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 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.]

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.

We propose our designed PHY and MAC of BAN satisfying the different requirements as follows,

1. PHY
   - 1.1 Pulsed Chirp UWB using sequence
   - 1.2 Error controlling scheme using hybrid ARQ and FEC for medical and non medical uses, respectively
2. MAC
   - 2.1 Protocol considering SAR or thermal influence to a body by switching cluster

2. Physical Layer design: Pulsed Chirp UWB

2. Body Area Network: BAN

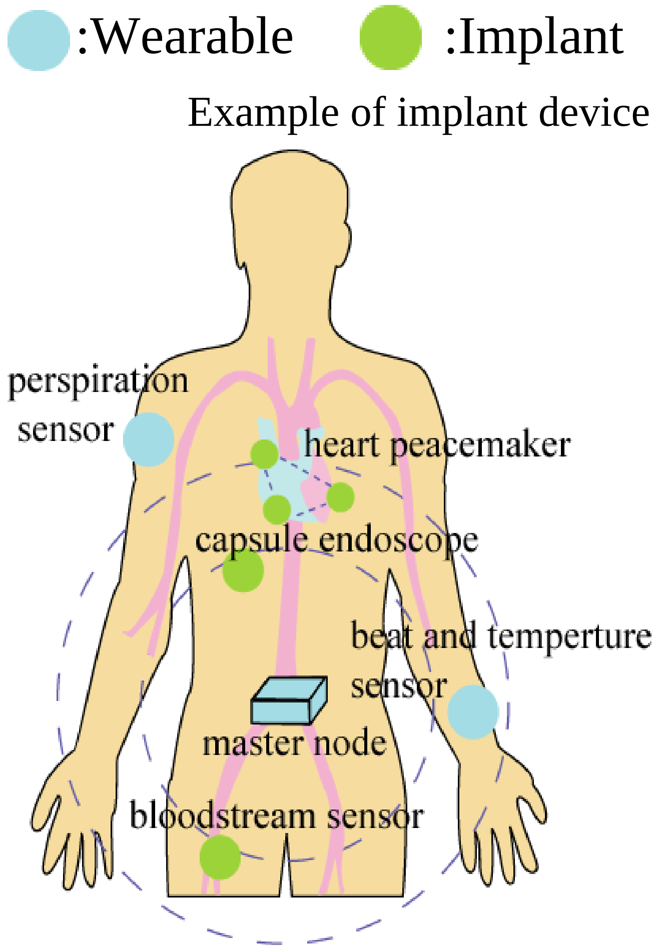
•Body Area Network

Networks composed of wireless communication inside and/or outside a human body

Implant WBAN

Wearable WBAN

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.



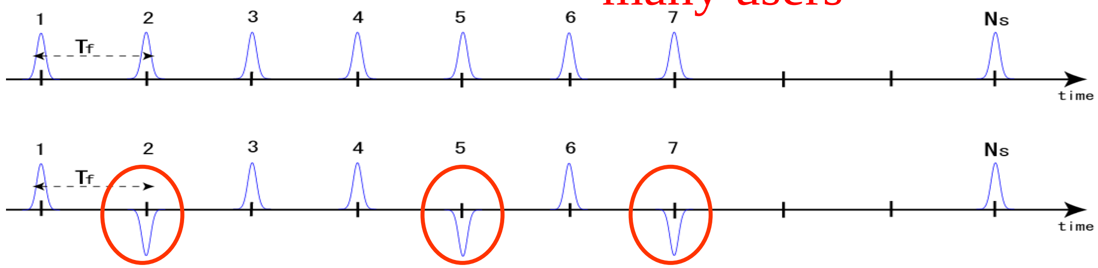
2.1 Direct Sequence UWB (DS-UWB) and Chirp on UWB (Co-UWB)

DS-UWB system

Characteristic

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

→ We can distinguish many users



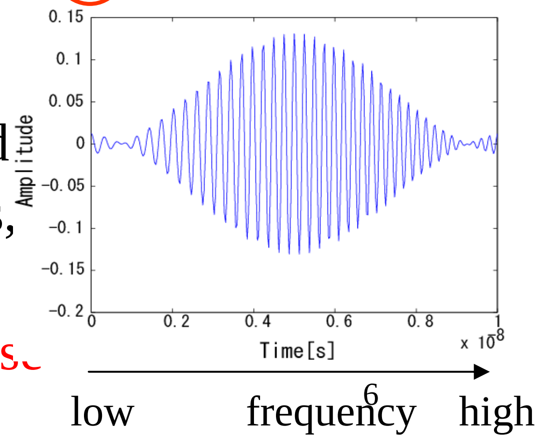
Chirp on UWB (Co-UWB) system

Characteristic

- 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 interference immunity with combined chirp-on-UWB and DS-UWB

Chirp-on-UWB system + DS-UWB system

Using different frequency band,
it is good performance in case
SIR is low (near-far problem)

Using direct sequence,
It is good performance in case
SIR is high

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

Each pulse uses different frequency band for tolerance to near-far problem

+

Transmitting signal uses spreading sequence to distinguish multiple BANs

2.1 Pulsed Chirp UWB system for medical use

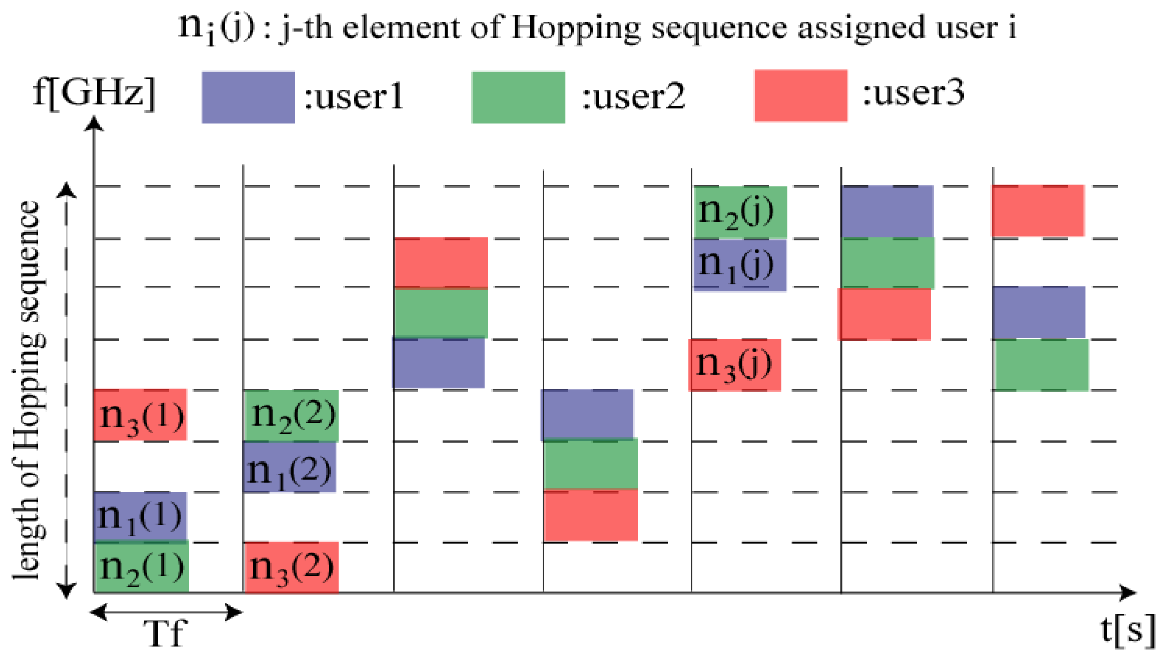
We defined using frequency sub-bands by hopping sequence

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 adapts to each pulse by hopping sequence

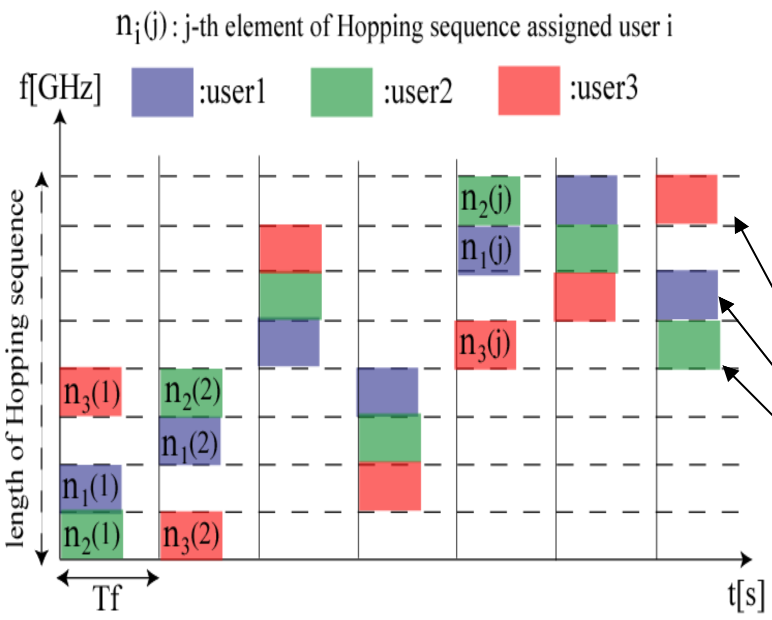
③ Make direct sequence by using direct sequence



2.1 Pulsed Chirp UWB system 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

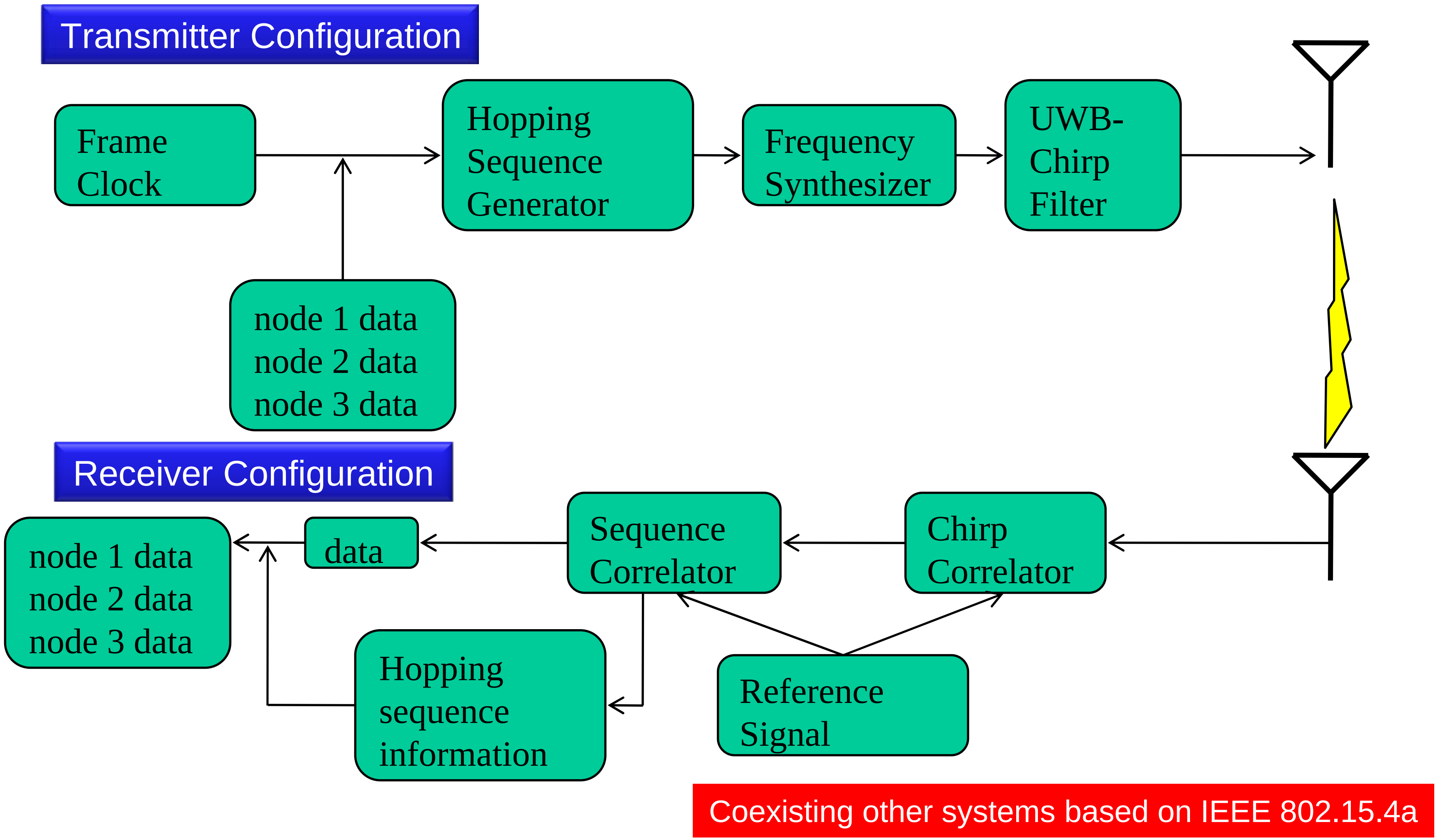


Tasks of Hopping sequence

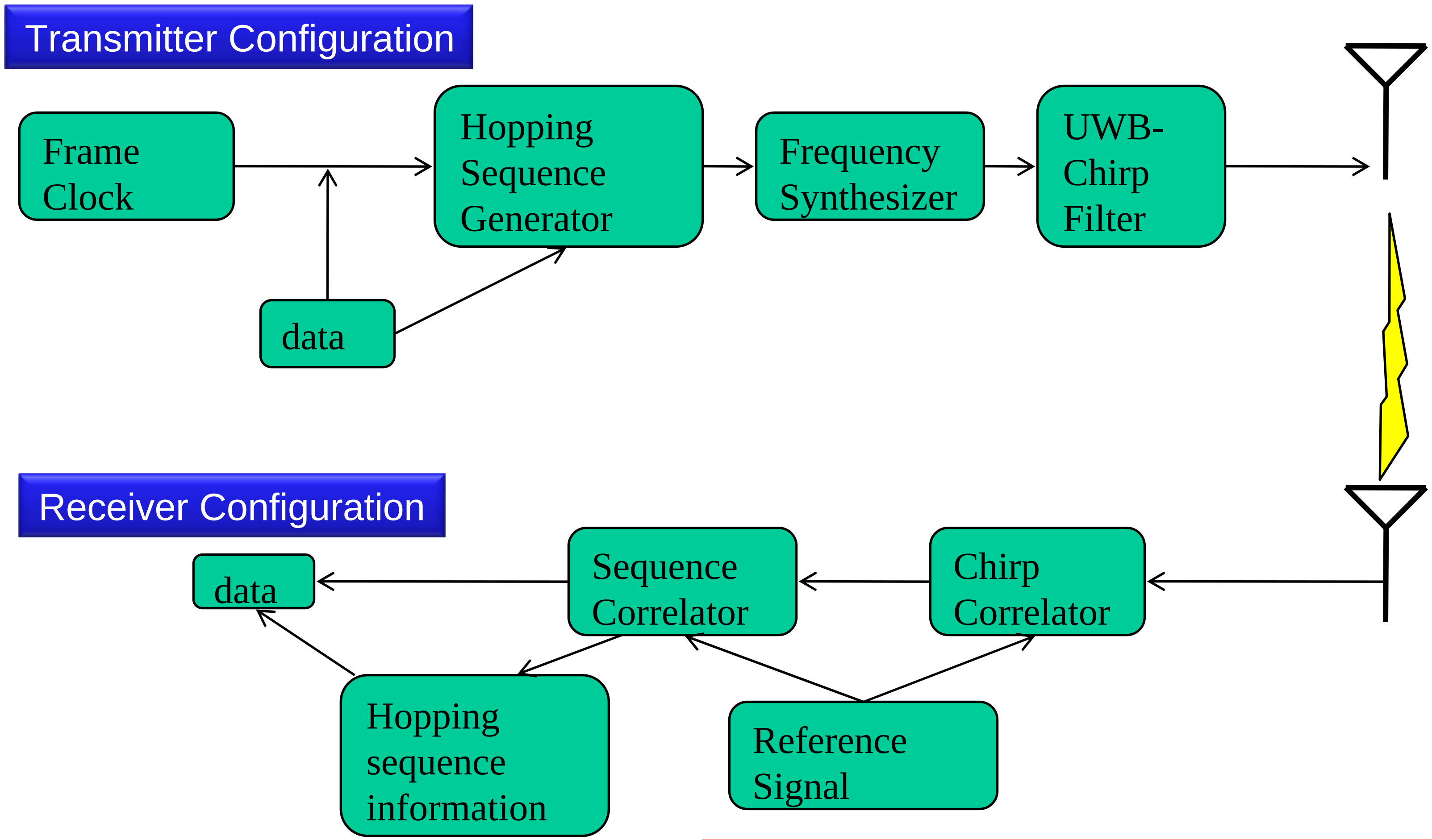
- For medical use: Use for identification of multiple BANs
- For non Medical use: Use for higher data-rate transmission with multi-value modulation

Representing data by each hopping sequence with RS code etc

2.1 System configuration for medical use



2.1 System configuration for non-medical use



Coexisting other systems based on IEEE 802.15.4a

2.1 Wearable Wireless BAN channel model

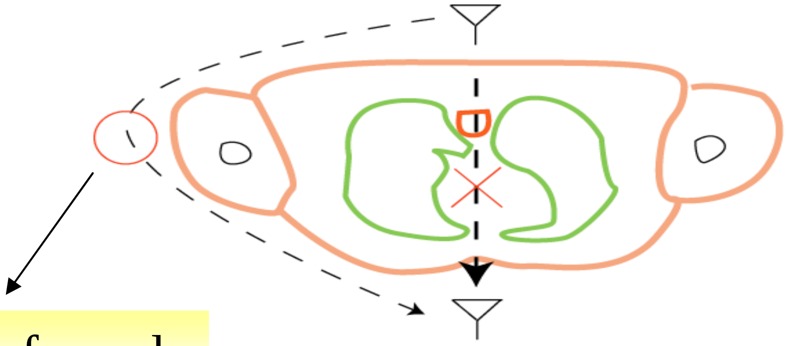
Using channel model of IEEE802.15.4a final report

Characteristic

- frequency is 2~6GHz

→ No energy penetrating through a body

Path loss model are defined according to distance around a body



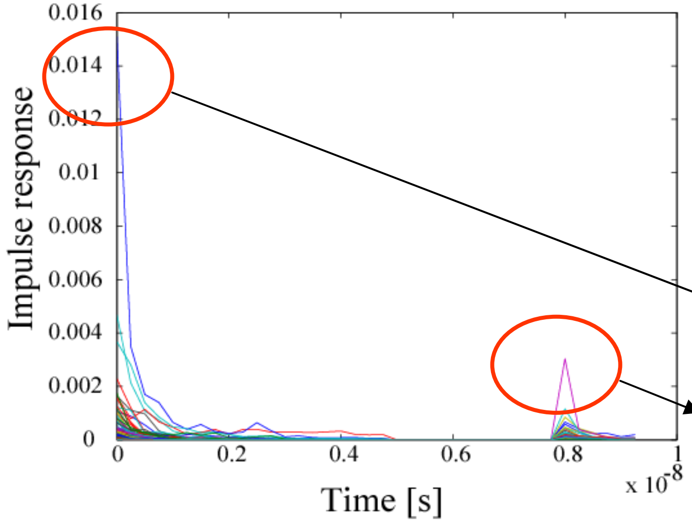
Path loss formula

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

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

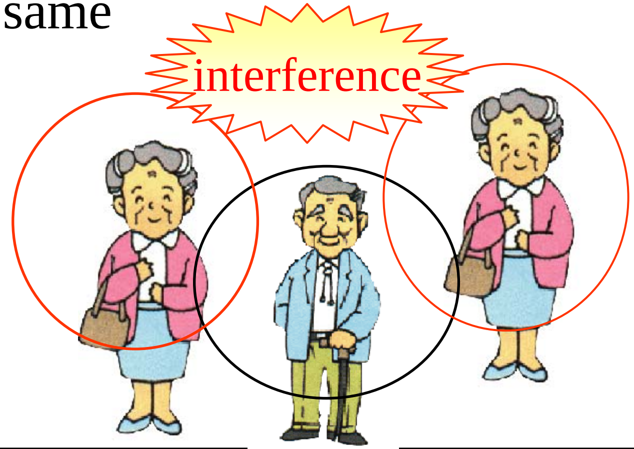
Depending on transmitter and receiver position, the power of reflection wave is higher

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

2.1 Simulation Model

- Simulation model
  - Multi pico-net (Multiple BAN) interference problem
  - Assuming multiple BAN are perfectly synchronized and channel propagation is known
  - Undesired factor : interfering signals and AWGN

- Parameter of each system
  - Total frequency bands used in wearable BAN is the same in each system
  - Bit rate and power consumption of 1bit is the same
  - Number of multiple nodes is the same



2. Performance Evaluation

Simulation Parameters

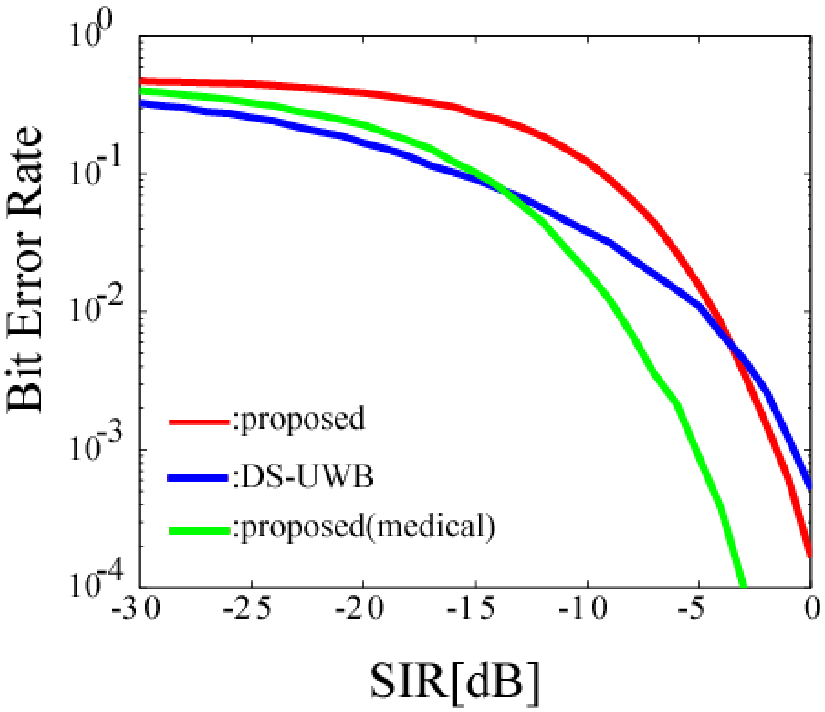
Simulation Situation

Number of Pico-nets (BANs): 10
Both medical and non-medical systems are coexisting.

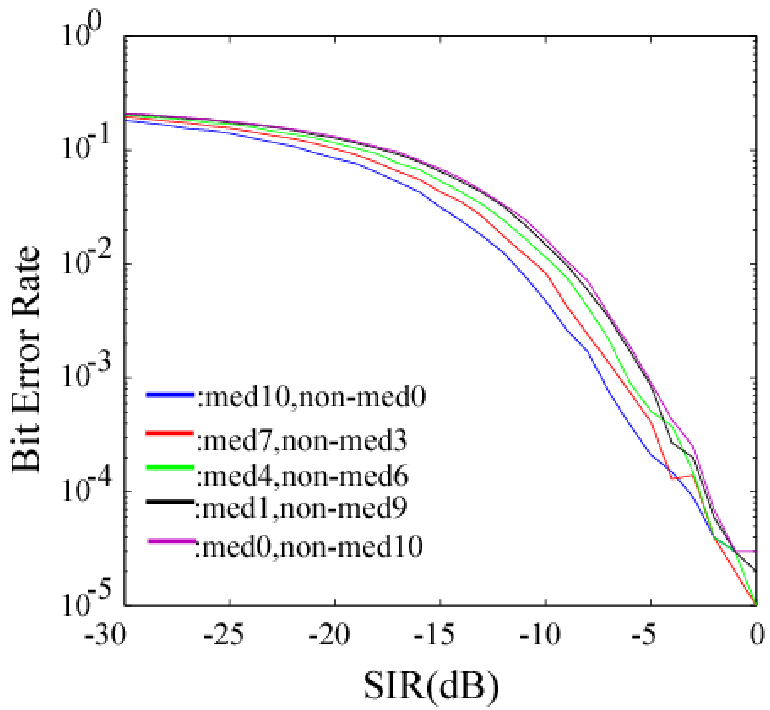
Pulse shape	Root raised cosine roll-off pulse(roll-off rate 0.6)
Bit rate	10Mbps (Non medical : 30Mbps)
Sampling interval	0.03125[ns]
Transmission device position	Front of stomach
Reception device position	arm
Interference Pico-net number	10

2.1 BER Performance Evaluation

Result



Case of number of Interference modes is 8



Case of co-existing medical and non medical systems

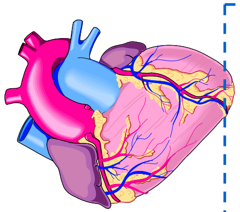
2.1 Conclusions for Pulsed Chirp UWB

- We compared conventional methods of IR UWB with proposed system of pulsed chirp with and without frequency hopping for medical and non-medical use.

- Both proposed pulsed chirp UWB with and without hopping sequence are superior to conventional IR UWB in a sense of high interference immunity.

2.2 Error Controlling Scheme in Physical Layer Design: Hybrid ARQ and FEC for Medical and Non-Medical Uses

2.2 Demand of medical and non medical system



Medical

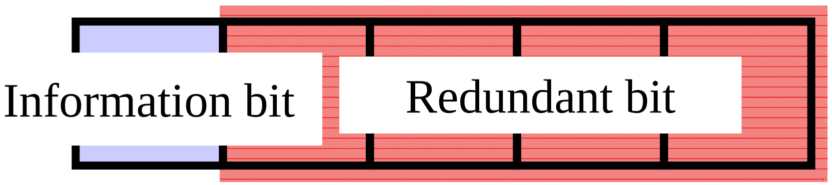
- Robust against interference
- High reliability

Non-medical

- High speed

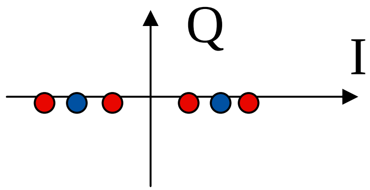
Aim : Consider BAN suitable for both medical and non medical uses

- **Coding 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 : Choose decoding scheme between hybrid ARQ and simple FEC for medical and non-medical uses, respectively in reception while the same modulation and coding 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**

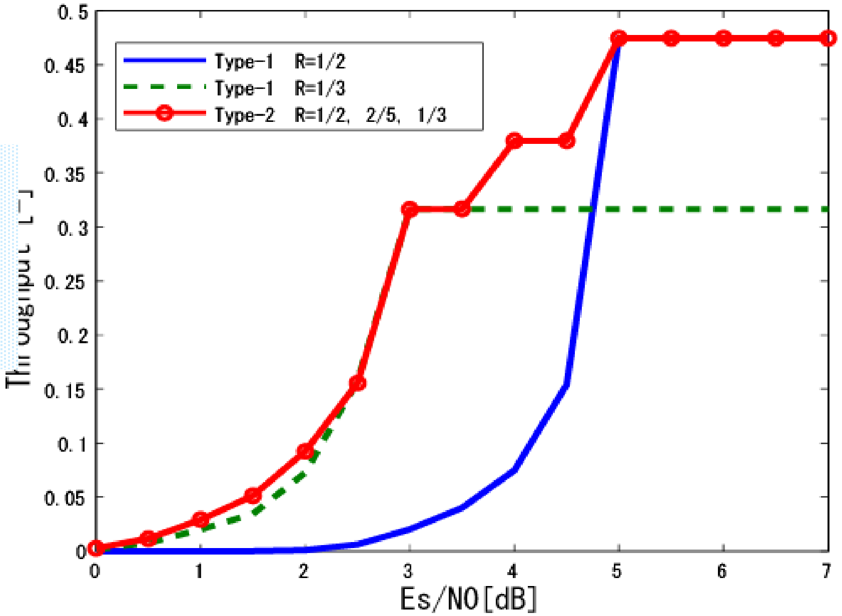
Error detection and correction is performed in decoding at reception and if the error is detected and cannot be corrected, retransmission is requested until correctly received.

- Type 1 of hybrid ARQ : Retransmit same data

  Example) Chase Combine method

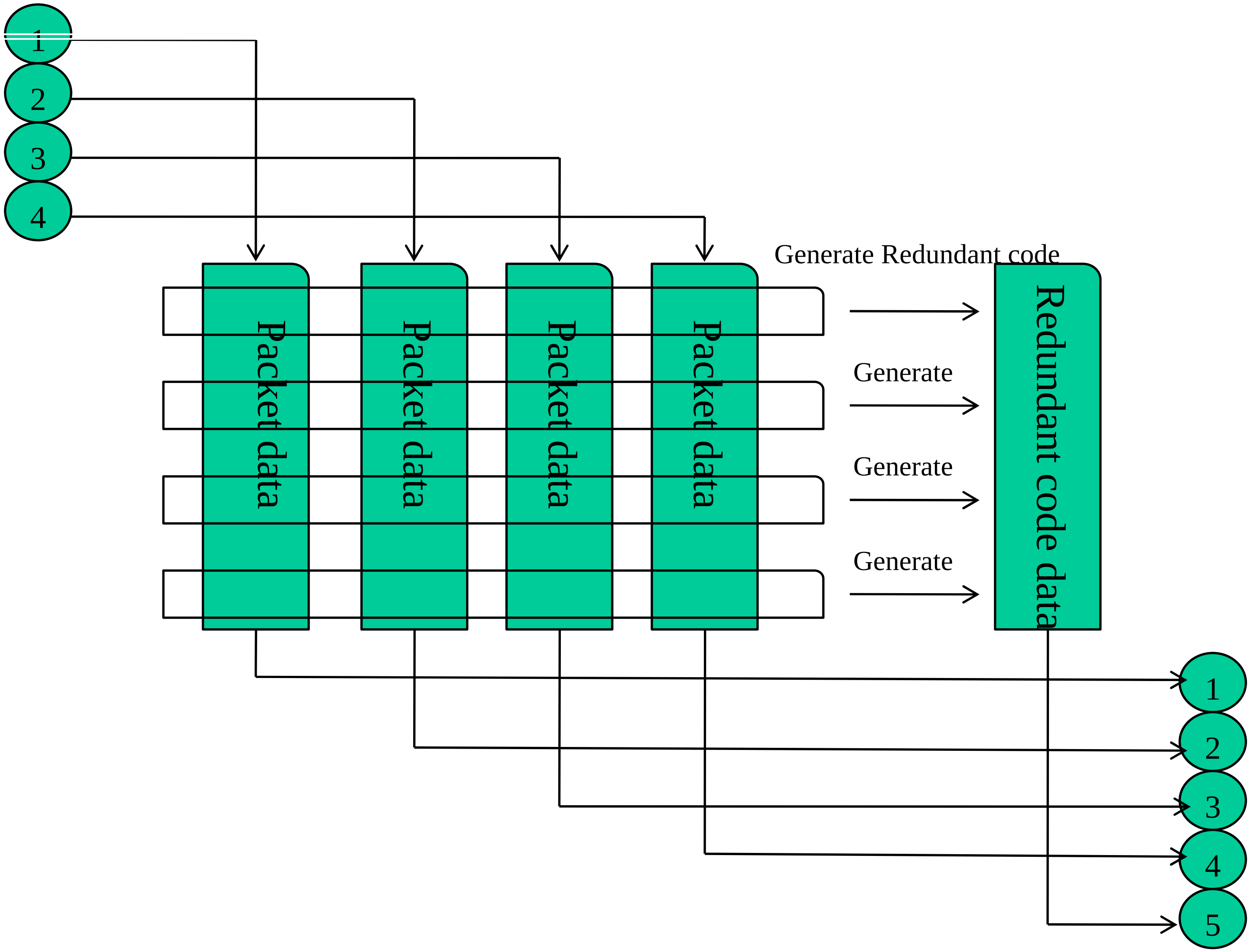
- Type 2 of hybrid ARQ : Retransmit other data

Incremental Redundancy method : Retransmit redundant bit



Modulation	BPSK
Noise	AWGN

2.2 Code Configuration (Interleaving)



2.2 Proposed combined hybrid ARQ and FCC for Error controlling 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 middle quality

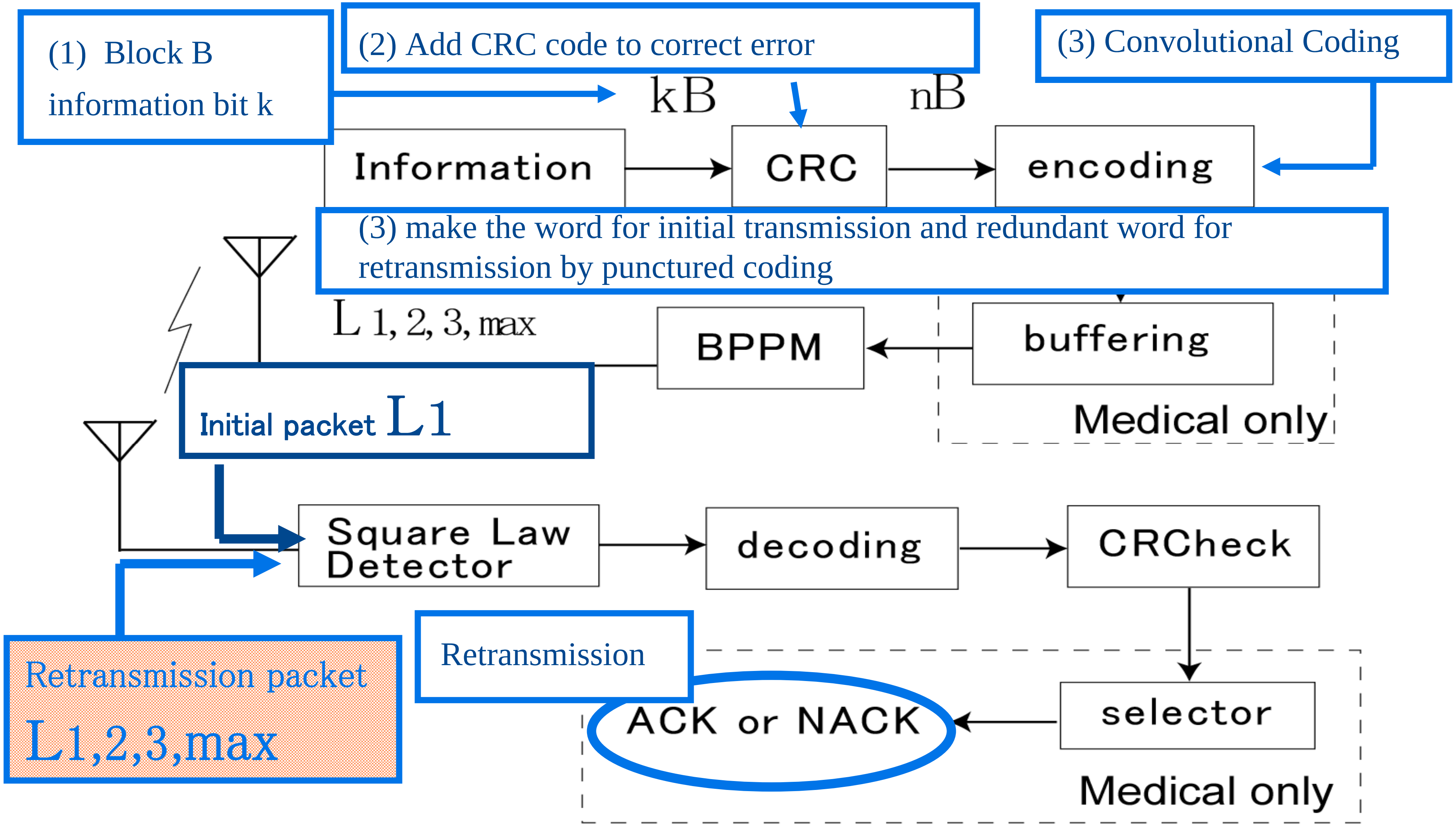
↓

Proposed method

Medical use:	**Hybrid ARQ**
Non medical use:	**FEC only**

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

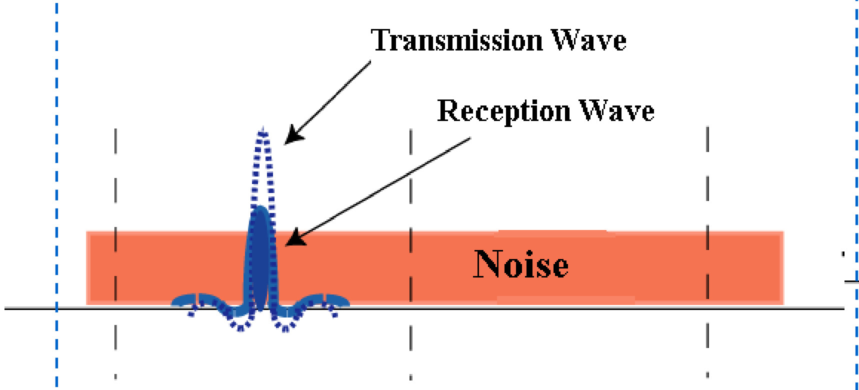
2.2 Flowchart of proposed error-controlling scheme



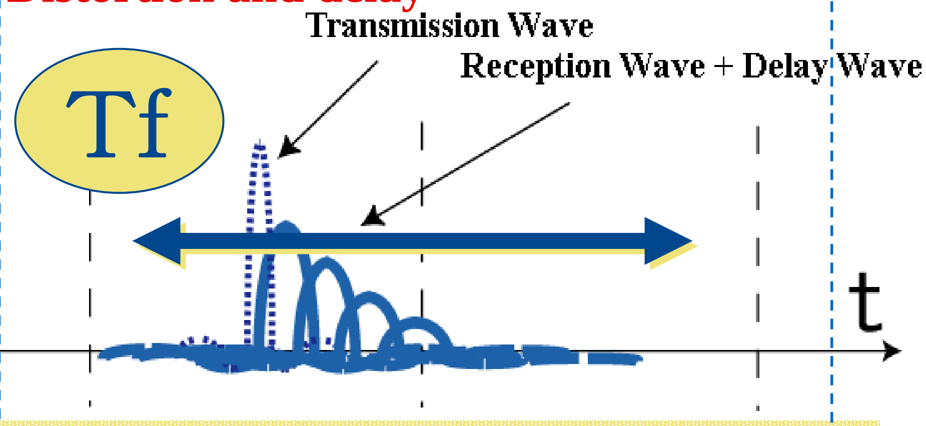
2.2 Reason for Retransmission

2-PPM (2-value Pulse position modulation)

Attenuation



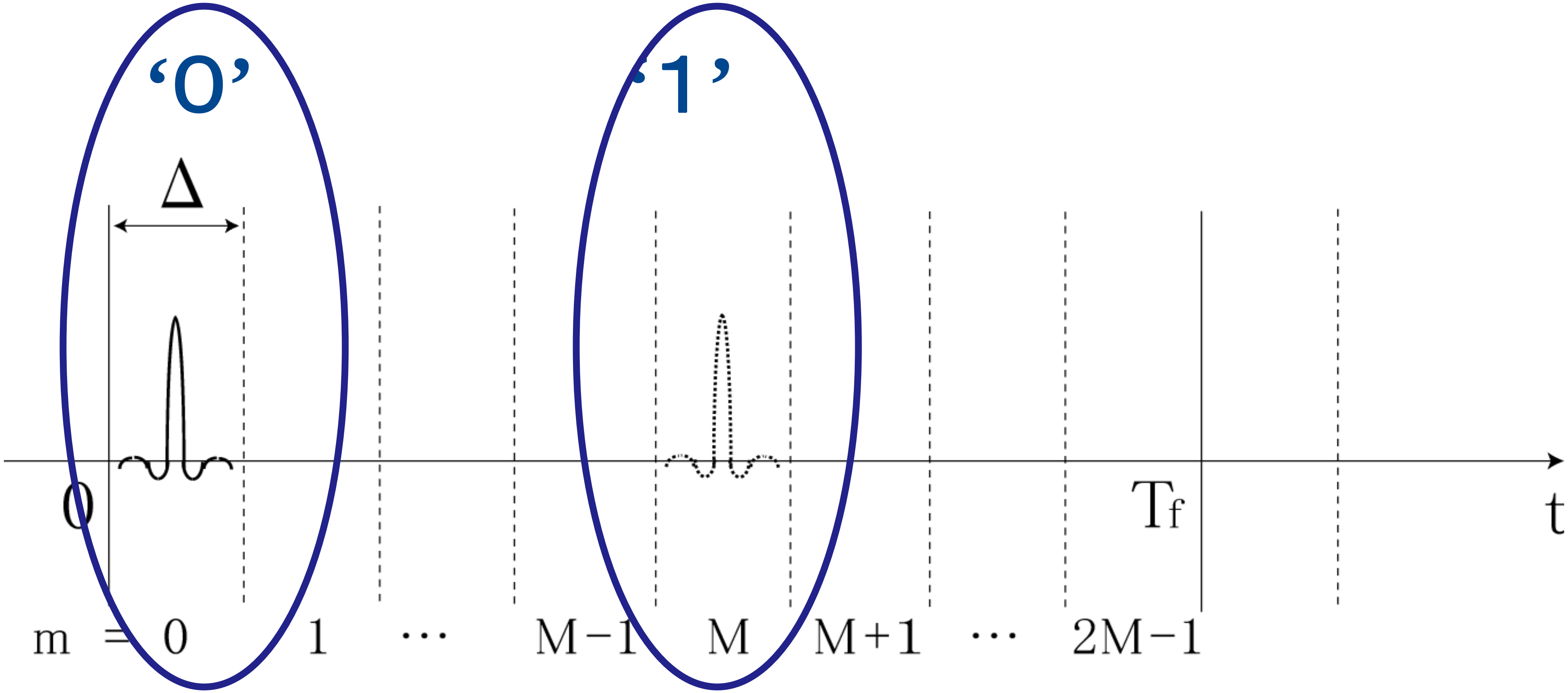
Distortion and delay



Error by ISI(Inter symbol interference)

Avoid the interference by expanding Tf

2.2 Time Flame Tf



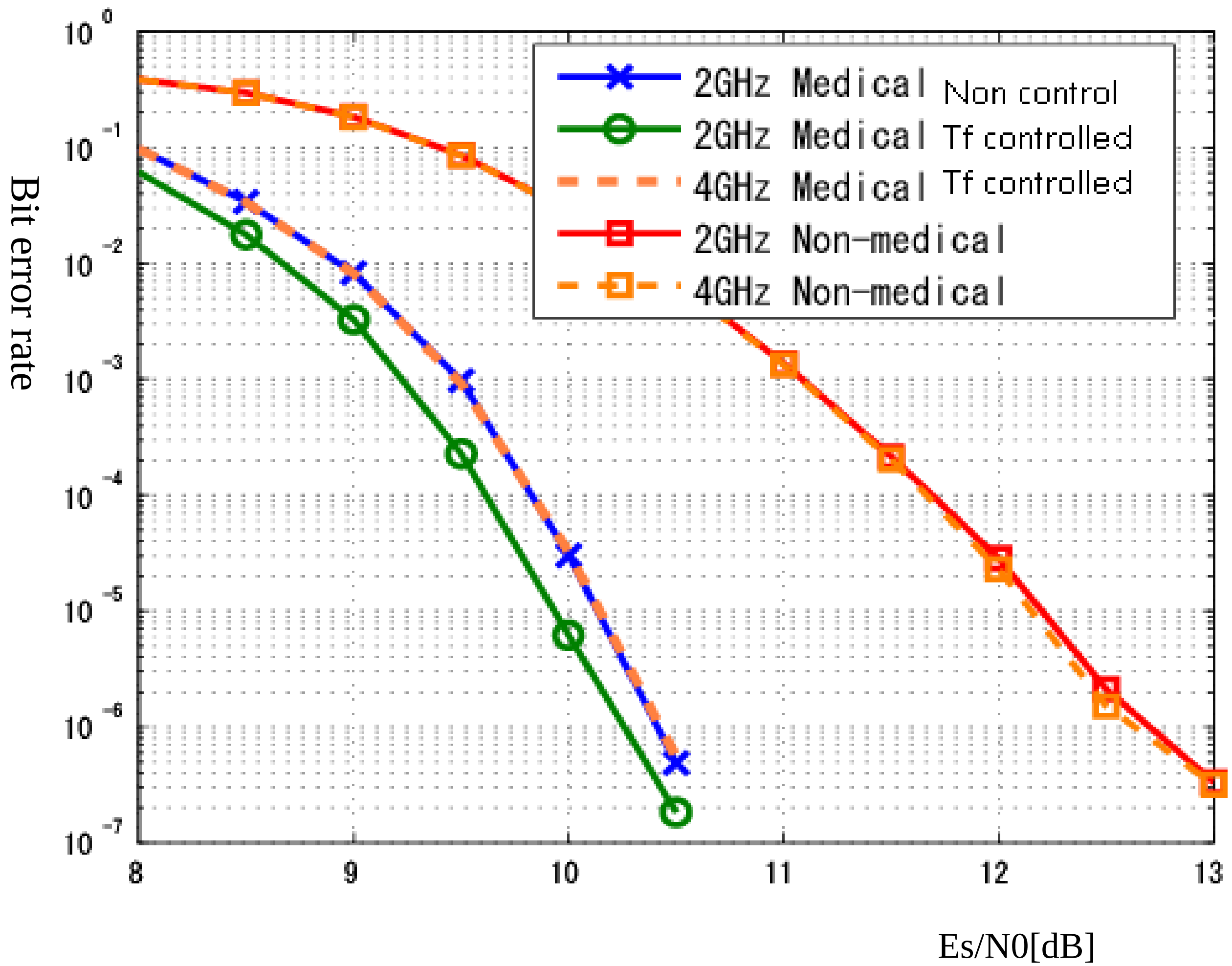
Short Tf : Interference of ISI
Long Tf : Interference of Noise

2.2 Performance Evaluation for Proposed Error-Controlling Scheme

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

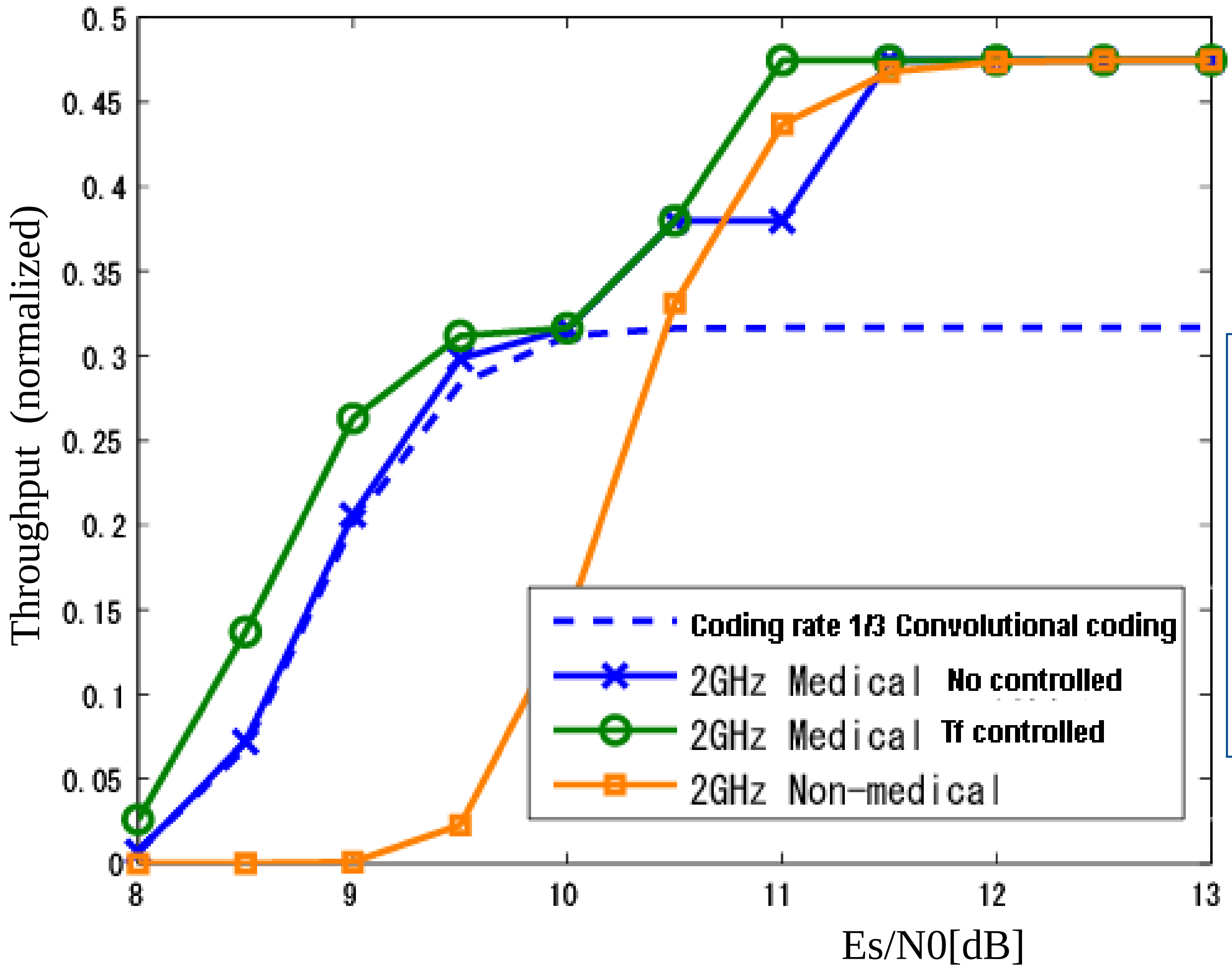
2.2 Evaluation of Bit Error Rate



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

- Considering attenuation, 2GHz fulfills better quality

2.2 Evaluation of Throughput



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

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.
- For instance, the proposed scheme 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.

3. MAC Layer design: Protocol considering SAR or thermal influence to a body by switching cluster

3. 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

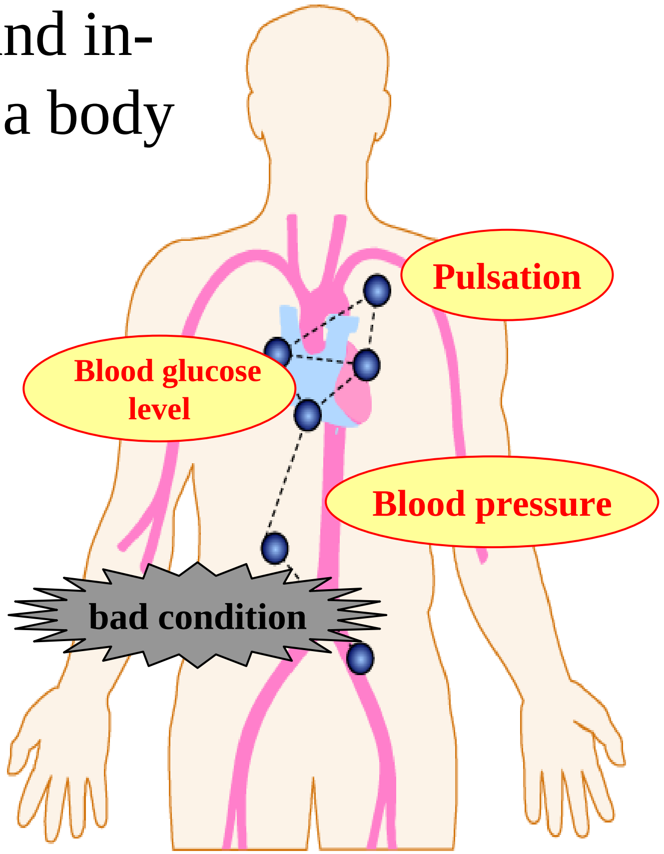
Ex) • Capsule Endoscope

• Cardiac pacemaker

etc･･･

✓ Smaller devices
✓ Longer-lasting batteries

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



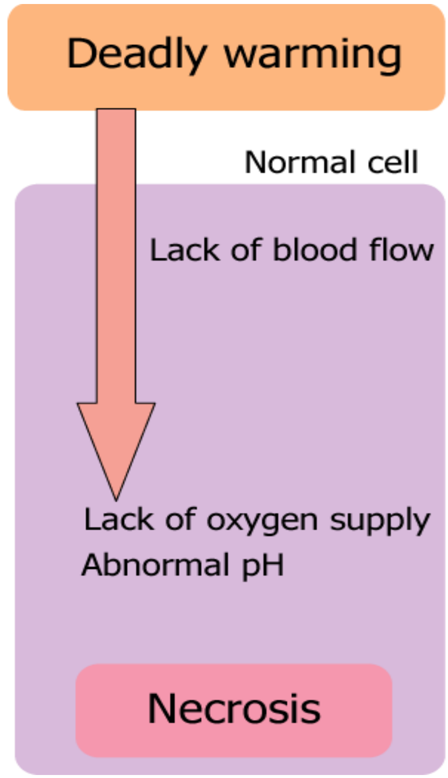
3. Motivation

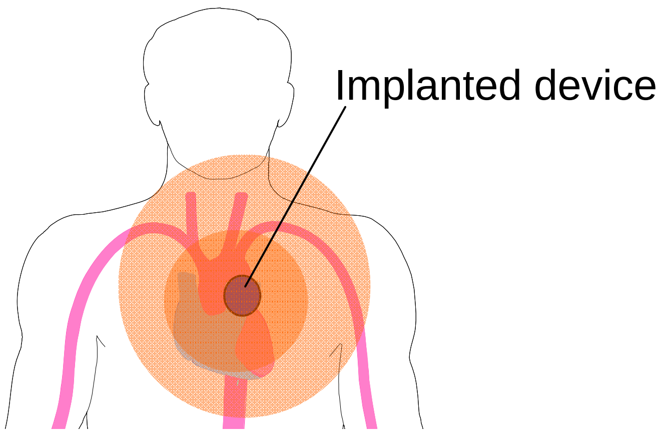
Focus on thermal influence for a body due to implanted devices

■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



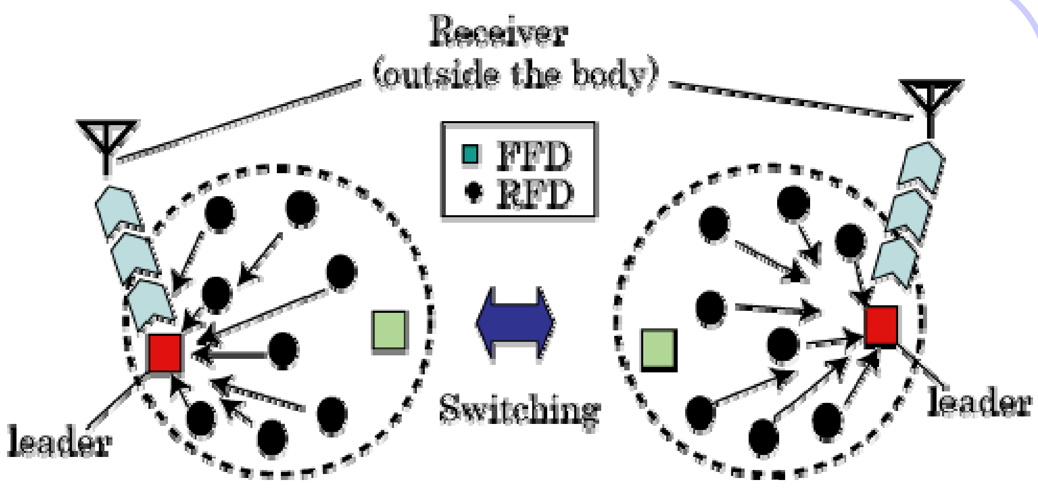


■**Objective**

Network modeling in the human body and proposal new MAC protocol minimizing thermal influence to a body

3. 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 the body.
- Switching of cluster leader
  - In order to disperse the thermal influence to a body, we switch the leadership between a couple of FFD nodes.



System model

FFD: Full Function Device

RFD: Reduced Function Device

3. 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

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

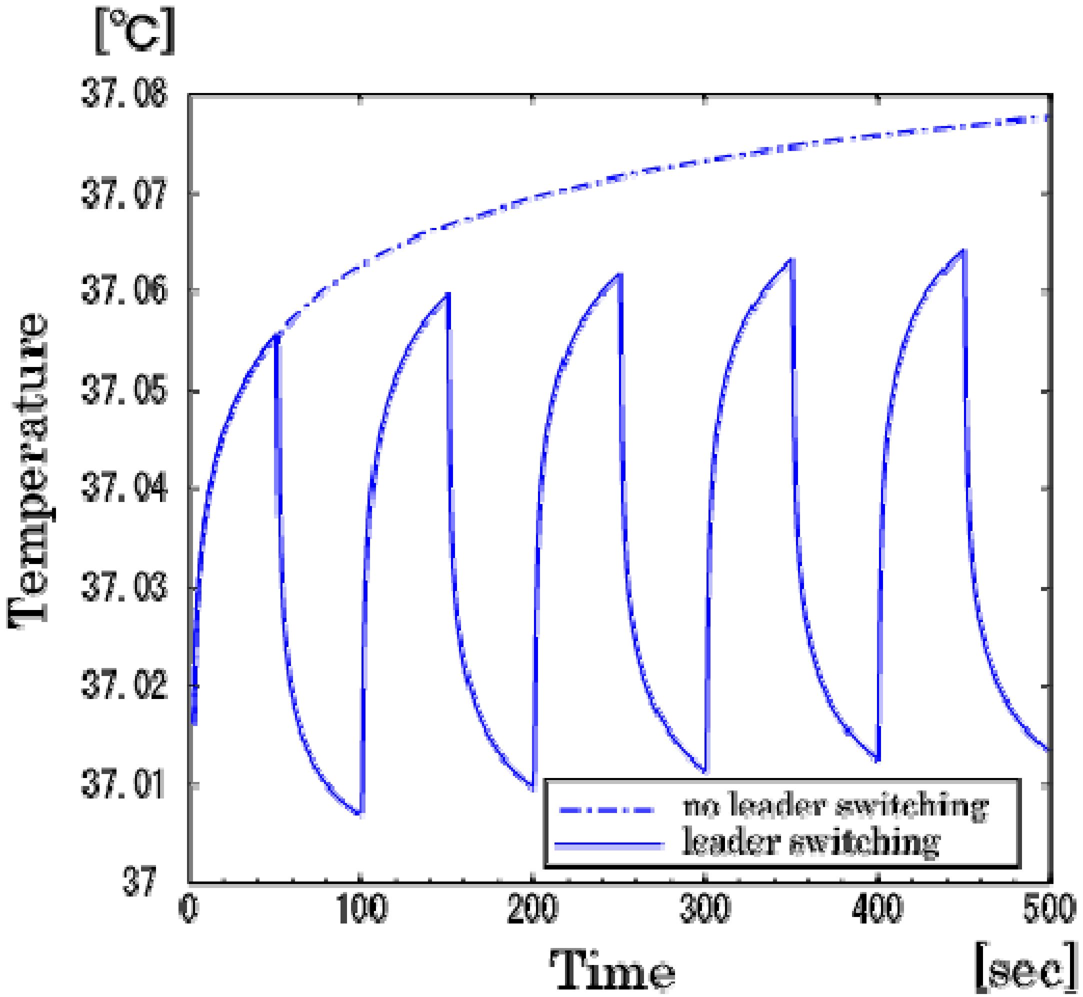
V : voltage of leader node [V]
A : current of leader node [A]
C : specific heat of tissue[J/kgK]

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

3. Temperature Characteristic



✓Surrounding medium of the leader is muscle.

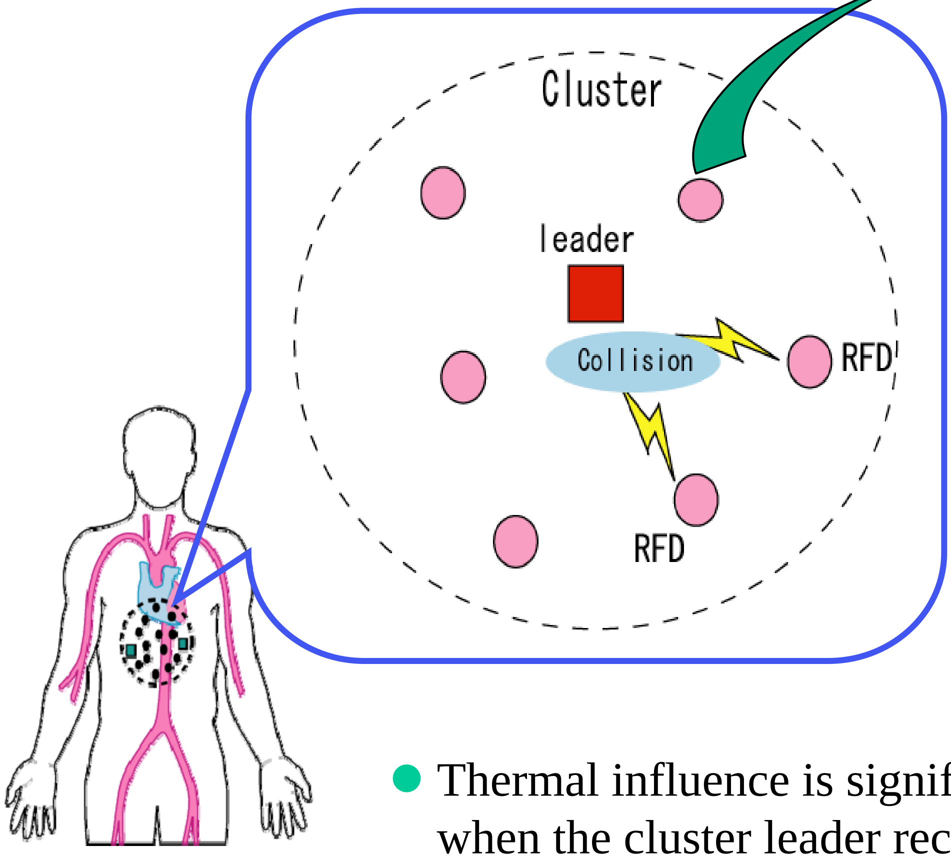
✓Consider the temperature in the leader position.

Temperature characteristic with or without leader switching

3. Aim of Proposed MAC protocol

Problem of collecting the information

Communication in the cluster



Collision of packets

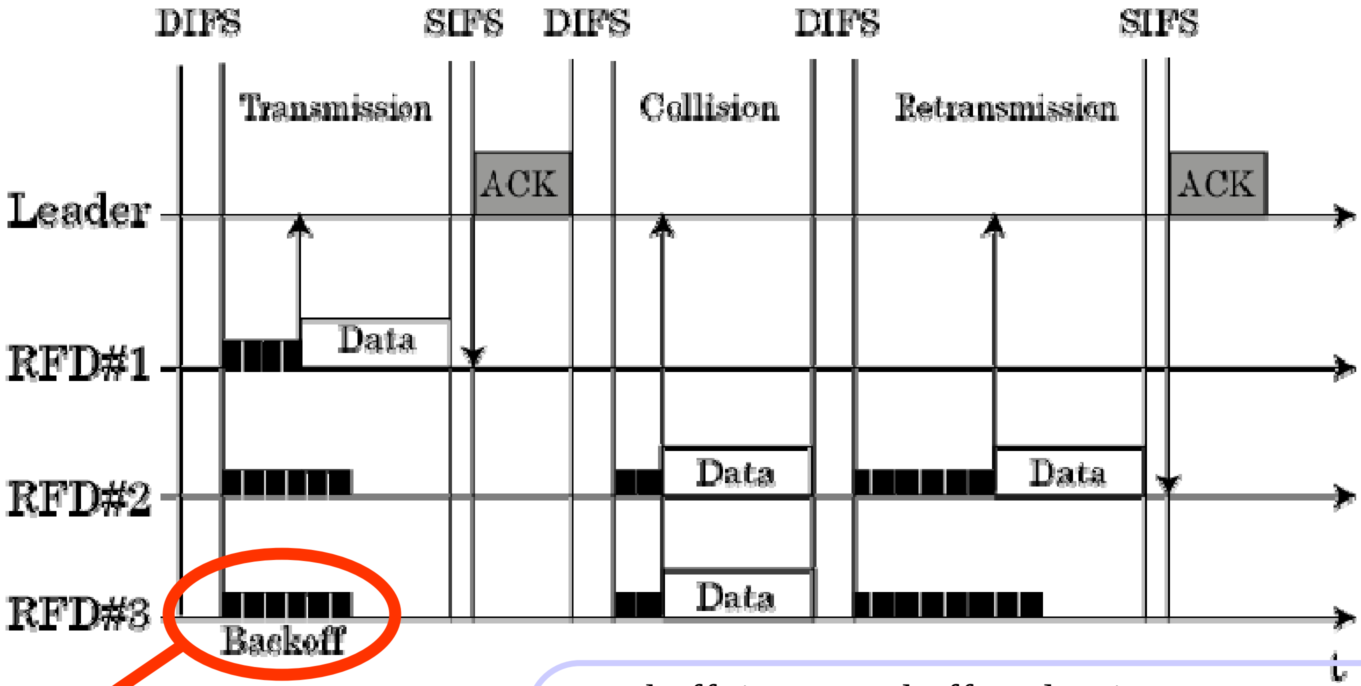
Collecting the information from each RFD node will become inefficient.

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

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

3. Access Procedure of Proposed 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: $(CW_{\min} + 1) \cdot 2^n - 1$

3. Adaptive Back-off Algorithm

The proposed Algorithm

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

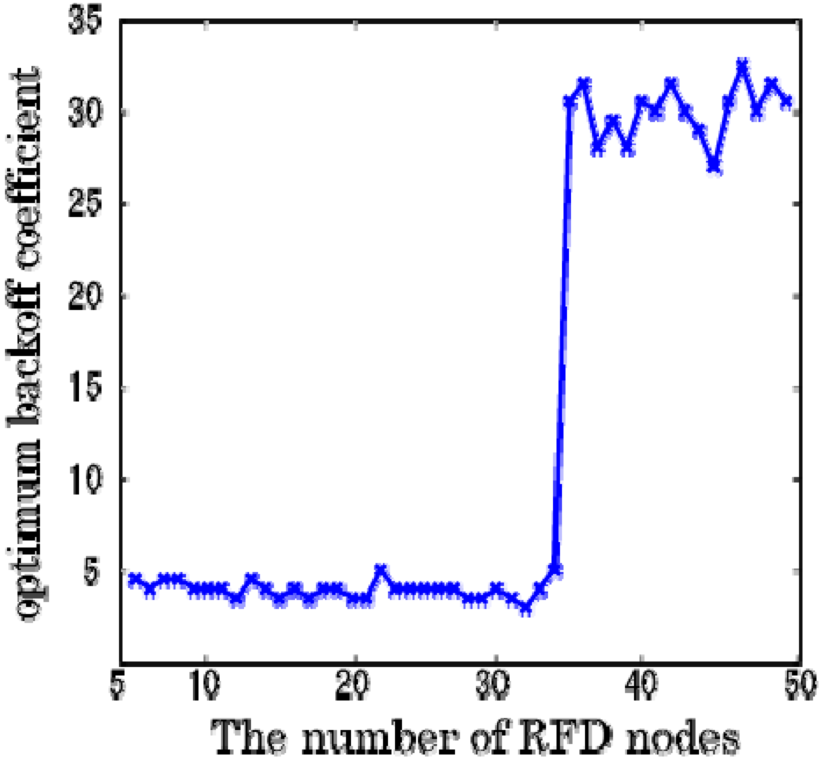
Backoff Coefficient

Backoff Coefficient Table

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

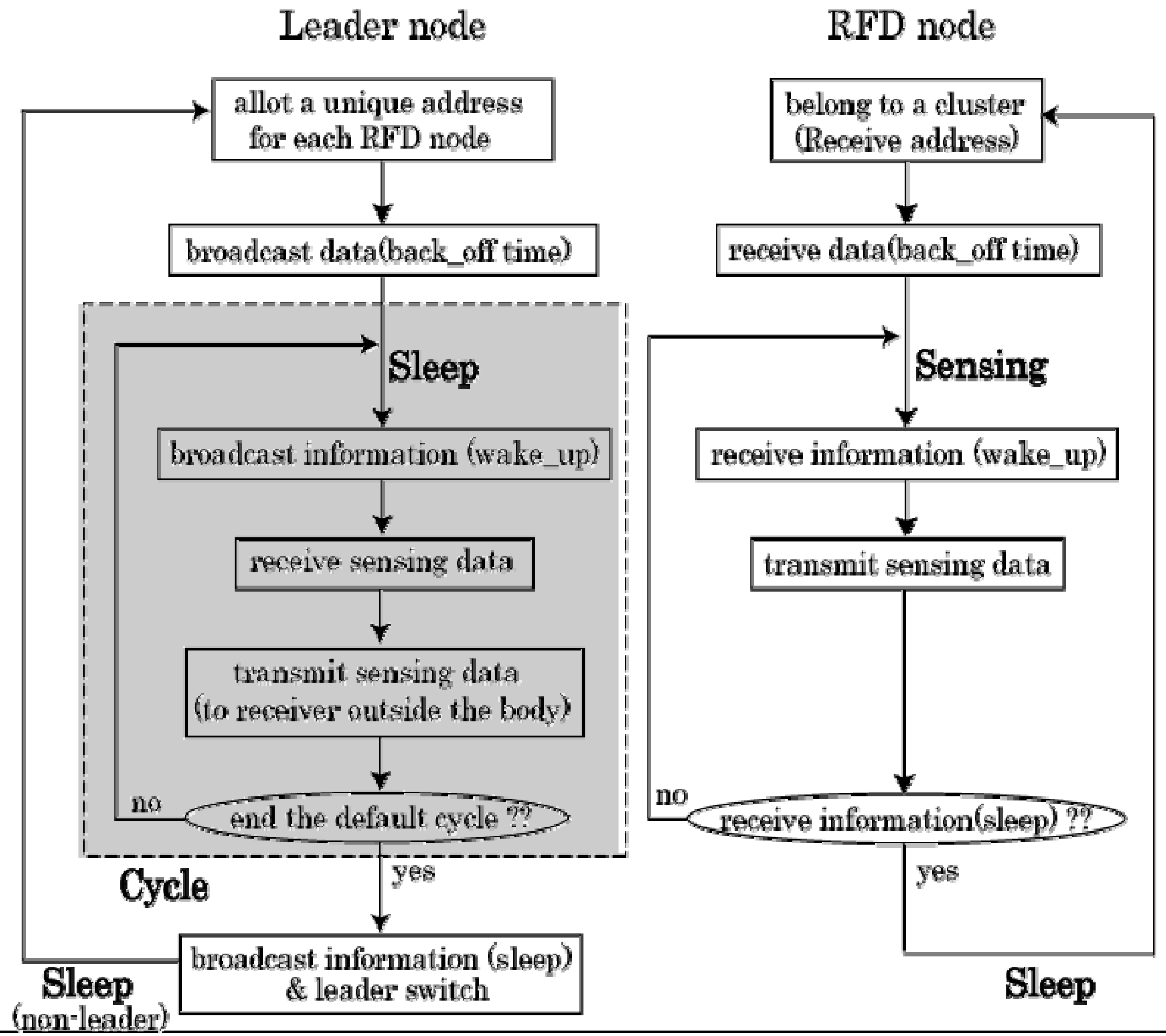
✓ **Objective of our algorithm**

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

3. Flowchart of Proposed Protocol



3. 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

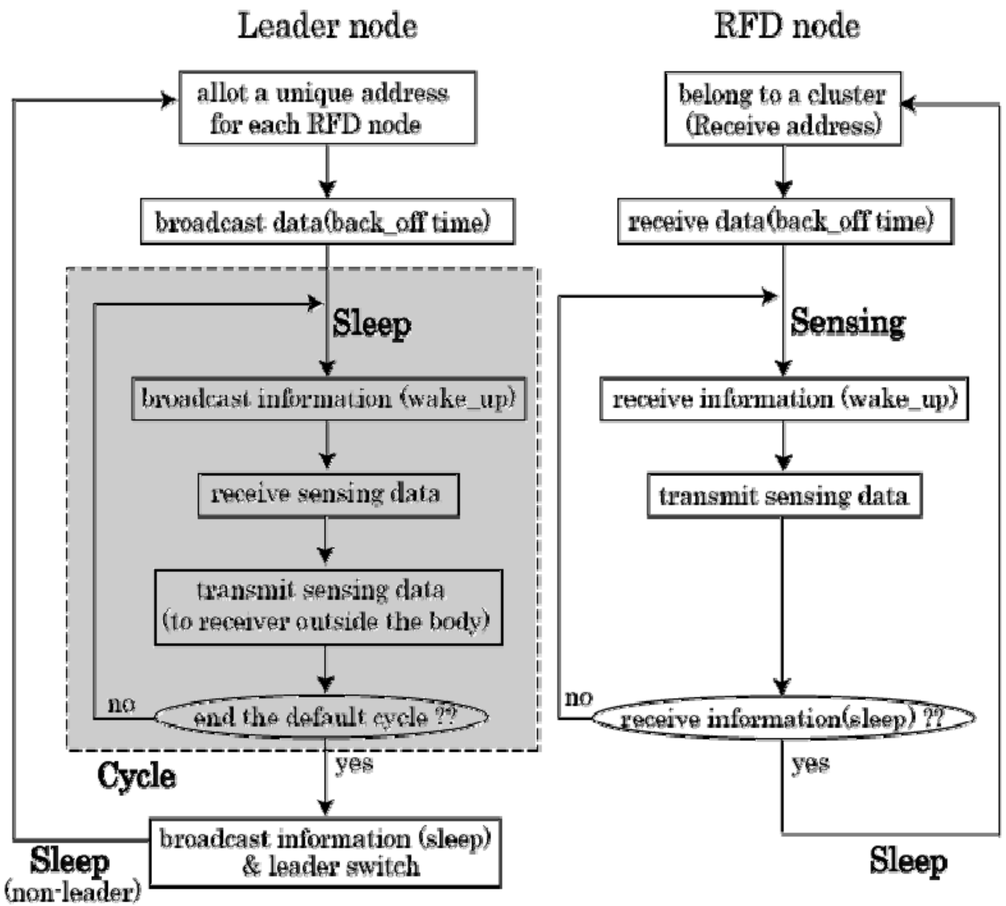
■ Assumption

We assume that range attenuation and packet error are ignored.

✓Number of packets

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

3. Performance Evaluation



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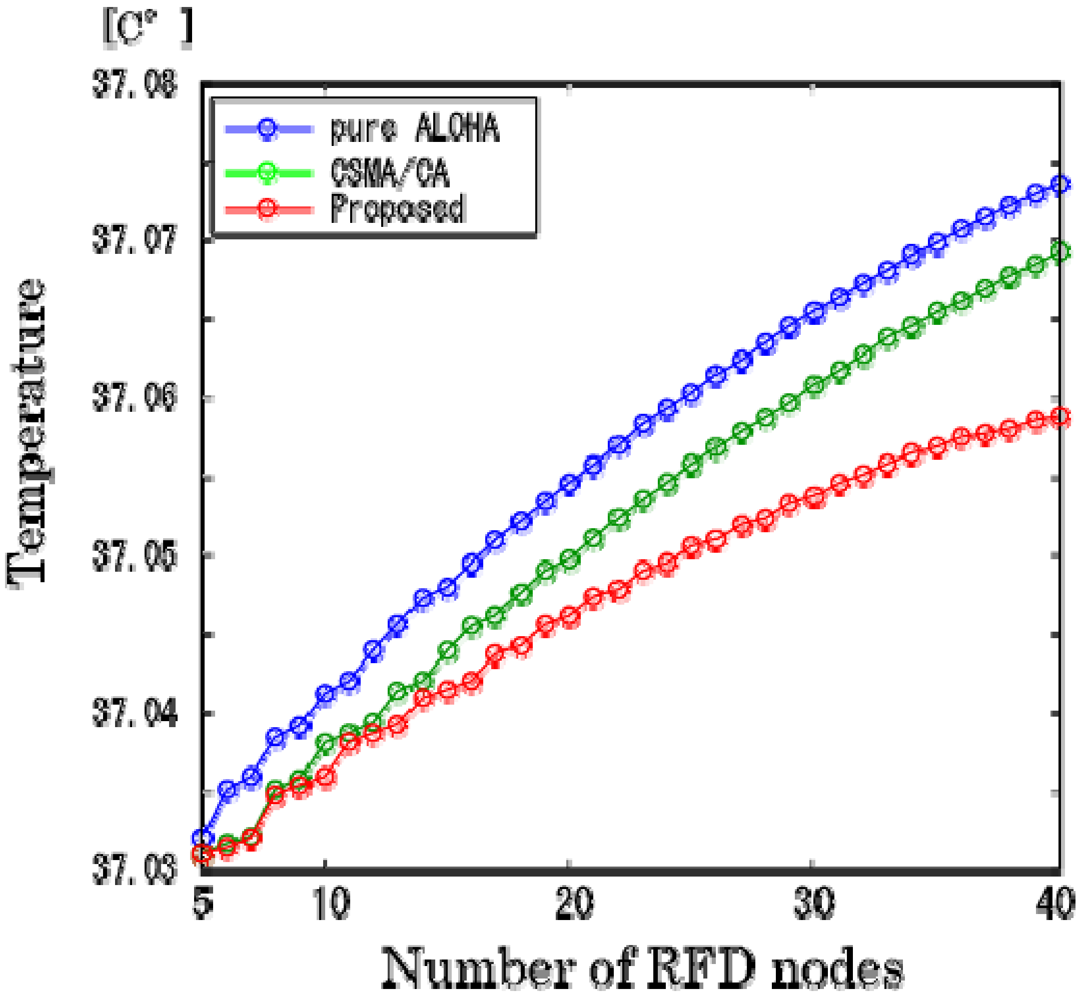
3. Thermal Influence Evaluation



- ✓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

3. Conclusions of MAC Protocol Considering Thermal Influence to a Body

- 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.

4. 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 chirp UWB using sequence 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 has been proposed.
- This presentation has not contained detail specification and performance analysis yet but introduced key ideals in conceptual base to be involved in a complete standard.