Design of Communication Model Suitable for Implanted Body Area Networks

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Abstract

Recently wireless communication has been developed with nano-size devices by semiconductor technology. By means of transmitting vital data, we can observe the body's conditions and detect any possible problem in the human body at anytime. However, not only power consumption of implanted wireless communication devices with a sensor function (node) but also thermal influence on human body should be considered carefully for implementation of such technology. So, it is difficult to apply current sensor network technology directly to the human body. When implanted nodes communicate, it is expected to raise thermal influence caused by the electromagnetic wave exposure and circuit heat. And power-efficient information gathering is preferable that long term continuous duty for implanted nodes if they cannot be recharged. So, we suggest that a sensor network inside the body takes a clustering form and switching leadership between two nodes in order to control their thermal influence. In this paper, we design a communication model. Specifically, we propose network configuration, communication flow, and MAC protocol including alarm mode which is a countermeasure against emergency.

Keywords: Body Area Network, thermal influence, MAC protocol

Ⅰ. Introduction

With the increased sophistication of semiconductor technology, smaller wireless communication devices have been developed. Nowadays the wireless communication has been developed with nano-size devices by these technologies. In the near future, these advances will make possible to implant wireless communication devices with a sensor function (node) and form a sensor network inside the human body for health monitoring purposes. Such system is generally called implanted body area network (BAN). Each node can monitor health data such as blood pressure, blood glucose level and pulsation, and transmit them to a medical server.

For implementation of such technology, not only power consumption of node but also thermal influence on human body should be considered carefully. So it is difficult to apply current sensor network technology directly to the human body because there is no model considering thermal influence yet. Additionally, when we assume that such technology will be applied to medical systems, it is very important and essential to immediately deal with emergency situation because of being fatal to humans.

A power-efficient information gathering structure is necessary because it is preferable that long term continuous duty for nodes implanted in a human body [1]. In case that implanted nodes cannot be recharged, we anticipate that this demand is higher. The received power depends on the transmission distance, so it is advisable to take a clustering form for controlling power consumption. In a clustering form, neighbor nodes form a cluster, where a full function device (FFD) node is the cluster leader that gathers biometrical data from another node that belong to the cluster. The FFD node interfaces with a medical server outside the body. Therefore, in this paper we adopt the clustering form as a network model. In this case, the leader consumes more power than the other nodes. So, it offers a higher rise of thermal influence caused by circuit heat and electromagnetic wave exposure.

Consequently, we can choose which node is the leader, switch leadership to another node in order to disperse the thermal influence. For temperature rise caused by thermal influence, we employ an approximation of the Pennes' biologic thermal transport equation that is often used as the computation approach of heat propagation in a human body caused by electromagnetic waves and circuit heat.

While communication leader, there are two conditions for it. The leader collects information from all the non-leader nodes (reception mode) and transmits the information to a receiver outside the body (transmission mode). Notice that reception mode takes a longer time since the information of several nodes must be collected. Thus, this longer time increases the risk of thermal influence. So, we proposed a method for controlling the thermal influence by considering MAC [2]. In this paper, we improve the aforementioned protocol.

In Section Ⅱ, we describe the proposed communication model inside the human body. Specifically, we propose network structure, communication flow, and MAC protocol including alarm mode which is a countermeasure against emergency [3]. Then, We discuss the calculation of temperature increment and power consumption in Section Ⅲ.We assume that they are evaluation standards. In section Ⅳ, we evaluate the improved MAC protocol by computer simulation and show the effectiveness in point of thermal influence and power consumption. Finally, conclusions are given and we describe future works in Section Ⅴ.

Ⅱ. Design of Implanted BAN Communication Model

A. Network Structure

Since implanted biosensors must operate with very limited power, energy efficiency is an important aspect of design. Prior research shows that a cluster-based communication protocol is more energy efficient than a tree-based approach [4] [5]. Cluster-based communication protocol is based on the idea that energy consumption can be reduced by having particular nodes performing long range communication with a receiver outside the body. These nodes are called cluster leaders. The FFD node is equipped with more complex circuits. So, all the non-leader nodes are denominated as reduced function device (RFD) nodes that contain simple sensors, a processor, and a transceiver. We assume that a cluster consists of a couple of FFD nodes and a number of RFD nodes, see Figure 1.

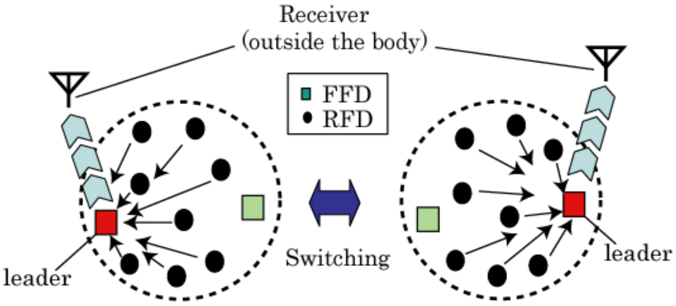

Figure 1- Switching leader structure

We propose switching leadership between a couple of FFD nodes to disperse the thermal influence.

B. Communication flow

We proposed communication flow of the leader and RFD nodes while the leader form a cluster and switch leadership ultimately. Then we describe proposed flowchart in Figure 2.

Initially, the leader allots a unique address for each RFD node to acknowledge the number of them belonging to a cluster. After clustering, the leader broadcasts *backoff data* on the basis of it. Then the leader sleeps for a given period while RFD nodes sense biometrical data. When the leader wakes up, it indicates that and makes each RFD node to stop sensing. After that, the leader gathers biometrical data from all RFD nodes and transmits it to a medical server outside the human body. And then, the leader sleeps again. We define this communication flow as a cycle. The leader switches leadership from itself to another FFD node after a set number of cycles. When the leader switches, each RFD node begin to sleep until a new cluster is formed.

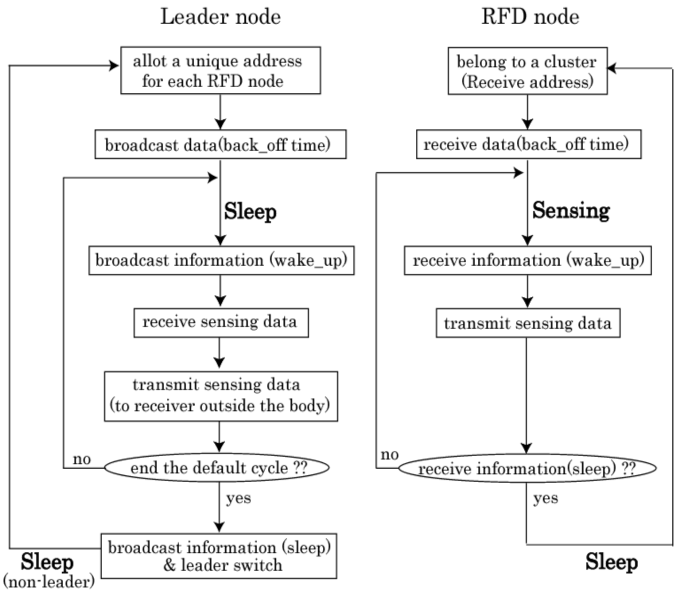

Figure 2-Communication flowchart

C. Proposed MAC protocol

The leader receives the information from a number of RFD nodes in reception mode. So, it is expected that the processing time in that mode changes significantly depending on the number of RFD nodes and media access control. Therefore, we proposed a MAC protocol, which is effective at collecting the information from each node to the leader in order to control the thermal influence. In this paper, we improved our proposed MAC protocol to make communication more efficient.

New proposed protocol adopts carrier sense and backoff, so it is based on CSMA/CA protocol essentially. A term of the carrier senses, that is to say waiting time, is called *backoff time*. A *backoff* is determinant factor of *backoff time*. It is a random integer number that is generated from a uniform distribution in [0, CW]. We propose a new protocol that $CW_{\min}$ is defined as following expression including the number of RFD nodes,

$$CW_{\min} = \alpha M \tag{1}$$

where M is the number of RFD nodes in the cluster, α is the *backoff-coefficient* we defined. This coefficient is chosen from database (Table 1) which is computed preliminarily.

Table 1 - Backoff-coefficient

α	**the number of RFD nodes**
4.5	~10
4.0	~20
3.5	~30
3.0	~40

RFD nodes transmit sensing data most effectively by choosing appropriate *backoff-coefficient*. Figure 3 shows the simulation result of processing time when the number of RFD nodes is 10.

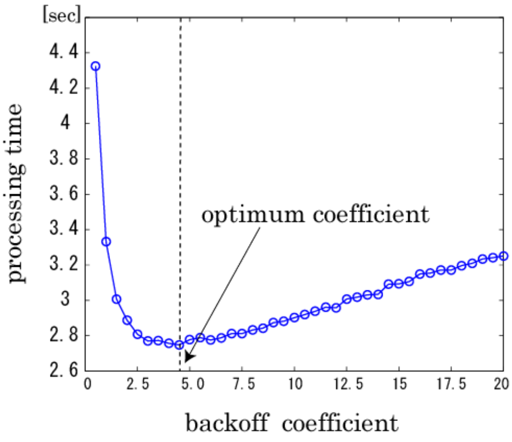

Figure 3- Processing time (10 RFD nodes)

Optimum coefficient of this result is saved as *backoff-coefficient*. Practically, the leader figures out the number of RFD nodes in the cluster and broadcasts *backoff data* whose expression is allotted *backoff-coefficient* depending on the number of RFD nodes like Table 1.

D. *Alarm mode*

Particular demand in medical systems includes a countermeasure against emergency situation. In such cases, it is very important and essential to immediately communicate because of a circumstance to human vitality. So, we need to consider a certain method in an emergency. Then we propose alarm mode which is a function of the proposed MAC protocol .

Alarm mode initiates with transmission of an alarm signal from a RFD node to the leader. When a RFD node detects biometrical data out of healthy range, it transmits an alarm signal to the leader to acknowledge an emergency situation. After receiving the signal, the leader wakes up from sleeping and transmits updated *backoff data* to that node. *Backoff data* is updated as,

$$CW = 1 \qquad \text{(constant).} \qquad (2)$$

This algorithm let an alarmed node to transmit biometrical data preferentially each time because that it can transmit with minimal-length waiting consistently. As soon as the leader received all data from that node, it transmits to a medical server outside the human body. Then alarm mode finishes and each node returns to normal mode. We describe a communication flow in alarm mode in Figure 4.

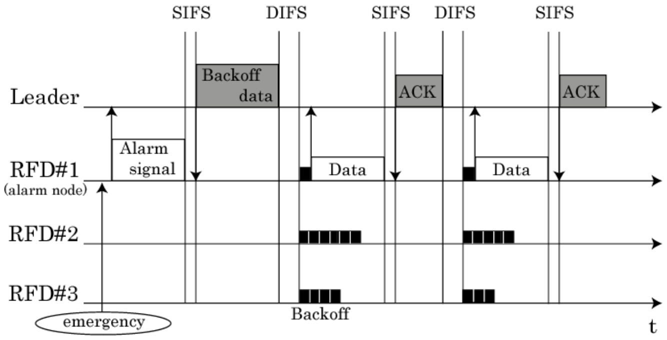

Figure 4- Alarm mode

We compute the time required for the leader to make a medical server know about the emergency to confirm the effectiveness of alarm mode function. In addition, we apply this function to our proposed protocol. So we estimate the simulation result compared with pure ALOHA, CSMA/CA and proposed protocol without alarm mode.

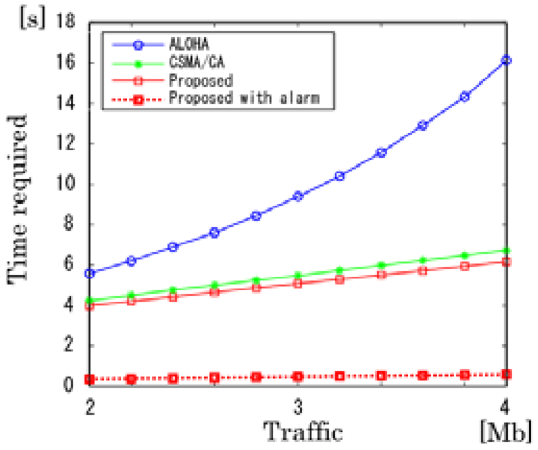

Figure 5- Time required

Figure 5 illustrates the time required depending on traffic. It denotes the characteristic when the amount of biometrical data which RFD nodes sensed changes. This graph shows there is few time required with the alarm mode. We can confirm that updating *backoff data* and reducing *backoff time* enable to receive data from a specific RFD node preferentially.

Additionally, the time required in alarm mode hardly change even if traffic increases. We consider that the increment of traffic affects collision of packets, too. And there is no collision in *alarm mode* because an alarmed node to transmit biometrical data preferentially each time. So it would appear that existence or nonexistence of packet collisions makes a difference in this result. Consequently, we can evaluate the effectiveness of *alarm mode* function.

Ⅲ. Thermal Influence and Power Consumption

In this section, we explain the thermal influence and power consumption as evaluation standards of our proposed communication model inside the body.

A. Biological thermal propagation

We consider the thermal influence caused by electromagnetic waves (EM) and circuit heat by using the modification of the Pennes' biologic thermal transport equation given by

$$\rho C_p \frac{dT}{dt} = \kappa \nabla^2 T - \rho \rho_b C_b F(T - T_b) + \rho SAR + \frac{VA_{active}}{\rho C}, \quad (3)$$

where ρ is the tissue density, C is the specific heat of the tissue, κ is thermal conductivity of the tissue, T is the temperature of the tissue, F is flow rate of blood, V and A_{active} is the voltage and current of the leader, respectively. The suffix b expresses blood parameter. We calculate the SAR by using the three-dimensional field analytic simulator XFDTD.

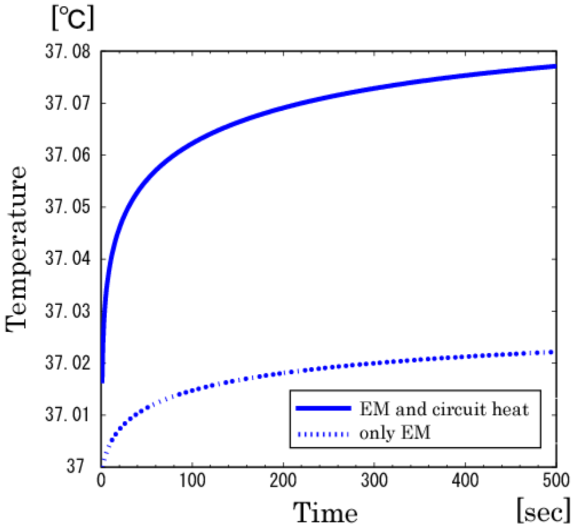

Figure 6- Temperature increment

Figure 6 shows the temporal characteristic of temperature increment when there is no leader rotation. So, the tissue surrounding the leader is heated continuously. In this paper, we assume that the medium in which the leader exists is muscle because it comes in a larger proportion relative to other tissues or organs. Furthermore, muscle is more susceptible to thermal influence than other tissues or organs. From this result, we assume that thermal influence caused by circuit heat is much larger than by electromagnetic waves.

B. Power Consumption

We express the calculation formula of the leader's power consumption divided into communication (active) mode and sleep mode. It is given by

$$\begin{aligned} P_{active} &= T_{receive} \times A_{active} \times V, \\ P_{sleep} &= T_{receive} \times A_{sleep} \times V, \end{aligned} \quad (4)$$

where $T_{receive}$ is the processing time while receiving biometrical data from all RFD nodes. It differs depending on MAC protocols. So the difference of $T_{receive}$ comes to the difference of protocols directly. The value of A and V refers to related study [6].

Ⅳ. Computer Simulation

A. Simulation purpose and setup

We compute the thermal influence and power consumption in proposed protocol compared with the existing protocols ALOHA and CSMA/CA. The purpose of this simulation is to confirm the effectiveness of our communication model in point of these standards. We examine the characteristic when the sleep time of the leader changes. Parameters in this simulation are shown in Table 2.

Table 2 – Simulation setup

parameter	value	parameter	value
bit rate	250kbps	sleep time	1-20sec.
pay load	500bits	Switch cycle	10
slot time	144μs	packet	50
DATA time	2480μs	V	3.0V
SIFS time	192μs	A_{active}	20mA
DIFS time	400μs	A_{sleep}	1μA
ACK time	352μs	the number of RFD nodes	10

B. Simulation result

Figure 7 shows the saturated temperature during a long time, where leaders can switch several times. This result is the characteristic when the sleep time changes in pure ALOHA, CSMA/CA and proposed, respectively.

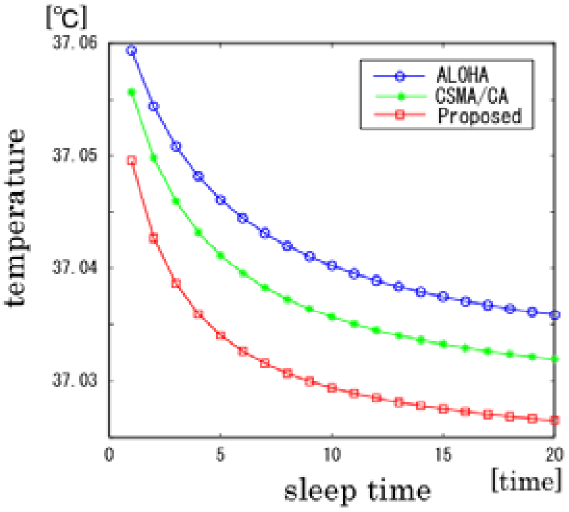

Figure 7- Saturated temperature

Figure 7 shows the saturated temperature during a long time, where leaders can switch several times depending on the sleep time in pure ALOHA, CSMA/CA and proposed, respectively. As shown in Figure 7, it is most affected by thermal influence in ALOHA. We consider the factor of this result is the processing time of receiving biometrical data from all RFD nodes, that is $T_{receive}$. When the value of $T_{receive}$ is large, the switching interval comes to long too. So the time the leader is affected thermal influence by exposing radiation and circuit heat comes to the longest in ALOHA. And then the temperature increment in the proposed protocol is less than ALOHA and CSMA/CA. This result proves that nodes can communicate most efficiently and reduce the thermal influence in our proposed protocol.

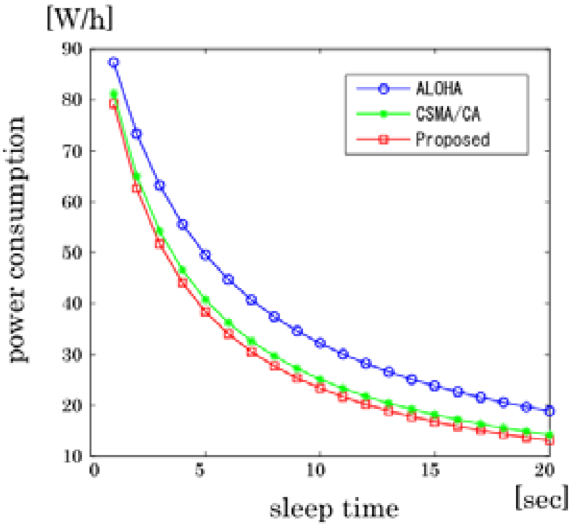

Figure 8- Power consumption

Figure 8 shows the power consumption of the leader in an hour. The proposed protocol can control power consumption better than ALOHA and CAMS/CA because the processing time of receiving data is the factor that influences power consumption directly, too. However, there seems to be less difference between the proposed protocol and CSMA/CA compared to the result of Figure 7. We consider that while differences of power consumption depends mostly on differences of the processing time, differences of thermal influence depends on differences of circuit heat and exposing radiation time caused by increase of the processing time.

Ⅴ. Conclusion

In this paper, we design a communication model such as network structure, communication flow and MAC protocol in an implanted body area network. We also show the effectiveness of our communication model in terms of thermal influence and power consumption.

In a future work, we plan to consider optimum sleep time on the basis of update rate which has relationship of tradeoff with sleep time. Moreover, we will propose the metrics which evaluates comprehensively and compare with the existing protocol.

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