PERFORMANCE ASPECTS OF isMAC PROTOCOL FOR WBANS USING isMOTES

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ABSTRACT

Wireless body area networks (WBAN) consist of wireless smart sensor nodes placed on, in or around the human body for medical monitoring systems, entertainment and ubiquitous computing. The nodes in WBAN are usually battery-powered and they send sensed data from a human body, including heart rate, temperature and ECG, etc. to the medical centre to monitor the health situation of individuals. One of the major problems of a WBAN is to prolong the sensor network lifetime. To solve this major problem, different approaches are used, but the most effective one is a well-designed MAC protocol. This paper investigates three inter-BAN communication methods and suggests a coordinator node rotating mechanism to ensure energy balance among the sensor nodes and to extend the network lifetime up to 59%.

Index Terms— Wireless Body Area Networks, isMAC, isMOTE, energy saving, energy effective MAC protocol.

1. INTRODUCTION

A wireless sensor node generally measures one or more physical and biological signals from the environment where they deploy. Besides sensing feature, they are capable to collect and process information from the environment and then transfer to a specified destination. Two or more sensor nodes can be deployed or implanted in a human body and connected each other to constitute a Wireless Body Area Network (WBAN) [1].

Fig. 1 depicts a simple WBAN application which includes five wireless sensor nodes. Sensor nodes (blue ones) measure biological signals and send the data to the Coordinator Node (CN). The CN is responsible to manage the communication between sensor nodes and the base station. It collects measured data from sensor nodes then transmits all information to the base station wirelessly. The base station is connected to a local server via a cable. Thus, gathered medical information can be recorded on a web server so that doctors or other medical professionals can access patients' real time records through the internet.

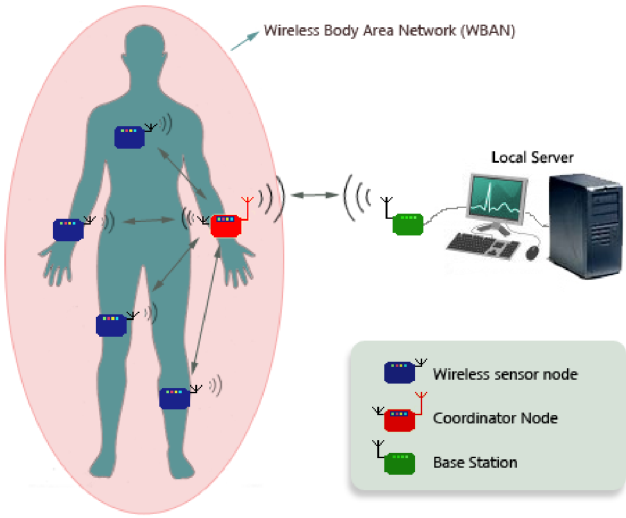

Fig. 1 Communication structure of a simple WBAN

A wireless sensor node is mostly a battery-powered device and energy is severely constrained. In a WBAN, it is assumed that network lifetime ends when a sensor node cannot send and receive any message packet. Therefore, the sensor node which has the lowest lifetime, determines the lifetime of the network. Consequently, the lifetime of the greediest node in the network should be maximized to prolong the network lifetime.

In order to extend sensor node lifetime some methods (i.e. relay nodes, energy harvesting on body, adjusting transmission power, low power listening, listen before send, low duty cycle etc.) have been developed but most effective ones are energy-efficient medium access control (MAC) protocols. The radio part of a sensor node consumes the highest battery power during both receiving and transmitting message packets and MAC protocol specifies when the node radio will be turned on and off. The main goal is to turn the node radio on only if the node has a packet to transmit or receive, otherwise it should stay turned off to save energy. Therefore, MAC protocol is a key factor to minimize energy wastage [2].

In literature, there are many studies on energy-efficient MAC protocols specially designed for WBANs. At the same time, some surveys comprehensively investigate different approaches and compares well-known energy-efficient MAC protocols [3, 4].

2. isMAC PROTOCOL

In order to prolong network lifetime, a new beacon enabled Time Division Multiple Access (TDMA) based MAC protocol (isMAC) is proposed with three salient features multi-channel architecture, CN rotation and collision preventing mechanisms.

In this protocol, the proposed scheme is a "many to one communication" using two-tier star topology and supports the periodic data-gathering applications even if sensor nodes have different time intervals. To provide the energy balance among the sensor nodes, CN rotating mechanism [5] is used and CN is selected based on three metrics: current energy level (E_R), the number of becoming the CN (N_{CN}) and sensor node priority (N_{SP}). Fig. 2 describes a flow chart of suggested CN rotating mechanism.

At first, WBANs already know beforehand which node will be the next CN, depending on the N_{SP} parameter. However, according to the network conditions, such as unexpected battery depletion or malfunction, it may be necessary to select a new CN by taking into account N_{CN} and E_R parameters in such a way that the node that has the highest E_R value is chosen as the CN. The threshold value also limits the number of becoming the CN in sequential [6].

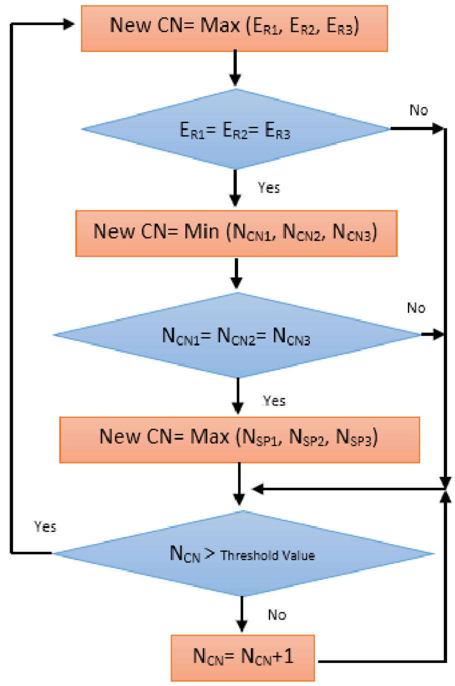

Fig. 2 Flow chart for the suggested coordinator node rotating mechanism

3. isMOTE SENSOR NODES

isMOTE wireless sensor nodes are designed to examine numerous MAC protocols and routing algorithms for academic and industrial purposes [7]. An isMOTE node uses the Microchip PIC 18F2525 microcontroller, operating at 20 MHz, with very low power consumption (100 nA - 11µA).

4. APPLICATION SCENARIOS

In this paper, we investigate three different scenarios to compare network and sensor node lifetime values. To decide the best scenario, three sensor nodes are defined that measure various medical signals (i.e. Electrocardiogram - ECG, accelerometer – Acc. and oxygen saturation – SPO_2). Sensor types, data parameters and duty cycle values are listed in TABLE 1.

Table 1. Sensor types and data parameters

Sensor Type	Data Rate	Bandwidth	Duty Cycle
ECG	288 Kbps	100-500 Hz	0.29491
Accelerometer	43.2 Kbps	0-500 Hz	0.04424
SPO_2	0.15 Kbps	0-1 Hz	0.00016

isMOTE node parameters and current consumption values are also listed in TABLE 2.

Table 2. isMOTE wireless sensor node parameters

Parameter	Value
Idle mode node current consumption	16.62 mA
0 dBm signal transmit current	34.18 mA
-18 dBm signal transmit current	29.88 mA
Receive mode current	30.65 mA
Battery power	580 mAh
Data transmit rate	1 Mbit/s
Data packet length	256 bit
Idle mode CPU current consumption	8.32 mA
Sleep mode CPU current consumption	11 µA

All scenarios use TDMA technique to access media and it is assumed that packet loss does not occur during message transmissions.

In the first scenario, all sensor nodes send data packets directly to the base station with the highest transmit power (0 dBm). Fig. 3 shows two-way communication between sensor nodes and the base station.

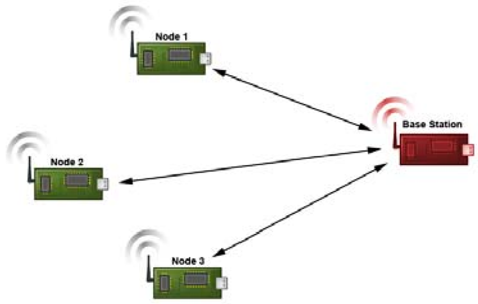

Fig. 3 Communication structure for scenario 1

In the second scenario, the sensor node which has the minimum duty cycle in WBAN is selected as a CN at first, and other two sensor nodes transmit measured value to the CN. Then, CN sends collected data packets and its own measured data to the Base Station (BS).

In this method, sensor nodes communicate in low transmission power mode except the CN. To reach maximum communication range between the CN and BS, the CN transmits packets with maximum output power. Fig. 4 demonstrates communication among sensor nodes, CN and BS.

Scenario 2 has a big drawback in terms of network lifetime because when a node is selected to become a CN, it is obligated to consume much more power, and deploys its energy long before the others.

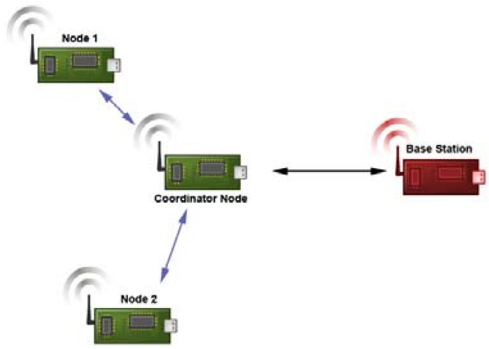

Fig. 4 Communication structure for scenario 2

Scenario 3 also benefits isMAC protocol and all sensor nodes can play CN role according to their E_R level. The sensor node which has the highest energy level performs the coordinator node role. Fig. 5 displays communication between the sensor nodes and coordinator rotating mechanism.

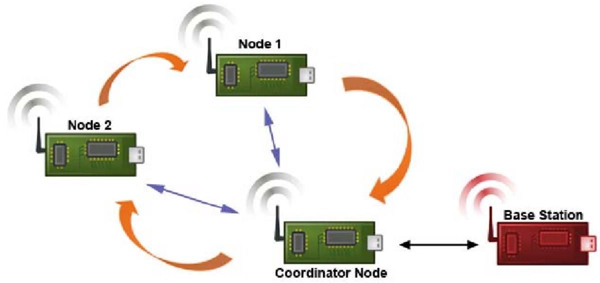

Fig. 5 Communication structure for scenario 3

5. ANALYTIC CALCULATIONS AND RESULTS

To calculate sensor node's residual energy value and lifetime for each scenario, ten different parameters and equation (1) are used, as below:

I_{Tx} = Average transmit current
I_{Rx} = Average receive current
I_I = Average idle current
I_S = Average sleep current
T_{Tx} = Average transmit time
T_{Rx} = Average receive time
T_I = Average idle time
T_S = Average sleep time
E_I = Initial battery power
E_R = Residual battery power

$$E_R = E_I - [(I_{Tx}.T_{Tx})+(I_{Rx}.T_{Rx})+(I_I.T_I)+(I_S.T_S)] \quad (1)$$

Fig. 6 depicts sensor nodes lifetime charts for scenario 1. It is clearly seen that ECG sensor has the lowest lifetime while oxygen sensor has the highest lifetime value. TABLE 3 shows analytically calculated sensor lifetime values for all three scenarios.

Table 3 Sensor lifetime comparison for three scenarios

Sensor Node	Lifetime (minutes)		
	Scenario 1	Scenario 2	Scenario 3
ECG	1597	1696	1677
Acc.	1997	2013	1677
SPO_2	2094	1055	1677

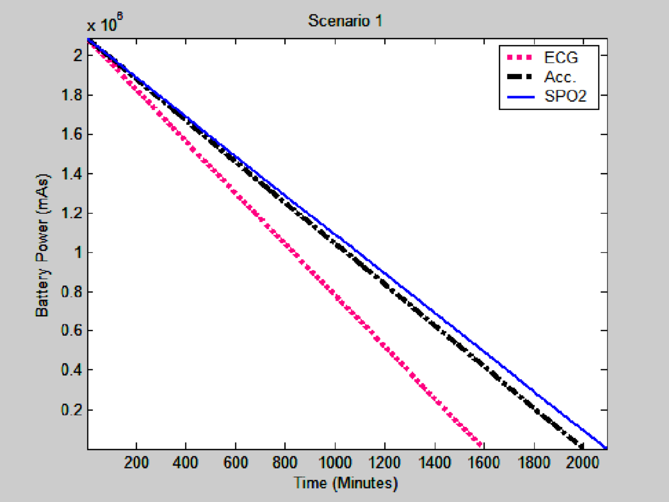

Fig. 6 Wireless sensor nodes lifetime chart for scenario 1

Fig. 7 shows sensor lifetime charts for scenario 2. The lifetime value of the oxygen sensor is 50% decreased evidently when it is employed as CN. The main reason for this dramatic shortening of life is caused by the increase in duty cycle of oxygen sensor.

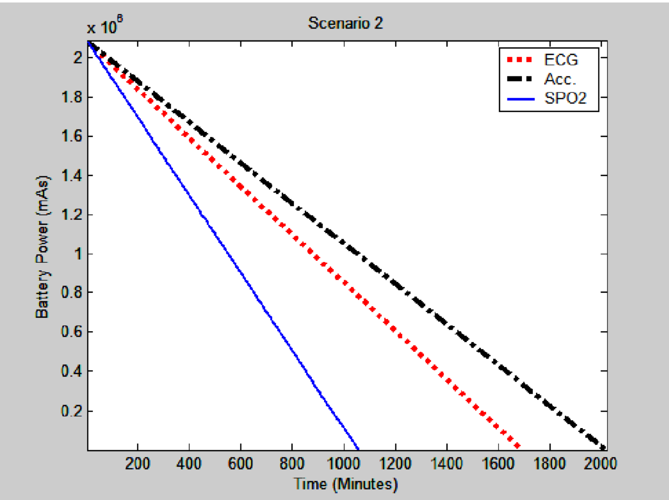

Fig. 7 Wireless sensor nodes lifetime chart for scenario 2

Fig. 8 displays lifetime charts for scenario 3. In this scenario, all nodes perform as a CN according to their remaining battery power. As a result, the residual energy level of sensor nodes is always balanced among all nodes.

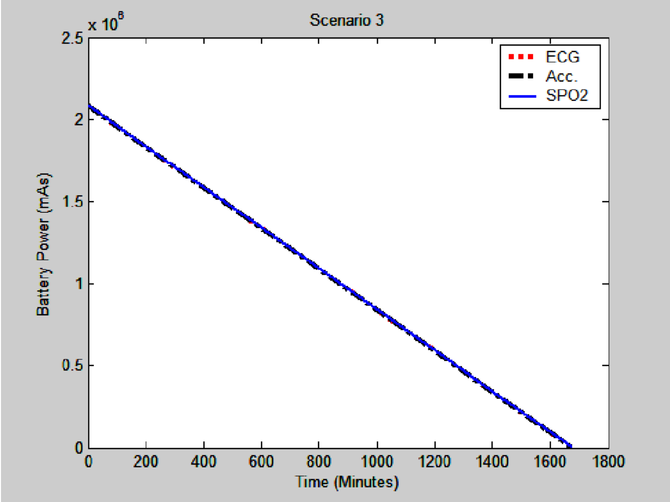

Fig. 8 Wireless sensor nodes lifetime chart for scenario 3

6. CONCLUSIONS

The results of this study shown in TABLE 3, clearly indicate that the third scenario provides 5% - 59% longer network lifetime comparing to the first and second ones. The findings may help us to understand how energy balance between the sensor nodes is important to extend the network lifetime.

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