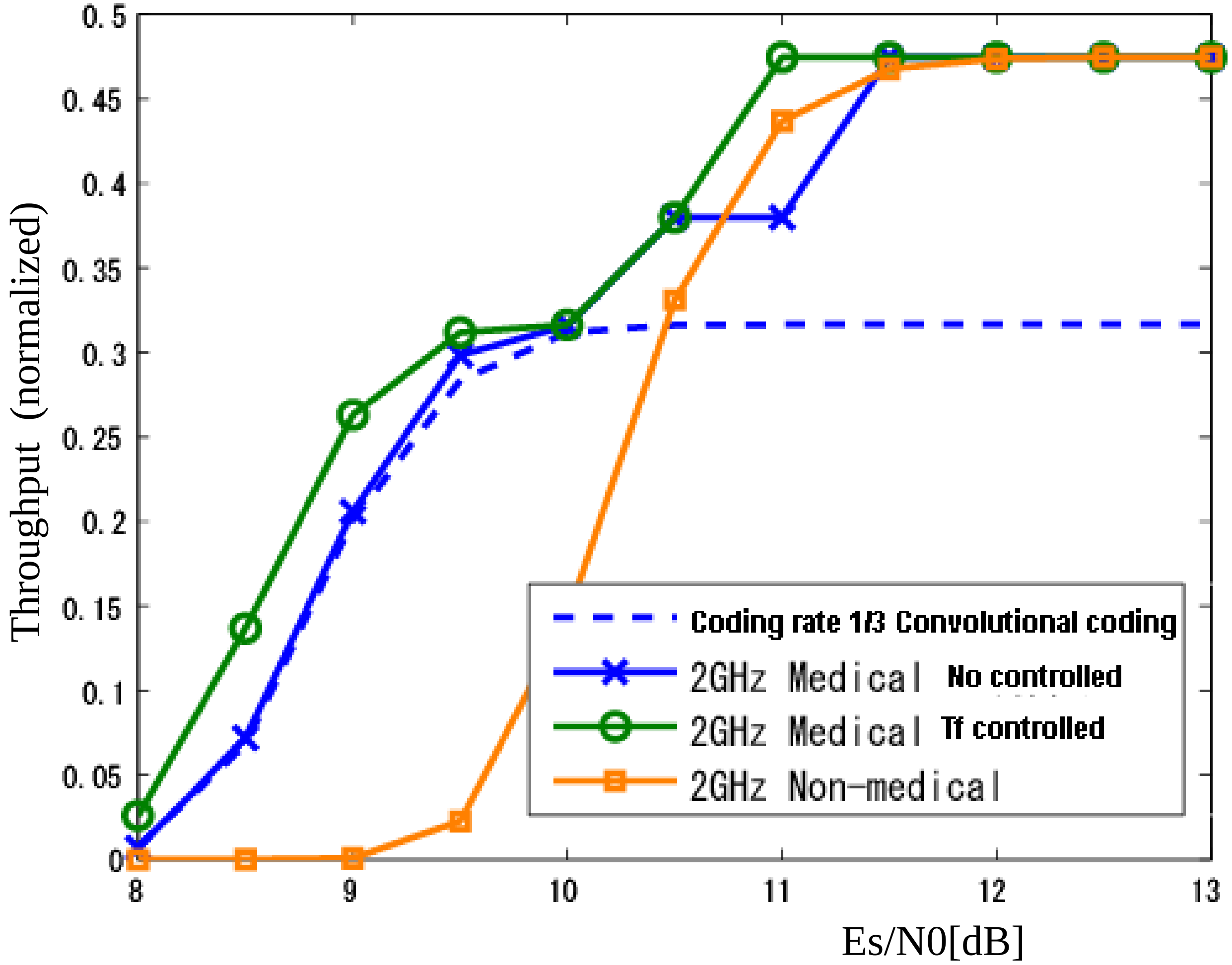


Proposed method fulfills better accuracy about 0.5 dB than normal FEC or ARQ

•Considering attenuation, 2GHz fulfills better quality

3. Performance Evaluation

Evaluation of Throughput



- •Medical use : Max 1Mbps
- •Non medical use : Max 10Mbps
- •Proposed method improves 18-40% compared with coding rate 1/3

3. Conclusions of Error Correction design

- We proposed the error correction method to switch 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.
- This method could satisfy the demand of both medical and non-medical simultaneously.
- Our proposed method can improve bit error rate 0.5dB and throughput 18-40% compared with FEC (coding rate 1/3)
- 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.

4. MAC Layer design

4. Background of MAC design

Integration of medical field and wireless communication technology

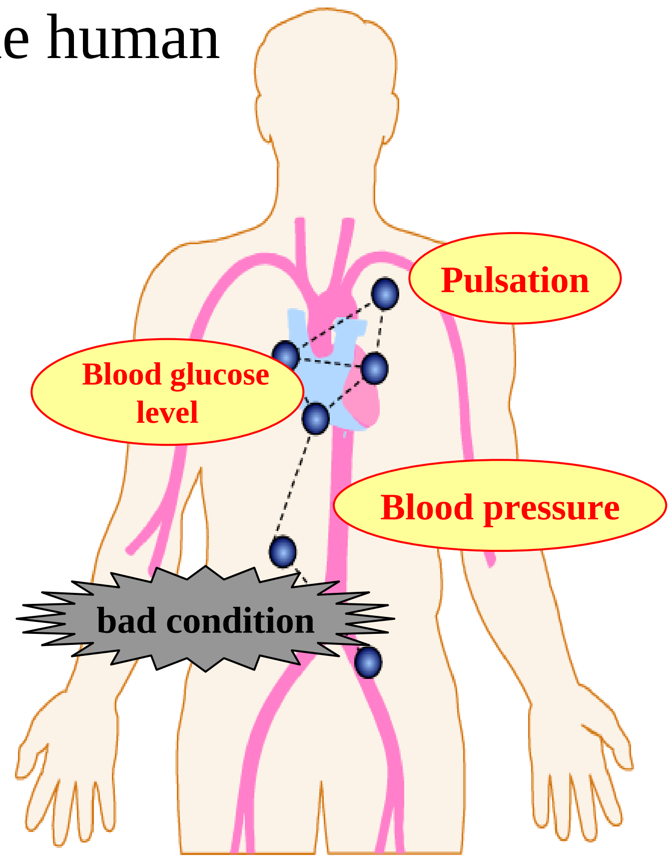
- Implementation of network inside the human body

Ex) • Capsule Endoscope

• Cardiac pacemaker
etc･･･

✓Smaller devices
✓Longer-lasting batteries

●Wireless communication devices (nodes) will be able to form a sensor network inside the human body.



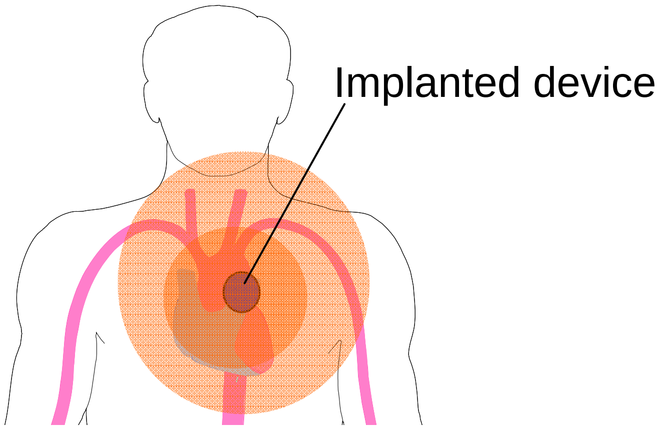
4. Motivation

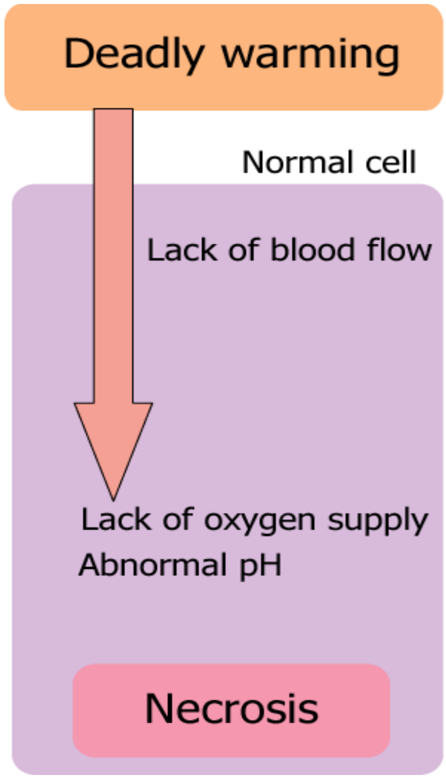
Thermal influence

- The problem of wireless communication inside the human body
  - Thermal Influence by electromagnetic wave exposure and circuit heat

Radiation absorption

Increase of the cell’s temperature





- **Objective**

Network modeling in the human body and
proposal new MAC protocol considered thermal influence

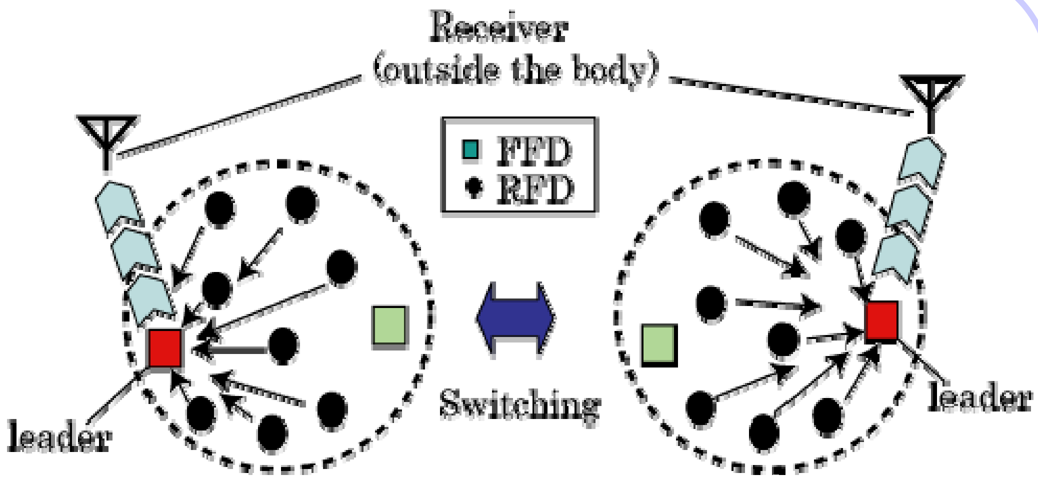
4. Network Structure of Implanted BAN

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 the body.

Switching of cluster leader

- In order to disperse the thermal influence, we switch the leadership between a couple of FFD nodes.



System model

FFD: Full Function Device

RFD: Reduced Function Device

4. Thermal Propagation Modeling

1. Electromagnetic Wave Exposure

- SAR (Specific Absorption Rate) … the rate at which radiation energy absorbed by tissue per unit weight

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

σ : electrical conductivity of the tissue [S/m]

ρ : density of tissue [kg/m^3]

E : RMS induced electric field [V/m]

Indicator of thermal influence by electromagnetic wave exposure

2. Circuit Heat

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

V : voltage of leader node [V]

A : current of leader node [A]

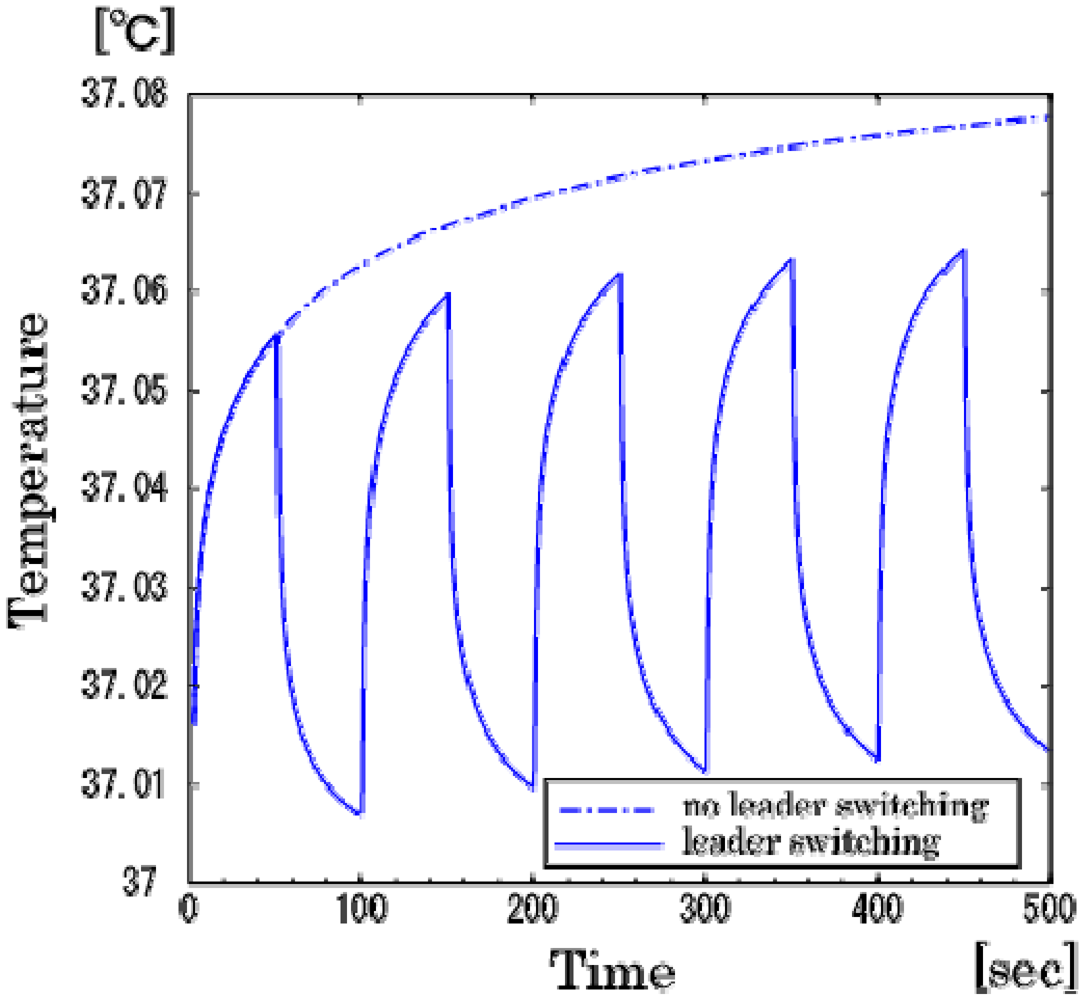
C : specific heat of tissue[J/kgK]

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

4. Temperature Characteristic



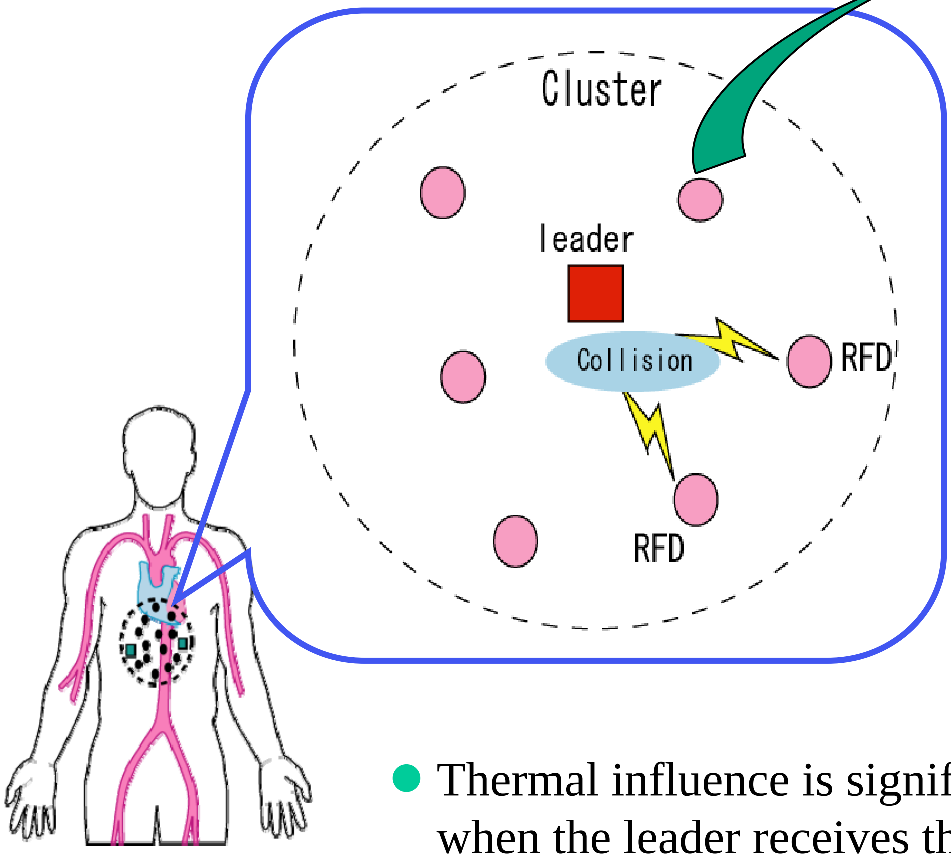
- ✓Surrounding medium of the leader is muscle.
- ✓Consider the temperature in the leader position.

Temperature characteristic with or without leader switching

4. Aim of Proposed MAC protocol

■ Problem of collecting the information

Communication in the cluster



Collision of packets

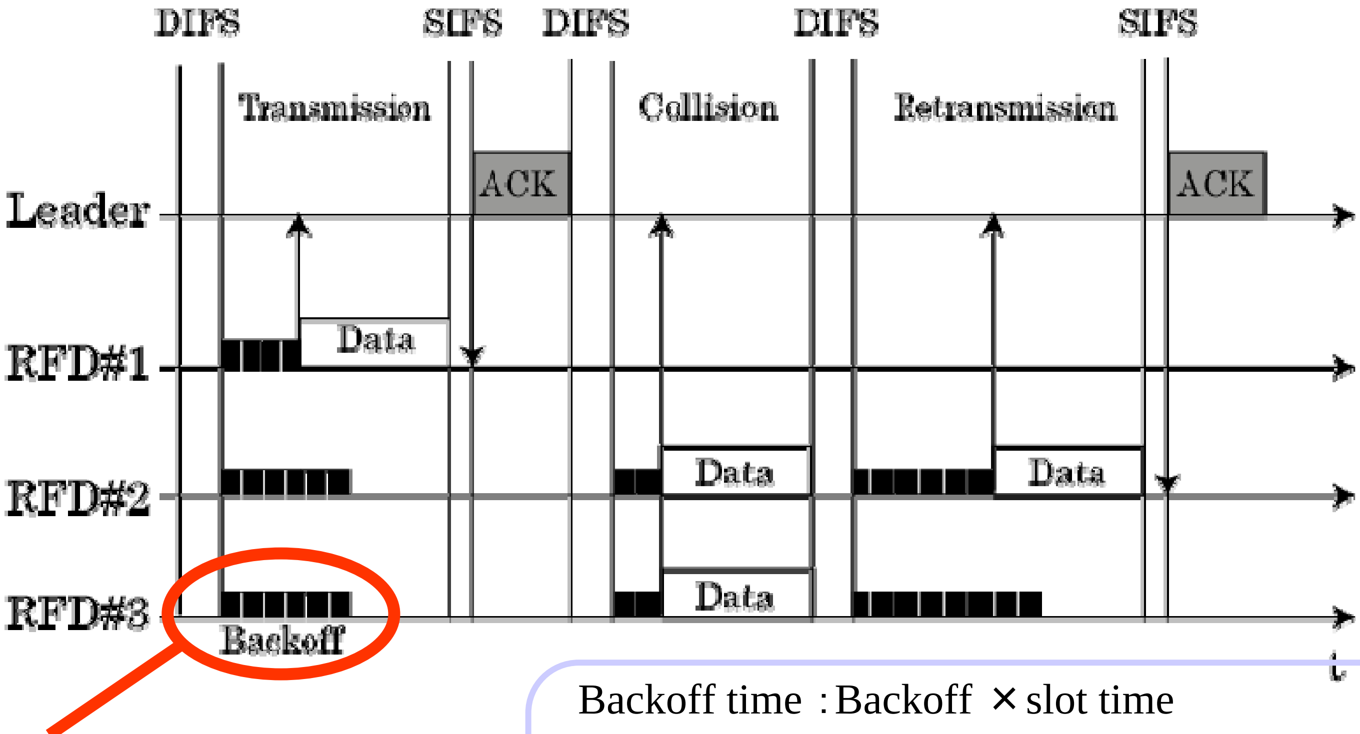
Collecting the information from each RFD node will become inefficient.

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

- Thermal influence is significantly depend on the processing time when the leader receives the information from each RFD node.

4. Access Procedure of Our Protocol

- Fundamental access procedure



Backoff time
: a term of carrier sense

Backoff time : Backoff × slot time

Backoff : integral number randomly generated in the interval [0, CW]

CW: $(CW_{\min}+1)\cdot 2^{n}-1$

4. Adaptive Back-off Algorithm

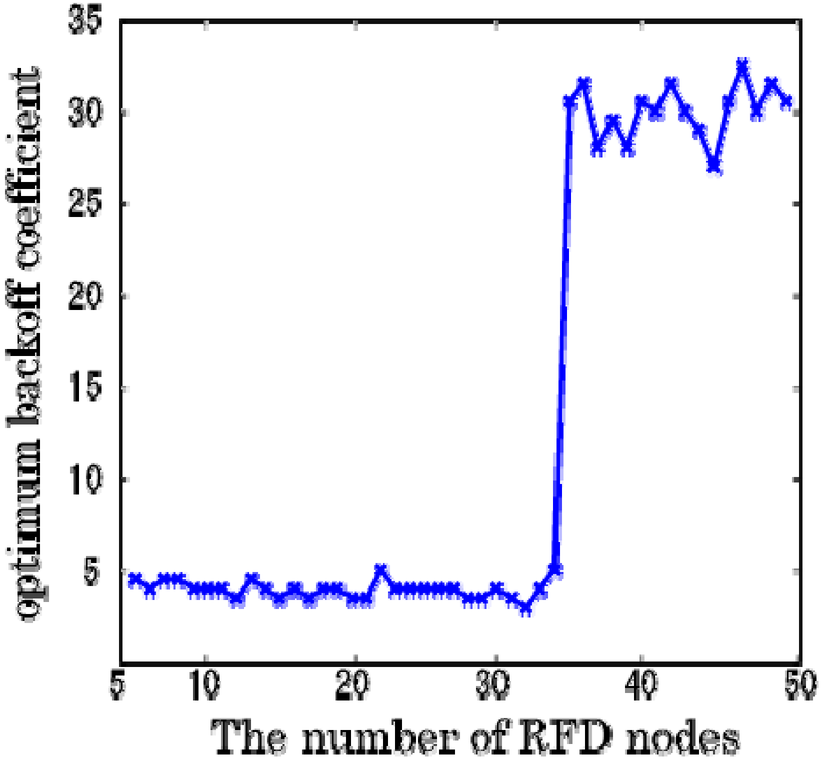
Our proposed Algorithm

$$CW_{\min} = \alpha \cdot M$$

Backoff Coefficient

Backoff Coefficient Table

α	M (The number of RFD node)
4.5	35<
30	35≧

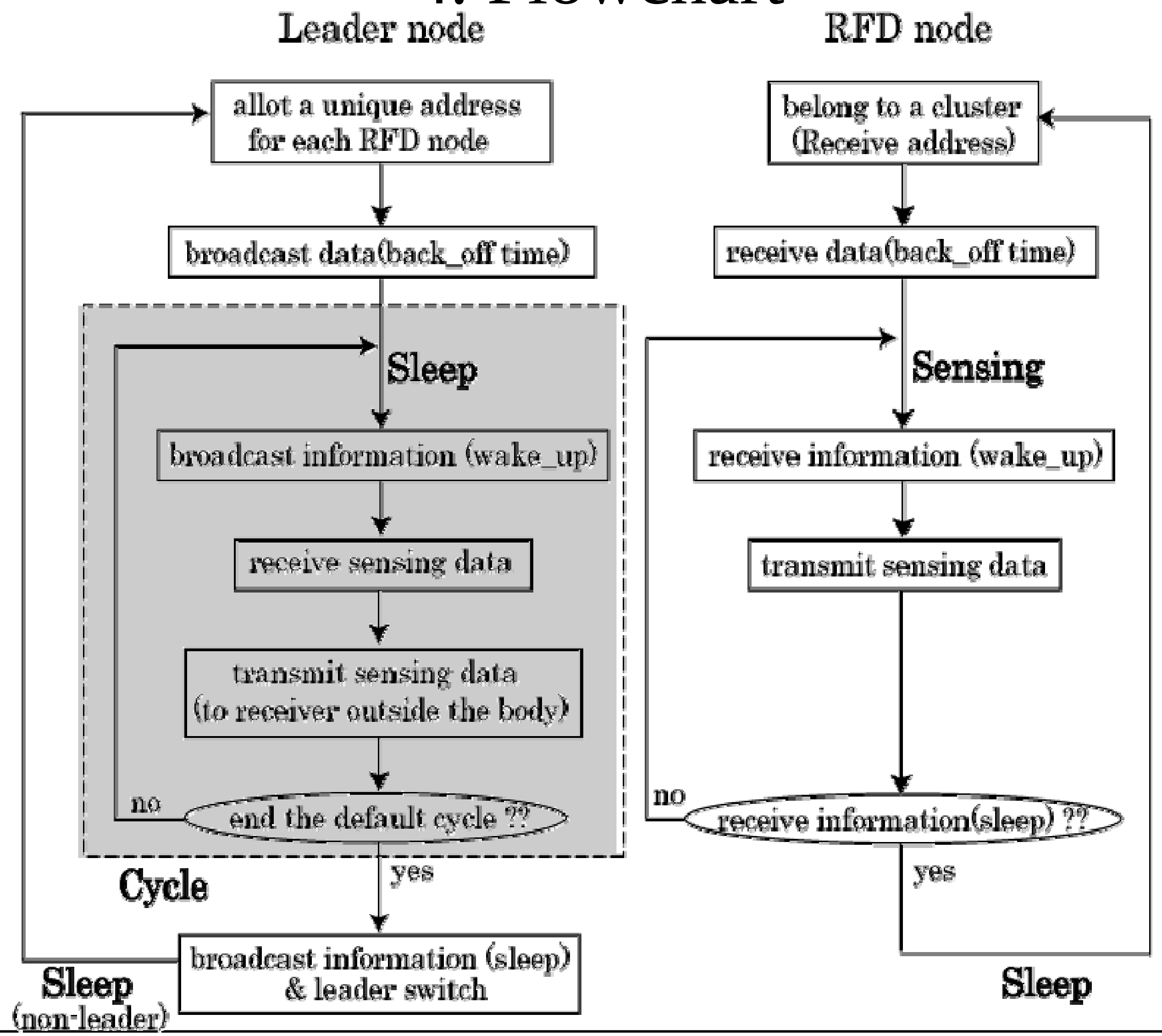


✓ **Objective of our algorithm**

Design of an optimum scope of backoff time depends on the number of RFD nodes to communicate most efficiently

Optimum back-off coefficient computed in advance

4. Flowchart


Leader node
RFD node
allot a unique address for each RFD node
broadcast data(back_off time)
Sleep
broadcast information (wake_up)
receive sensing data
transmit sensing data (to receiver outside the body)
end the default cycle ??
no
yes
Cycle
broadcast information (sleep) & leader switch
Sleep (non-leader)
belong to a cluster (Receive address)
receive data(back_off time)
Sensing
receive information (wake_up)
transmit sensing data
receive information(sleep) ??
no
yes
Sleep

4. Performance Evaluation

Simulation parameters

Data-rate	250kbps
payload	500bits
DATA time	2480 μs
Slot time	144 μs
DIFS time	192 μs
SIFS time	400 μs
ACK time	352 μs
Switching interval	10cycles
Number of packets	50packets
RFD nodes	5～40

※extract a referential treatise

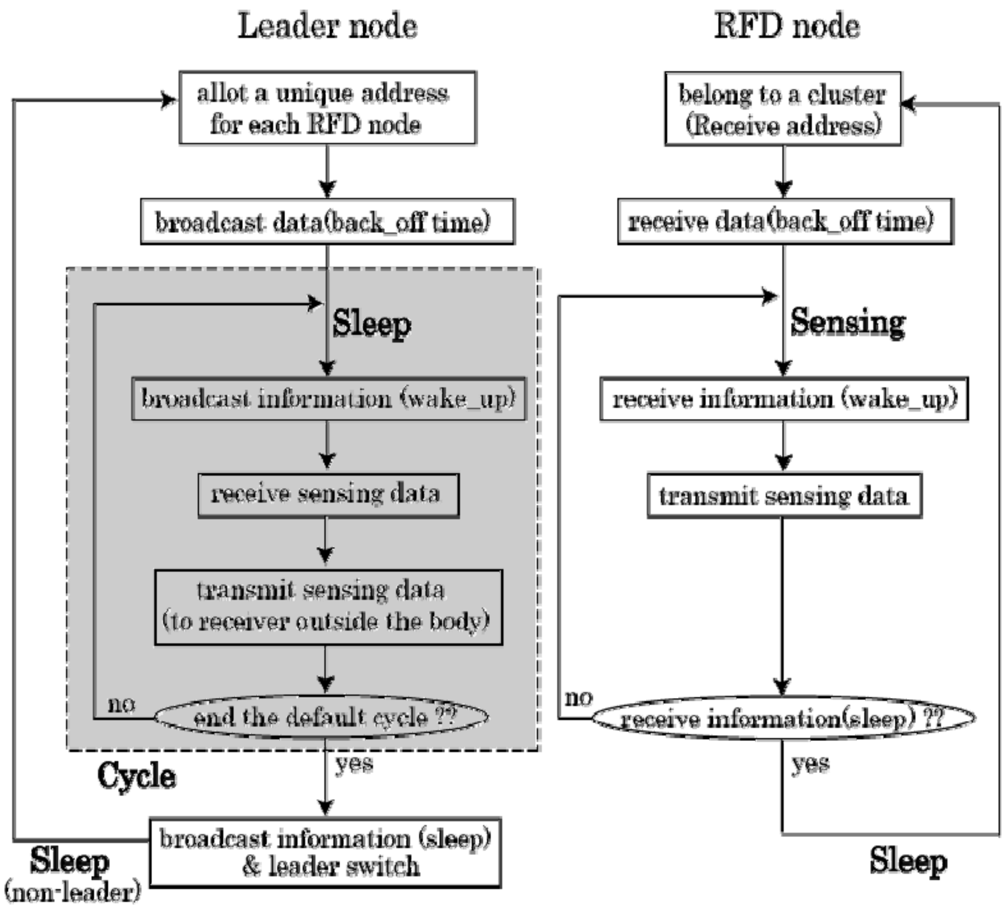
■ Assumption

We assume that range attenuation and packet error are ignored.

✓Number of packets

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

4. Performance Evaluation



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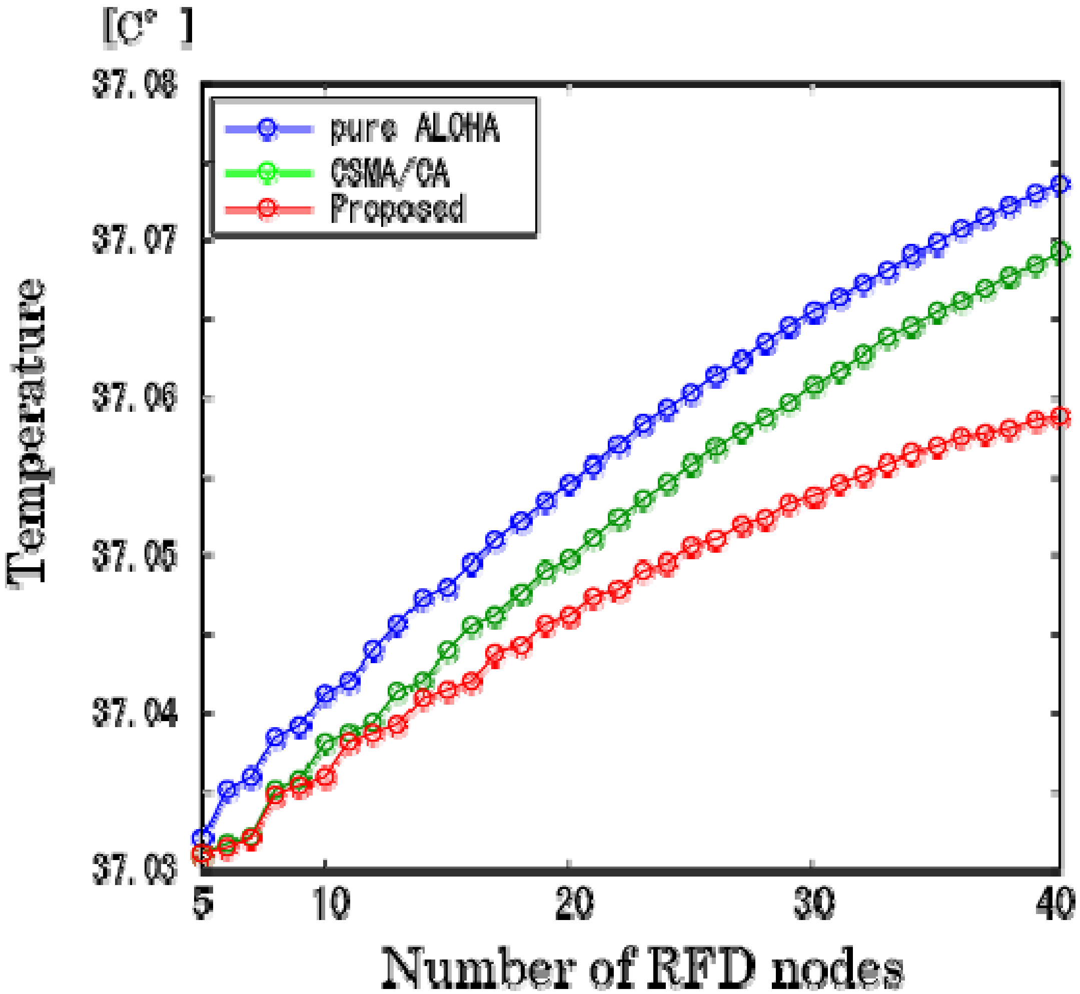
4. Thermal Influence Evaluation



✓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.

Saturated temperature characteristic of each protocol

4. Conclusions of MAC Layer design

We have proposed the system model, which is appropriate for an implanted body area network.

We have proposed a novel MAC protocol, which controls the thermal influence better than existing protocols and confirmed its performance.

5. Concluding Remarks

- We have proposed PHY and MAC of BAN satisfying requirement of both medical and non medical systems considering reliability and safety of a human body and efficiency.

- For PHY, a pulsed UWB using sequence and conbined hybrid ARQ and FEC for medical and non medical have been proposed.

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