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Study on WBAN-Based Efficient and Energy-Saving Access Mechanisms

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Abstract

With the constant development of wireless communication technology and gradual maturity of sensor technology, WBAN has gradually become research focus, mainly used in such fields as medical treatment, daily life, entertainment and military. Its main units are sensor nodes, responsible for data collection, processing and transmission. Sensor nodes are usually powered by batteries, and due to limited energy, reducing energy consumption of sensor nodes and extending the life cycle of such nodes are of great importance to WBAN. In this paper, WBAN is briefly introduced first, and the research status of MAC protocols for WBAN is analyzed, with focus placed on the introduction to wakeup radio mechanism-based MAC protocols. Then priority is set for business type and sensor nodes, emergency business data flow is simplified and TDMA modulation mechanism is adopted to optimize awake up radio-based protocol. The optimized MAC protocol has realized a good result in terms of energy consumption reduction of WBAN, reduced terminal node energy consumption and extended the network lifetime.

***Keywords**: WBAN; MAC protocol; wireless sensor network; priority*

1. Introduction

With the constant development and maturity of wireless communication technology, sensor technology, computer technology, *etc.*, WBAN has become the focus of research and application [1-2]. WBAN is an individual-centered micro communication network consisting of various kinds of sensors and individual terminals distributed on the human body and clothes and inside the body [3-4]. In the application of WBAN, sensor nodes are generally powered by batteries. As battery replacement for implantable nodes is hard to realize, reducing energy consumption of sensor nodes and extending their life cycles seem to be very important [5]. In WBAN, an MAC layer protocol has a significant effect on WBAN, determines the way sensor nodes use wireless channels and allocates limited wireless channel resources for sensors [6], so research on low-power MAC protocols is of practical significance for improving the performance of WBAN. In this paper, an MAC protocol for WBAN is optimized from the angle of priority setting. First, brief introduction to WBAN is given, the research status of MAC protocols for WBAN is analyzed, with focus placed on the introduction to an MAC protocol for the wakeup radio mechanism [7]. Then, the MAC protocol for the wakeup radio mechanism is optimized and the optimized MAC protocol has improved the energy efficiency of WBAN, reduced terminal node energy consumption and extended the network lifetime.

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2. Optimization of MAC Protocol for Wakeup Radio Mechanism Based on Priority

2.1. Research Status of MAC Layer Protocol

Starting from the system structure of WBAN, such parts as wireless communication, sensor signal detection and data processing are the main source of energy consumption and node wireless communication consumes far more energy than the other two parts. Therefore, the study on a low-consumption communication mode is the key to extending network lifetime. In WBAN, the energy consumption during the channel access process of sensor nodes mainly occurs in the following aspects [8-9]:

(1) Information Collision: a few nodes send data packets simultaneously and result in information collision due to the occurrence of conflicts at the receiving end, and resending data packets results in the consumption of extra energy.

(2) Crosstalk Problem: a wireless sensor node receives a data packet whose destination address is not the node in the channel monitoring process. Adjacent nodes are prone to crosstalk phenomena, thereby consuming unnecessary energy.

(3) Idle Listening: a node cannot predict when other nodes send data, so its sending and receiving module is always in the listening state, thereby consuming a lot of energy.

(4) Control Information: a node adds some extra control information while transmitting data, thereby increasing data frame length and causing extra energy consumption.

The current research on MAC protocols for MBAN mainly focuses on three aspects, *i.e*. energy efficiency, low latency and reliability, but sometimes compromises have to be made because it is impossible for an MAC protocol to be prominent in terms of effectiveness, low latency and reliability at the same time. In the paper, the research focus of an MAC layer protocol is its energy efficiency.

Based on different strategies during access to channel resources, the MAC protocols for WBAN can be competition mechanism-based MAC protocols and TDMA-based MAC protocols [10], with their respective advantages and disadvantages as shown in Table 1.

Table1. Comparison of CSMA and TDMA Protocols

Performance Parameter	CAMA Protocol	TDMA Protocol
Energy Consumption	High	Low
Scalability	Strong	Weak
Synchronization	Unnecessary	Necessary
Packet Loss Rate	Low	High
Band Utilization Rate	Low	Maximum

2.2. Wakeup Radio Mechanism-Based MAC Protocol Model

In the current research on MAC protocols for MBAN, apart from competition mechanism-based and TDMA-based MAC protocols, a wakeup radio mechanism-based MAC protocol has gradually become research focus, and it is a hybrid mechanism-based MAC protocol, different from a CSMA competition mechanism-based protocol and a TDMA mechanism-based protocol [11].

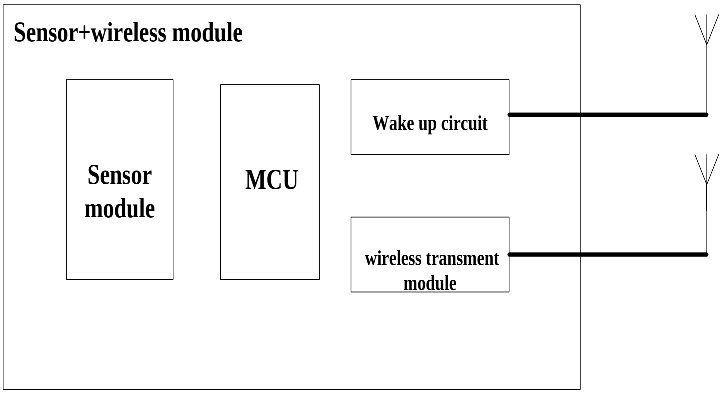

Figure 1. Sensor Node and Wakeup Module Schematic Diagram

A typical sensor node with a wakeup circuit is as shown in Figure 1, and the wakeup signal packet format is as shown in Figure 2. Due to simple and easy design and strong operability of wireless wakeup circuit, it has good economic rationality. Therefore, it can be effective applied to the sensors of WBAN.

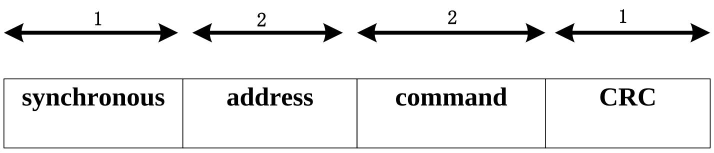

Figure 2. Wakeup Data Frame

2.3. System Model

A wakeup radio mechanism-based MAC protocol divides the sensor nodes in WBAN into two parts, the central control node (Hub) and sensor (Nodes) [12]. Network topological structure is usually a star form. In WBAN application, not all nodes need to send data all the time, so nodes enter a sleep state when not transmitting data and are woken up when there are data to process, thereby reducing extra energy consumption of nodes. The status transition of nodes is as shown in Figure 3.

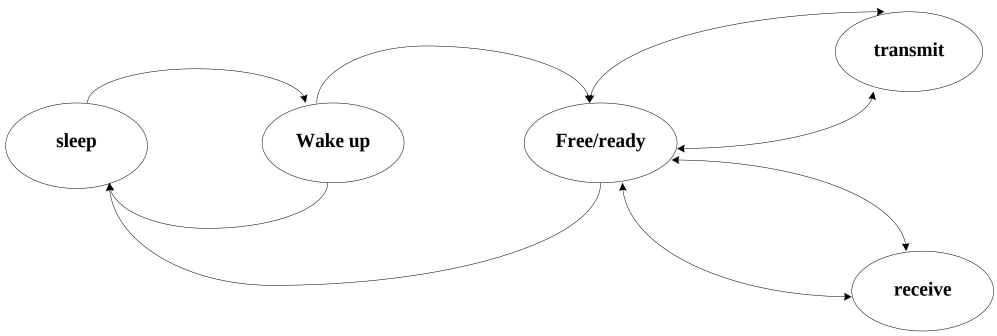

Figure 3. Status Transition Diagram of Sensor Nodes

The data transmission in WBAN is bi-directional reversible exchange between hub data and sub-node data. Based on the initiator and business characteristics of data transmission, business can generally be divided into two types, *i.e*. cycle business and emergency business, as shown in Table 2.

Table 2. Cycle Business and Emergency Business

Node Type	Cycle Business	Emergency Business
Central Control Node (Hub)	Sending wakeup signals to the nodes	Receiving wakeup signals from the nodes
Sensor Nodes (Nodes)	Receiving wakeup signals from the hub	Sending wakeup signals to the hub

Cycle business is the business initiated by the hub, which wakes up the sensor nodes cyclically, with the wakeup interval determined by the hub based on the business type and data volume of each sensor.

In cycle business, the hub sends a wakeup signal to the sensor nodes first, and the sub-nodes are woken up after receiving the wakeup signal and then send an ACK frame to the hub. After the hub receives the ACK frame, it sends the sub-nodes a beacon frame, which contains the time slot and channel information allocated by the hub to the sub-nodes. After receiving the beacon frame, the sub-nodes begin data transmission and after the hub completes data receiving, it sends back ACK to the sub-nodes, with the communication process of the entire transmission process is as shown in Figure 4.

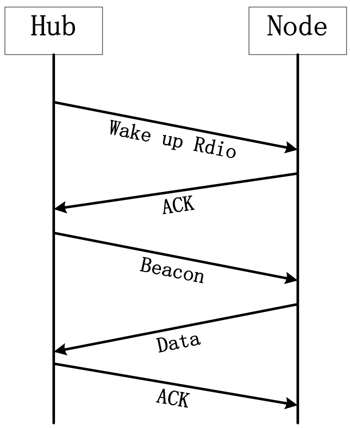

Figure 4. Communication Process of Cycle Business

2.4. Optimization of Wakeup Radio Mechanism-Based MAC Protocol

The optimization method adopted in this paper is multi-priority setting, with the setting of multi-priority setting specifically shown in the following two aspects:

(1) Priority is set for business type. The business in WBAN is divided into cycle business and emergency business, of which cycle business refers to the hub asking the sub-nodes for data at a certain wakeup interval, and emergency business usually occurs in a sudden situation, with transmission involving the key data information requiring immediate processing by the hub. Therefore, high priority is set for emergency business and low priority is set for cycle business. When cycle business and emergency business occur at the same time, priority should be given to ensuring the transmission of emergency business, followed by cycle business.

(2) Priority is set during transmission of sensor nodes. In order to effectively avoid the conflicts and collision caused when a number of sensor nodes are woken up and need to transmit data, causing a waste of energy. Different priorities are set for the sensor nodes in WBAN, with high priority set for the sensor nodes transmitting key information such as

blood pressure and heart rate and low priority set for the sensor nodes related to body temperature, *etc*. Therefore, by setting different priorities for sensor nodes, the data transmission of the most important physiological parameters of the body can be guaranteed, thereby avoiding energy waste brought about by data collision and at the same time providing an important support based on the above key factors for timely diagnosis of patients.

(3) Additionally, optimal design of communication process and frame structure of emergency business is conducted. Due to the particularity of emergency business data, the hub is required to start to receive data with possibly shortest time delay and then send the received data to the remote control center, where medical personnel diagnose the condition of a patient in a timely manner by processing and analyzing the receive data and determine a correct diagnosis and treatment method. In this paper, the time slot of wakeup radio work is optimized as a modulation mechanism-based MAC protocol, with the time-slot distribution for a single sensor node as shown in Figure 5.

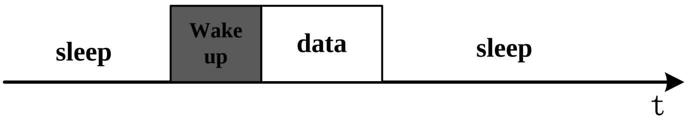

Figure 5. Work Mechanism of a Single Sensor Node of Wakeup Radio Mechanism

For the whole system, the work time slot of the hub based on TDMA resource allocation is a shown in Figure 6.

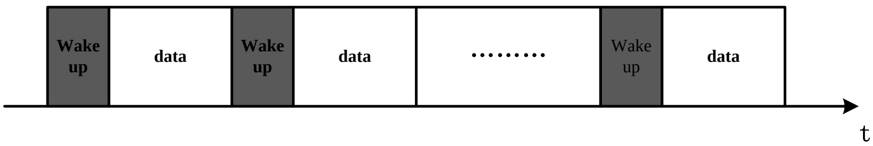

Figure 6. TDMA System-based Wakeup Time Slot and Transmission Time Slot Allocation

3. Simulation Analysis

3.1. Simulation Environment

(1) Network topology

In order to analyze the advantages of low-power MAC protocols proposed in this paper, Matlab simulation is adopted to construct a simulation platform. A star structure is a typical topological structure in WBAN, a situation involving general response. In this paper, such a star structure is used for simulation. A typical WBAN may involve up to 10 sensor nodes, as shown in Figure 7, with 0 being the central control node, *i.e*. hub node, the rest being sensor nodes with different functions. The distance between adjacent nodes is set to be 60-90cm and effective data transmission distance is set to be 100cm.

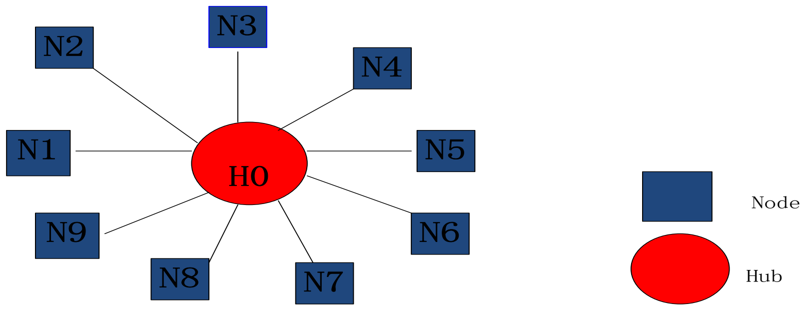

Figure 7. Network Topology

(2) Setting of node business flows in simulation

A single-hop star network topology structure is used in the simulation process and Poisson data flow is used to simulate the arrival process of data packets and the process of data packets arriving at the destination node is subject to Poisson distribution, with simulation parameters as shown in Table 3.

Table 3. Input Parameter Comparison Table

Number of Nodes	10	Size of wakeup response packets	6Bytes
Communication Frequency Band	2.4GHz	Size of data packets	Variable
Modulation Mode	O-QPSK	Size of response packets	10Bytes
Link Error Code Scope		Energy consumed for sending data packets/bit	47nJ/bits
Data Transmission Rate	25Kbps	Energy consumed for receiving data packets/bit	32nJ/bits
Simulation Time	1000s	Energy consumed for sending wakeup data packets/bit	14nJ/bits
Size of Wakeup Packet	6Bytes	Energy consumed for receiving wakeup data packets/bit	10nJ/bits

3.2. Simulation Result Analysis

In the simulation realization process, in the situation involving the same simulation environment and same parameters, an optimized multi-priority MAC protocol based on wakeup signals is compared with the original protocol and an X-MAC protocol based on asynchronous sleep wakeup mechanism to obtain energy consumption simulation Figure 8. Node energy consumption refers to the total energy consumed by sensor nodes sending a certain number of data packets to coordinator nodes. Simulation result comparison shows that due to full consideration given to emergency business and the hour interval at which data arrive, the optimized MAC protocol has achieved good results, compared with the original protocol and the X-MAC protocol. With the increases in the data arrival interval, the energy consumption of the whole system model is on the gradual decrease.

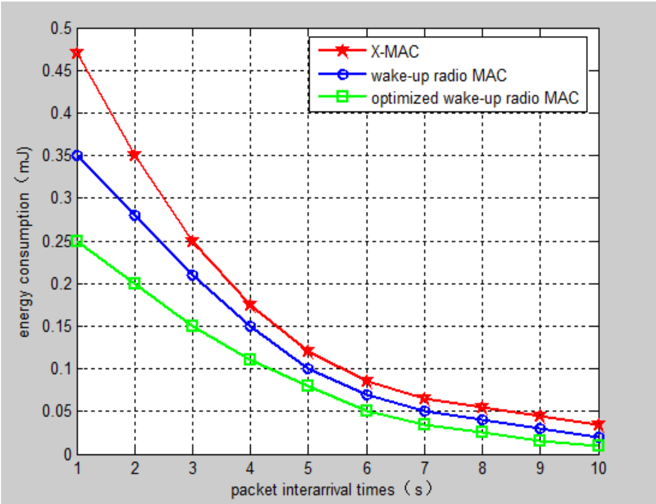

Figure 8. Energy Consumption Simulation Diagram

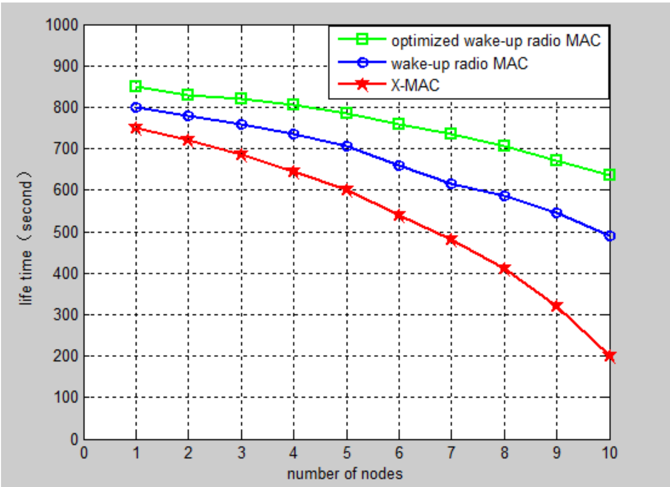

Figure 9. Network Lifetime Diagram

Reducing node energy consumption to further extend the lifetime of nodes is the key issue involved in MBAN and also an important indicator for measuring an MAC protocol. The network lifetime diagram is as shown in Figure 9. As for the MAC protocol based on wakeup radio mechanism, due to increased number of nodes and channel competition and signal interference involved in the lifetime, the transmission failure rate becomes larger, resulting in rapid consumption of energy, while the optimized MAC protocol based on wakeup radio mechanism adopts TDMA access mode and is provided with priority setting, thereby avoiding energy consumption caused by conflicts and reducing synchronous energy consumption of node wakeup so that the network lifetime will not decline sharply and the overall network performance can be improved.

4. Conclusion

The energy consumption problems with the sensor nodes in WBAX and the existing MAC layer protocols are analyzed in this paper, and based on the low-energy characteristics of WBAN and wakeup radio mechanism-based MAC layer protocols, optimization and improvement are conducted in terms of business priority, sensor node priority and frame structure. The optimized MAC layer protocol can effectively reduce energy consumption and improve the service quality of the entire network. Theoretical analysis and energy consumption simulation experiments show that compared with X-MAC and the MAC based on wakeup radio mechanism before optimization, the optimized MAC has great advantages in terms of node energy consumption, especially suitable for WBAN with low network load.

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