

## An Improved MAC Protocol for WBAN Through Modified Frame Structure

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### **Abstract**

*In WBAN environment, it is important to achieve energy efficiency of nodes implanting into human body. At the same time, a master also plays an important role in collecting data from nodes and controlling the nodes. By maintaining a master properly, any kinds of situation can be handled. Therefore, low power MAC protocol between a master and a node is highly required appropriately. A MAC protocol proposed in this paper aims to satisfy with these requirements and improve energy consumption rate that tends to grow high as the number of nodes increases. For the efficient and objective evaluation of the proposed MAC protocol, IEEE 802.15.6 MAC is used to compare with it and we show that the advantage of the proposed MAC meet our expectation.*

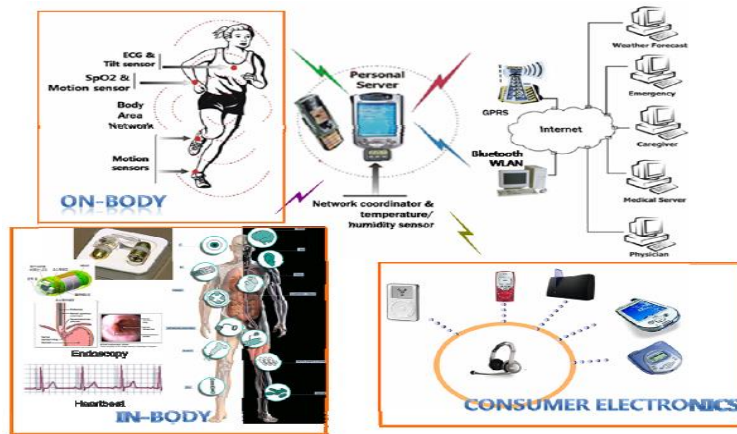
**Keywords:** WBAN, MAC Protocol, Superframe, Master and Node, synchronization

### **1. Introduction**

Wireless body area network (WBAN) is a new type of networking technology that provides intercommunication of wireless devices attached to a human body within 3 to 5 meters distant from the center of the body. A task group 6 of IEEE 802.15.6 has been established to work on the standardization of WBAN since 2006. WBAN can be implemented by integrating a number of advanced technologies such as local area communication, biosensor, implantable nanotechnology, human attachable type of RF interface and driver etc. Figure 1, illustrates a concept of WBAN [1].

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**Figure 1. A Concept Of WBAN**

In terms of WBAN devices, portability should be guaranteed. It means it needs to be operated by battery. Consequently, it is necessarily important to save power when using it. That is the reason why many studies have focused on proposing solution for improving an energy efficiency in various way, such as by concentrating power consumption of PC instead of nodes [3], of by varying superframe structure [4], and by using data collision avoidance [6]. In terms of a device implanted into the human body, it is designed to aim for having long lifetime with low power consumption because its power resource is constrained, that is, it cannot be recharged or replaced with new one once it is implanted into the body. Moreover, high power consumption might cause damage to human body. Therefore, low power consumption is highly required in WBAN technology.

To overcome a problem of implantable devices, this paper proposes low-power MAC protocol for complying with WBAN environment.

The remainder of the paper is organized as follows. Section 2 presents a background of this study focusing on MAC protocol for WBAN. Section 3 describes a proposed algorithm. Section 4 evaluates and analyses performance through simulation. Finally, section 5 draws conclusion from this work.

## 2. Background of the Study

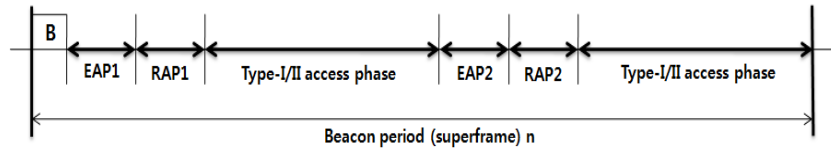
### 2.1. IEEE.802.15.6 Superframe

The IEEE 802.15.6 standard is a communication standard for WBAN technology. A task group 6 of IEEE 802.15 is formed to work on the IEEE 802.15.6. In this standard, MAC layer adopts a distributed time slot allocation mechanism using beacon. In this standard, wearable device such as attachable-type of sensor is called a node, and a device to collect data such as coordinator is referred to as a hub.

Superframe structure of WBAN is divided into beacon (B), exclusive access period (EAP), random access period (RAP) and type-I/II access phase.

In this model, all the nodes are controlled by on hub. In other words, each node determines time period for EAP, RAP and type-I/II by receiving beacon sent by the hub. After deciding the period, it uploads or downloads its own data according to control method for each period. In this case, type-I/II means a polling-type data transmission that is governed by the hub. Its main purpose is to provide a chance to transmit data for the nodes that could not get the

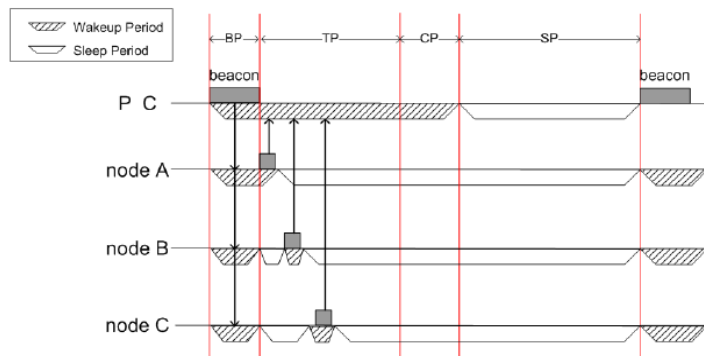
opportunity to send the data during the period of EAP and RAP. Figure 2 shows the MAC superframe structure specified in IEEE 802.15.6



**Figure 2. Superframe Structure of IEEE 802.15.6[2]**

## 2.2. Related Works on MAC Protocol

Aside from IEEE 802.15.6 standard, the studies related to WBAN have been conducted continuously. Likewise, MAC protocol structure also has been studied by many researchers. A Heartbeat Driven MAC protocol (H-MAC) is a kind of TDMA-based body sensor network that is designed to be synchronized using heartbeat of human being. The energy efficiency is improved by exploiting heartbeat information to synchronize the nodes. Another advantage is that it removes a need of a control message for synchronization. However, it also has disadvantage of having difficulty in handling sporadic events because heartbeat rhythm information is significantly diverse depending on human body's condition. In case of a MAC protocol with a variable superframe, it deals with data by changing periods when there is no data to send. Immediately after handling data, it goes to sleep, which leads to low energy consumption and low data loss. Therefore it is considered to be reliable. However, it does not support time slot for handling events. It becomes its weakness of having trouble in complying with emergency situation that might be caused by wearable device in healthcare environment [4].



**Figure 3. Asymmetric Energy use among Devices for MAC Protocol**

Figure 3 illustrates new mechanism to improve energy efficiency of non-rechargeable node and to ensure Quality of Service (QoS) by reducing transmission latency of emergency data. Since PC has relatively large energy resources compared to node, this mechanism aims to put the unavoidable energy consumption loads to the PC for achieving high energy efficiency of nodes. PC saves power by operating a duty cycle consisting of wakeup and sleep mode alternatively. However, PC remains in active mode even after completing data transmission. It means PC wastes power. In terms of a wearable device, portability is an important factor to

be guaranteed. A terminal that controls node is also required to be operated with low power in order to avoid unexpected system failure caused by accidental environment.

### 3. Proposed MAC Protocol

In this paper, a device that attaches to a body and senses data from the body is referred to as a node. Additionally, a device that collects sensed data is referred to as a master. Corresponding to the WBAN environment, this study assumes that network is established with start topology. It is also assumed that the node transmits sensed data to the master, but there is no data transmission between nodes. Based on those assumptions, this study designs MAC protocol with TDMA-based synchronization.

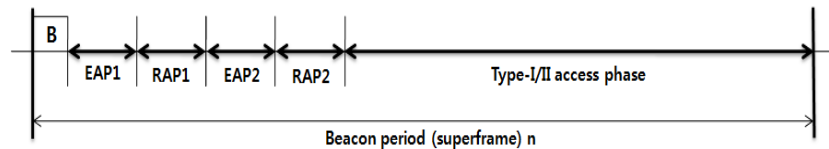
The proposed MAC protocol is based on superframe structure. This protocol is subdivided by four steps. First, a master receives beacon from a node, so that a master acquires node's data transmission information and data size from a node. Second, a master carries out synchronization with a node based on the data transmission information. Third, upon completion of synchronization, channel schedule is created in order to assign channel between a master and a node. Final step is where data transmission is controlled while channel is being assigned and connection is established based on channel schedule.

Using the traditional structure of WBAN superframe, a node has to wait until it is polled by a master without regards to whether it has data to send or not. As a result, the node should consume energy for waiting and the master also consumes power for polling.

Type-I/II period is used only when an amount of data is very large. This is not a common situation, for example, multiple nodes coexist with on master. In other words, this period is no frequently used.

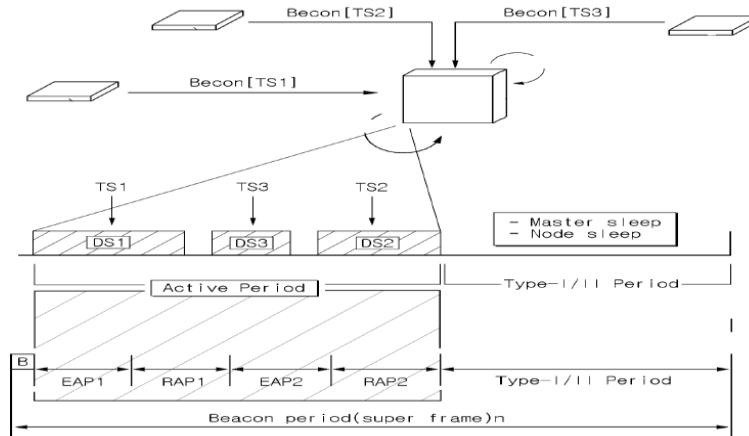
The conventional structure of superframe consists of EAP, RAP and Type-1 in a from EAP1 to the following EAP2. While it stays in an active state. it consumes power continuously. Furthermore, energy consumption continues until a master polls the node, even though there is no data to send until next beacon arrives. It is because type-II period exists at the end of the frame.

To overcome the energy wasting problem mentioned above, this study proposes enhanced scheme in two ways:(1) to minimize the use of type-I/II period by reducing the frequency of using type-I/II period, and (2) to change the node's state to SP state until next beacon arrives if there is no data to send.



**Figure 4. The Proposed Superframe Structure**

For doing this, the study proposes new structure of superframe that merges two periods of type-I/II into one period and moves it to the end of the merged frame. This structure is aiming to reduce power wasting by avoiding the need of polling when there is no data to send. Furthermore, EAP2 and RAP2 are followed immediately after EAP1 and RAP1. It indicates that both an exclusively allocated period and a randomly allocated period are located repeatedly without intermediate interval. If data exists in EAP1 but no data exists from the following RAP1, the node would be changed to SP mode after sending data on EAP1. In this way, energy consumed by the node can be saved.



**Figure 5. Superframe Structure of Proposed Scheme**

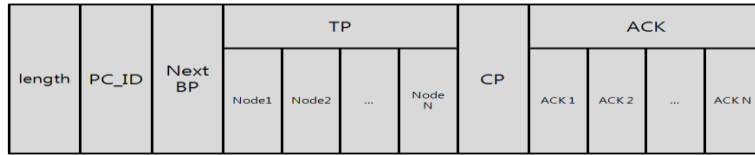
Figure 5 presents the proposed MAC protocol that supports flexible transition to sleep mode corresponding to environment. Unlike traditional method, the proposed mechanism improves energy efficiency in the period where master and node does not communicate, by flexible changing SP period during TP period according to the node information.

A node communicates with a master via WBAN. In addition, a node provides information about data transmission (TS1~TS3). Data transmission information indicates when a node sends data to a master, which can be defined as relative time instead of absolute time. In other words, the time information provided by a node implies how much time needs to be elapsed until a node starts to send data to a master. If each node gives the relative time information to a master in advance, a master can efficiently synchronize with a node based on the information. To determine which node sends data at which time, the master converts a relative time into an absolute time in conjunction with a real time clock (RTC). The converted time will be stored in a data transmission information time table. The master refers to the time table when necessary. Referring to the time table, the master assigns available channel to a node that is supposed to send data, based on the transmission time information (TS1~TS3). The master can be controlled to be active only when a node is in active state, where the node has data to send.

Each node connected to the master is synchronized corresponding to the beacon interval. While synchronizing process, nodes send their information to the master by putting the information to beacon frame. Subsequently, the master receives beacon frame from nodes. Based on information sent by nodes, the master recognizes data transmission time of EAP, RAP and type-II for each node. Depending on respective control method for each period, the master flexibly performs active/inactive transition with nodes.

The master remains in SP mode until a node starts to transmit data. That is, it can save power when there is no data transmission from a node. With help of information gathered from nodes during SP mode, the master knows when a node wakes up for transmitting data. Therefore, the master turns in to TP mode shortly before a node starts to send data. Once it completes data transmission, the master activates SP period until next node starts to transmit data. This process is carried out repeatedly until all the nodes connected to the master complete their transmission. When all the nodes finish transmitting their data, the master changes its state into SP mode and stays in SP period until next beacon arrives. In this way, energy efficiency in the master can be achieved.

In a beacon period (BP) of duty cycle, the master broadcasts beacon frame to all the nodes. Figure 6 shows a structure of beacon frame.

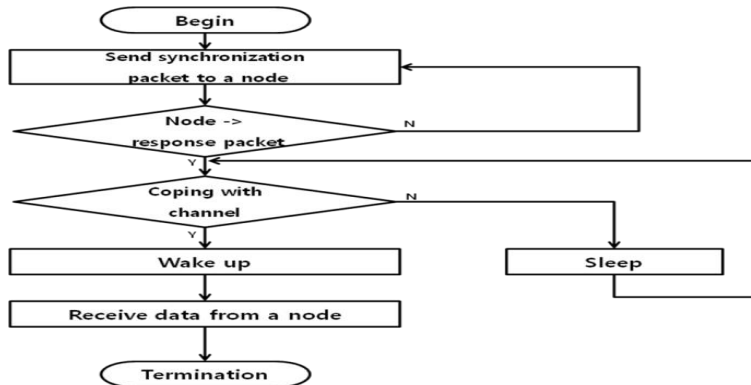


**Figure 6. Beacon Frame Structure**

A single master uniquely exists per on person and each node is operated under control of the master in WBAN MAC protocol. Thus all the nodes refer to PC\_ID residing in beacon frame in order not to be involved with other person's master. Next BP indicates a time when the following BP is triggered. All the nodes wake up when the following BP begins, by referring to Next BP information after receiving beacon frame. Each node identifies data transmission time corresponding to its own node\_ID using u-TP information. After that, if there is data to send, the node transfers the data within predefined period and determines whether data retransmission is required or not, based on acknowledgement information referring to beacon frame that would be received in next BP.

In this study, the synchronization between master and node is crucial because information sent by node is useful only if synchronization is successfully completed.

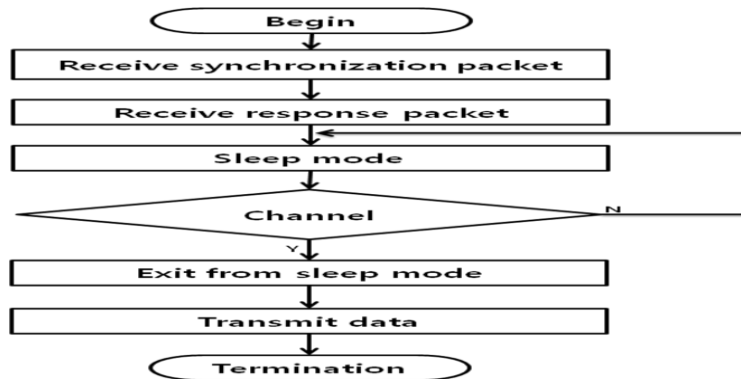
Figure 7 shows an operation sequence of a master. After completing synchronization, the master remains in sleep mode until a node begins to send data. Before data transmission time of node is due, the master wakes up from sleeping and is ready to receive data. Once the data transmission is completed, the master confirms whether all the nodes finish transmitting data. In this case, the master refers to the number of nodes that have been synchronized. If all the nodes complete transmission of data, the master goes to SP mode and remains in SP mode until next synchronization takes place. For example, there are three nodes in a network. If the master gets data from only two nodes, the master goes back to sleep mode and wait until the last node begins to send data.



**Figure 7. Operation Sequence of a Master**

After sending a synchronization request signal, a node enters sleep mode and remains in sleep mode until its own data transmission time arrives. When the time is due, the node transmits data to the master that wakes up earlier than the node. Once the transmission is completed, the node enters sleep mode and remains in sleep mode until next transmission

time arrives, if data remains. Otherwise, the node goes to SP mode and waits for taking place next synchronization. Figure 8 shows an operating sequence of the node.



**Figure 8. Operation Sequence of a Node**

#### 4. Performance Evaluation

In performance evaluation of the proposed superframe structure, the environment variables are set as follows: first, a master targeting on human body is placed with three-meter distance away from several other nodes. Second, the number of nodes increases starting from two up to ten and the nodes are supposed to be placed around a master. Third, packet loss due to synchronization is not considered. Finally, all nodes are assumed to be located at fixed position. While simulation is being performed, a node sends data of maximum 15 bits at random intervals. Simulation period is set to be 10 seconds. Through the simulation, system performance was evaluated in perspective of the amount of power consumed by a master and nodes. Additionally, communication parameters were set in accordance with requirements in WBAN environment.

**Table 1. Simulation Parameters**

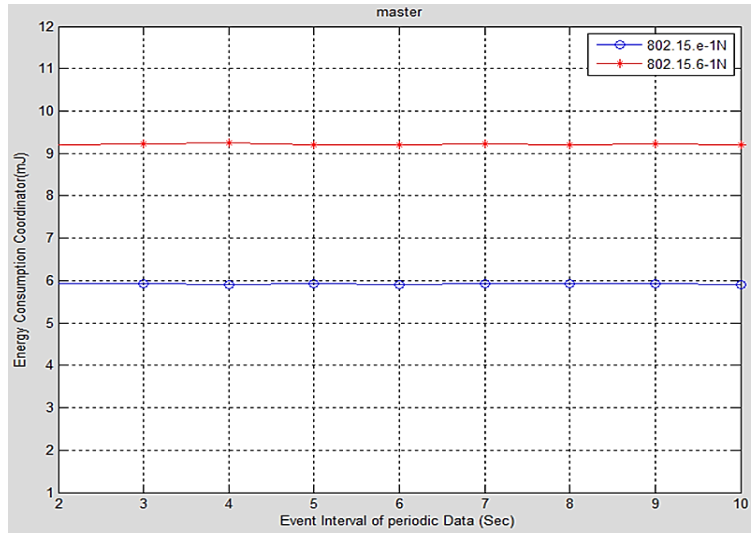
|                    | Parameter        | Value          |
|--------------------|------------------|----------------|
| <b>PHY</b>         | Data Rate        | 64Kbps         |
|                    | Tx               | 2.428mW        |
|                    | Rx               | 1.814mW        |
|                    | Sleep            | 0.027mW        |
| <b>Application</b> | Master           | 1              |
|                    | Node             | 1 ~ N          |
|                    | Network Topology | Star Structure |

The proposed protocol assumes that there is no data interaction among nodes. Therefore, star topology is used for establishing network. In IEEE 802.15.6 coordinator is referred to as "HUB", however in this paper, it is referred to as "master".

Figure 9 and 10 present the results about energy efficiency comparing the proposed MAC protocol to IEEE 802.15.6. Figure 9 is originated from power consumption of one master. On the other hand, Figure 10 comes from power consumption of several nodes connected to a master. In this simulation, all the nodes connected to the master are assumed to send all the periodically sensed data to a master.

The traditional scheme uses superframe structure specified by IEEE 802.15.6 when transmitting data. Hence, the master wakes up even if it does not need to maintain the active

state of communication. Additionally, the master stays in active state until next beacon synchronization is carried out, because it still needs to poll. All those things cause energy wasting. On the contrary, the proposed MAC protocol allows the master to wake up only when a node actually transmits data with help of information sent by node. Furthermore, if the master completely receives the data from all the nodes, the master can go to SP mode and stay in SP mode until next synchronization starts. As a result, the energy consumption by master can be reduced as shown in Figure 9.

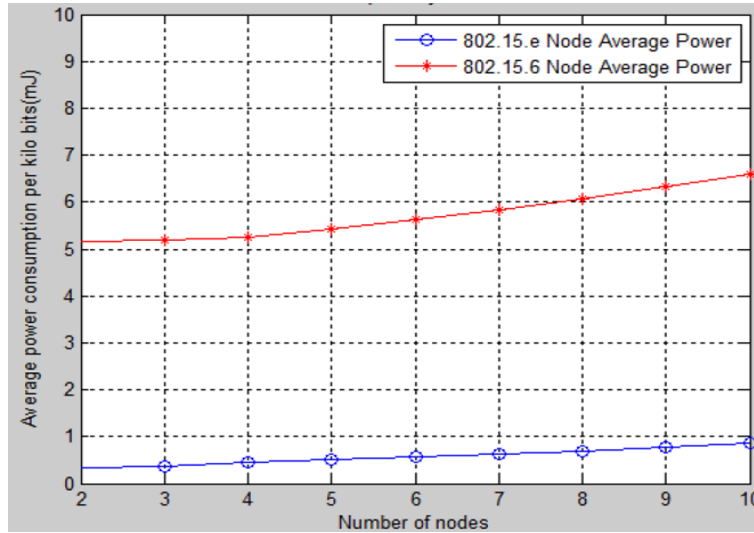


**Figure 9. Result of Energy Consumption on Master**

In the perspective of nodes, all the nodes in IEEE 802.15.6 have to wait for acknowledgement message after sending data. If acknowledgement message is not received, the node needs to retransmit data during transmission allowed period.

Therefore, it has low latency and ensures reliability. Unlike this mechanism, the proposed MAC protocol makes all the nodes go to sleep immediately after completion of data transmission. The node can comply with retransmission situation after getting next beacon frame that includes acknowledgement information on previous transmission. It indicates the proposed mechanism is less reliable than IEEE 802.15.6. However, reliability is not a significant issue in this case because periodic data is likely to be monitoring data rather than emergency data.





**Figure 10. Power Consumption by Number of Nodes**

In Figure 10 power consumption is presented as average power consumption per kilo bits by varying the number of nodes, comparing the proposed MAC protocol to traditional IEEE 802.15.6. The proposed mechanism considerably outperforms traditional on. The red line presenting IEEE 802.15.6 mechanism shows sharp increase in energy consumption, and then the energy consumption rate grows significantly high as the number of nodes increases. On the contrary, the proposed MAC protocol does not show significant increase as the number of nodes increases. It is mainly because the proposed mechanism activates only when there is data to send. Collision between nodes does not happen, therefore retransmission also is not taken place. It results to prevention of energy wasting. Additionally, state transition between active and inactive mod contributes to energy efficiency.

## 5. Conclusion

In WBAN environment, it is important to achieve energy efficiency of nodes implanting into human body. At the same time, a master also plays an important role in collecting data from nodes and controlling the nodes. By maintaining a master properly, any kinds of situation can be handled. Therefore, low power MAC protocol between a master and a node is highly required appropriately. A MAC protocol proposed in this paper aims to satisfy with these requirements and improve energy consumption rate that tends to grow high as the number of nodes increases. To evaluate a performance of the proposed protocol, the simulation is performed and the results are compared to traditional method based on IEEE 802.15.6. Since information is exchanged only when mutual channel is established, QoS is not totally guaranteed. In the future, QoS guaranteed low power MAC protocol needs to be studied further.

## Acknowledgements

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## References

- [1] IEEE 802.15.4: Wireless Medium Access Control(MAC) and Physical Layer(PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs), (2006) September.
- [2] IEEE 802.15.WPAN Task Group 6 Body Area Networks (WBAN), <http://www.ieee802.org/15/pub/TG6.html>.
- [3] J.-H. Lee and D.-S. Eorn, "An Energy-Efficient MAC Protocol for Weable Device WBAN Environment through Asymmetric Method and QoS", KICS, vol. 37A, no. 06, (2012) December, pp. 395-404.
- [4] J.-S. Lee, J.-K. Ahn and C.-Y. Yun, "Improved TDMA with Superframe Structure-based CSMA/CA MAC protocol for Wireless Body Area Network", Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, vol. 26, no. 1, (2012), pp. 87-93.
- [5] T. Hyoung Kim, H. Joong Joeng, Y. Hwan Kim and Korea Electronics Technology Institute, "WBAN MAC protocol for Data Reliability and Energy Efficiency", KIEE, (2010) July, pp. 1892-1893.
- [6] I. Lee, G. Lee, S. Cho and S. Choo, "Hybrid priority Medium Access Control Scheme for Wirelee Body Area Networks", KICS, vol. 35, no. 9, (2010) September, pp. 1305-1313.
- [7] T. Hyoung Kim, H. Joong Jeong, Y. H. Kim and J. Hong, "Development of MAC Simulator based Ultra Low Power for Implantable WBAN", KCC, vol. 37, no. 1(D), (2010), pp. 170-173.

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