Reliable Energy Aware MAC Protocol for Wireless Body Bio-Sensor Networks

Ch. Rajendra Prasad, Polaiah Bojja

Abstract**: *In the medical field, the WBBSNs is employed to monitor physiological signs of patients such as Electro Eencephal Ggram (EEG), Electro Cardio Gram (ECG), Heartbeat, Blood Pressure (BP), Temperature, etc. In WBBSNs consists of smart battery operated bio-sensors are deployed in/on-body of patients. The main constraint on these networks is the energy consumption and network lifetime. To address this we proposed Reliable Energy Aware Medium Access Control (REA-MAC) protocol for Wireless Body Bio-Sensor Networks (WBBSNs). This protocol employs Time Division Multiple Access (TDMA) approach for channel access with synchronization approach. To avoid idle listening and overhearing all bio-sensors remain in sleep mode until the time slot assigned by sink node. The proposed protocol performances are compared in terms of energy and reliability and simulation results shows that performance of overall network is improved by 20% as compared with* in IEEE 802.15.4 *protocol.***

Index Terms**: TDMA, MAC, REA-MAC, *WBBSNs*, superframe.**

I. INTRODUCTION

A Wireless Sensor Networks (WSN) uses air medium to accomplish distributed sensing tasks by interconnection of the several sensor nodes [1]. Advancements in wireless and storage technologies from last decade, number of smart bio-sensors are proficient of real-time health monitoring at the hospitals or remote places. WBBSNs allow us to use tiny bio-sensor nodes for real-time health monitoring. These tiny energy constrained bio-sensors monitor physiological signs of patient body and send to external monitoring station for analyze or treatment from a doctor. This streaming of data from patient to monitoring station employing wireless channel is energy consuming process. To prolong lifespan of these smart sensing devices and overall network energy efficient communication requires signal processing device equipped with low power. IEEE 802.15.4 describes a designation for Data Link and Physical Layers in Low-Rate Wireless Personal Area Networks [2].In [3], the WBAN is compatible to communicate with existing wireless technologies like Bluetooth, Wi-Fi, ZigBee, WLANs, WSNs, WPANs and the internet. Figure 1 shows the architecture of WBAN with 3 communication-tiers. In [4], communication Tier-1 is an Intra-WBAN which monitors the patient body through body sensors and collects the vital information like temperature, heartbeat, blood pressure etc, and send to the coordinator node using Bluetooth or Wi-Fi technology. Communication Tier- 2 is an Inter-WBAN, which comprises of a body coordinator that consolidated the data and transmits to the sink node. Tier-1 to Tier-3 data can be transferred through this gateway. In [5], the communication tier-3 is an extra WBAN where the sink transmits the gathered information to the remote medical centre and doctor through internet.

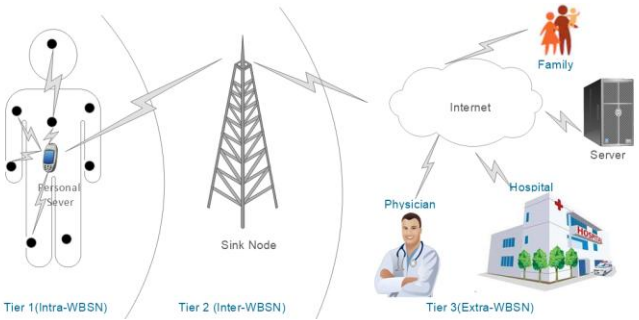

Fig. 1. WBBSNs communication architecture for medical applications[6]

The main problem that arises in WBBSN topology is battery recharging cycle and not feasible to detach batteries from body parts for charging them from time to time. Since each bio- sensor node continuously transmits their information to central device which is done at the cost of their energy consumption. Which result in stability of network and network lifetime is reduced, hence, energy distribution among the nodes is major factor for designing the WBBSNs [6,7]. Energy awareness is the vital specification for good MAC protocol in WBBSNs [8]. By concentrating on this above mentioned factors in mind, we proposed a new MAC protocol for WBBSNs. In this proposed topology, we adopted fixed mode communication and TDMA approach for channel access with a novel scheme of synchronization. To avoid inactive listening and excess hearing all bio-sensors remain in sleep mode until the time slot assigned by sink node. An adaptive guard band technique is employed to prevent collision due to clock drift of bio- sensor nodes. It minimizes the energy of bio-sensor nodes and stability of network is enhanced.

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II. MAC PROTOCOLS FOR WBBSNS

This section describes a few existing MAC protocols which are recommended for WBBSNs. This description concentrates on the in perspective of reduction of energy and utilization of resources for the MAC protocols. The subsequent subsections specify the working of these protocols by highlighting consumption of energy. In addition we discuss how MAC protocols for WBBSNS improve energy efficiency by handling energy consumption of the resources such as idle listening, collision, excess hearing and overhead of control packet (CP).

A. IEEE 802.15.4 MAC

For wireless applications low data rate IEEE 802.15.4 is designed with three operating frequency bands: 868, 915 and 2.4 GHz. Further these bands are splitted into 27 sub-bands i.e., one sub-channel in 868 MHz band, 915 MHz band into 9 sub-bands and 2.4 GHz band is splitted into 16 sub-bands. This protocol is working in 2 modes: beacon enabled mode (BEM) and non beacon enabled mode (Non-BEM).In BEM, central node uses periodic beacons device for synchronization, association and data streaming. This mode employs a super frame. Every super frame contains active and idle periods. The super frame in active period is splitted into 3 time slots: Contention Access Period (CAP) using slotted CSMA/CA, beacon and a Contention Free Period (CFP). Possibly 7 Guaranteed Time Slots (GTS) are allocated for bio-sensor nodes to have room for real-time in CFP. Due to its asymmetric nature of transmission, BEM of operation of IEEE 802.15.4 is not appropriate for WBBSNs.Non-BEM of IEEE 802.15.4 employs un-slotted CSMA/CA. In [2] authors, investigated slotted and un-slotted CSMA/CA and presented simulation results as shown in figure 2. The un-slotted technique is very sound in terms of utilization of bandwidth and energy.

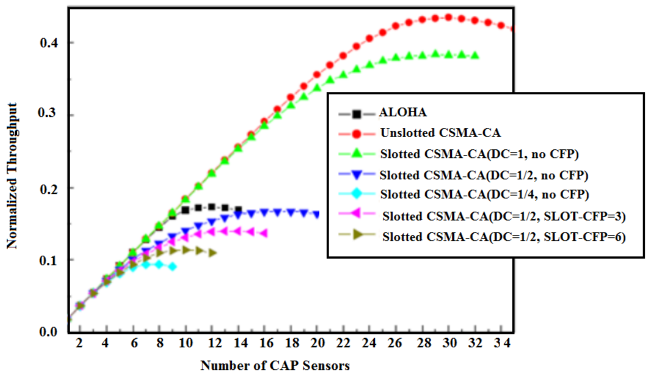

Fig. 2. CAP sensors Vs Normalized throughput

B. Battery-aware TDMA MAC

In [10], authors presented this MAC protocol to maximize the network life using cross-layer design. For medium access, this protocol concentrates on three factors: time-varying wireless fading channel, queuing characteristics of the pocket and electrochemical properties of battery. This protocol works similar to BEM in IEEE 802.15.4, where the modes pay attention once in a while to beacons from controller node. The time frame is spitted into three time slots; beacon, active time and idle time period as shown in the Figure 3.

C. Priority Guaranteed TDMA MAC

In [11], authors presented this protocol, which employs a novel super frame format as illustrated in figure 4. This protocol active period is splitted into 5 parts; a beacon, Time Slot Reserved for Periodic (TSRP) traffic Control Channel (AC1), Control Channel (AC2). AC1 is employed for uplink management of real-time health application where as AC2 is employed for uplink management of Consumer Electronics. This MAC is employs TDMA technique to allocate GTS within information slots TSRP and TSRB. Control channels assigns GTS based on their priority order. The simulation results of this protocol are improved in terms of consumption of energy as contrast with the IEEE 802.15.4 protocol. However, the major disadvantages of this protocol are super frame structure is complex and is not adaptable for emergency traffic.

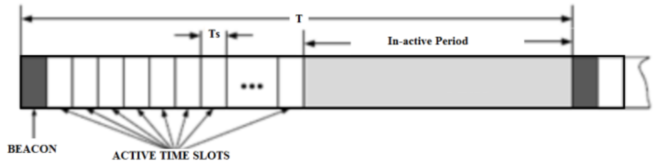

Fig. 3. Frame stucure of TDMA

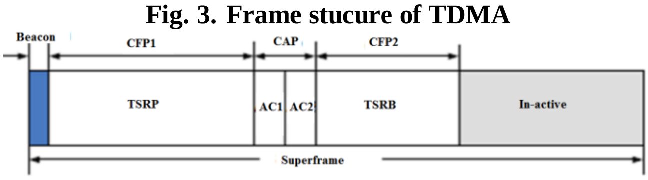

Fig. 4. Priority gaurantieed superframe stucure of MAC

D. Energy-Efficient Low Duty Cycle MAC

In [5] authors presented this protocol to support the static topology of BAN [5]. For streaming huge amount of data TDMA technique is used. The TDMA and Static topology are being used efficiently to exploit the stability and reliability of the network. In this network a Master Node gathers information from on- body bio-sensor nodes and transfers to the Monitoring Station. The gathered information is analyzed by monitoring station while the on-body management of the network and harmonization is being done by master node. As shown in Figure 5, the total frame is spitted into several time slots(TSs). The TS_1 - TS_n are assigned to sensor nodes where as time slots RS_1 - RS_k are reserved which are being provided when demanded.

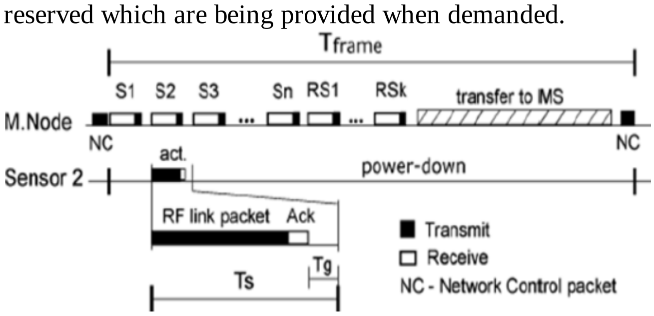

Fig. 5. TDMA frame structure

III. PROPOSED MAC PROTOCOL

The proposed REA-MAC protocol is employs TDMA method to decrease consumption of energy in the network. This protocol allocates GTS to every bio-sensor node for communication based on their necessities. To minimize excess hearing and inactive listening, proposed network employs sporadic sleep and awaken depending on necessities of the bio- sensor node. This protocol considered homogeneous topology; a central node gathers information from all bio-sensor nodes directly or indirectly via an Access Point (AP) and transmits to monitoring station.Central node is usually have superior computational power, transceivers (one or two) and equipped with larger batteries. The total time frame T_F is assigned in case of 2 transceivers, for efficient communication through all bio-sensor nodes. Where as in case of single transceiver the T_F is splitted into 3 parts: Contention Free Period (CFP) for communication with bio-sensors, Contention Access Period (CAP) to on-demand traffic or accommodate emergency and Time Management System T^{MS} for communicating sensor nodes' information to monitoring station.

A. Channel Selection

In the beginning, the central node starts searching for accessible free Radio Frequency (RF) channels. In case of current RF Channel is already in use, then the central node switches to actuate RF Channel. Once Central node gets a free RF channel for communication it transmits the Channel Packet (CP), channel information with its address to bio-sensor nodes. On the other side, the bio-sensor nodes scan RF channels for CP from central node. If it is free it switches to alternate RF channel. Else it waits for time T^{CP} to listen CP. If bio-sensor node does not receive the CP, it switches over to subsequent channel. By successful arrival of CP, the bio-sensor node initiates communication and transmits an acknowledgment packet to central node, as shown in fig. 6.

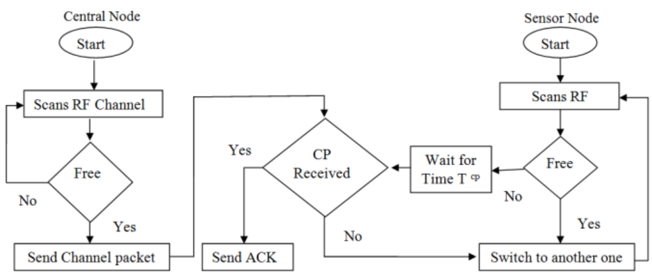

Fig. 6. Selection of Channel

Once bio-sensor node chooses a suitable RF Channel after receiving CP from central node, the bio-sensor node transmits a Time Slot Request (TSR) packet to central node. The TSR packet contains necessary time slot information and bio-sensor node's transmission baud. In [12,13] authors, presented fixed length time slot (TS) s using fixed guard time. On-body and implanted bio-senor nodes have different bauds and sampling intervals by dissimilar clock drifts. Allocation of time slots for fixed span and unequal necessities is expenditure of resources. REA-MAC employs a reliable method for TS and guard band time. Based on traffic model of nodes, central node allocates TS and transmits Time Slot Request Reply (TSRR). These TSs are of variable span depending on the necessities of bio-sensor nodes. Allocated TS can simply contain the transmission data pocket, ACK, reception data pocket and adequate delay, based on the network topology. A guard band time T^{GB} is placed in between the two consecutive TSs to prevent the interference caused by clock drift of bio-sensor node and central node are illustrated in Fig. 7.

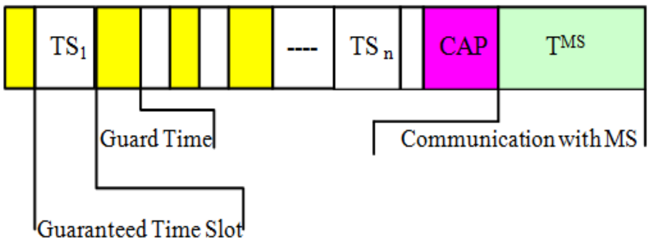

Fig. 7. TSs Assignment with GBT

Assignment of TSs with Guard-band Time Value of T^{GB} depending on time span of the consecutive TSs and is computed by using eq. (1), eq. (2) and eq. (3). Adaptive guard band prevents probability of collision and interference caused by clock drift.

$$T^{GB}_{n,n+1} = \frac{F}{100} \times 0.5\left[TS_n + TS_{n+1}\right] \quad (1)$$

$$T^{GB}_{1} = \frac{F \times TS_1}{100} \quad (2)$$

$$T^{GB}_{n} = \frac{F \times TS_n}{100} \quad (3)$$

where F is factor of guard band, which is function of average drift period. Conversely, the T^{GB1} is placed before TS_1 and similarly T^{GBn} is placed after TS_n. On successful TS assignment, bio-sensor nodes go to sleep mode and only awaken to transmit information to central node in assigned TSs. This sporadic sleep mode minimizes energy consumption due to inactive listening and excess hearing. Allotted TSs in CFP are absolutely collision free which minimizes the consumption of energy and provide reliable communication.

B. Synchronization

TDMA method needs additional energy expenditure for sporadic synchronization [14, 15]. The synchronization of all bio-sensor nodes itself is the energy consuming process for N number of cycles. The proposed protocol employs a innovative synchronization scheme to prevent collision and to decrease consumption of energy. After successful assignment of TSs to bio-sensor nodes, the central node listens to information packet within estimated TS. On successful reception of information packet, central node contrast the current arrival time and expected arrival time of the packet with negligible delay (D) and compute the Drift Value (DV).

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This DV is send to bio-sensor node through the acknowledgment to re-adjust TS for next transmission. But, DV depends upon D and F. If the deference greater than D, central node transmits DV within Synchronization Acknowledgment packet for next harmonization to bio-sensor nodes or else, central node transmits simple acknowledgment packet for received data packet. Bio-sensor nodes adjust it's awaken time by employing DV for future communication. In this synchronization scheme a bio-sensor node can enters to sleep mode within synchronization for total number of cycles (N). The Acceptable delay D is the function of TS_1, TS_2,..TS_n and the guard band factor F as under:

$$D = Min(TS_1, TS_2, ...TS_n) \times \frac{F}{100} \quad (5)$$

$$DV = \begin{cases} \Delta T, & if\ |\Delta T| > D \\ 0, & if\ |\Delta T| < D \end{cases} \quad (6)$$

where

$$\Delta T = Expected\ \ Arrival\ \ Time - Current\ \ Arrival\ \ Time$$

The choice of transmitting DV to end bio- sensor nodes is based on ΔT for further synchronization.

C. Analysis of Energy consumption

To model energy consumption analysis of the overall network, we presented the energy consumption in terms of the transceiver. In this analysis, the energy consumption of processing and sensing devices are assumed to be invariable. We presume sporadic traffic pattern, i.e., bio-sensor nodes transmit sporadic data to central node in allocated TSs. Bio-sensor nodes stay in sleep mode most of the period. During allotted TSs, they wake up to transmit the information. The energy consumption for N number of cycles for total network is computed using eq. (7).

$$E_{Total} = \sum_{k=1}^{N} E_{Active_k} + \sum_{k=1}^{N} E_{Sleep_k} \quad (7)$$

The total energy consumption is a sum of total time of the frame and the total current drawn from voltage source for a particular action. In sleep mode also bio-sensor nodes consumes the energy and is given in eq. (8). The sleep mode time is computed from length of the total time frame and active mode time period and is given in eq. (7).

$$T_{Sleep} = T_{Frame} - T_{Active} \quad (8)$$

$$E_{Sleep} = T_{Sleep} \times V \times T_{Sleep} \quad (9)$$

I_{Sleep} is the sleep mode current, which is drawn from voltage source(V). The bio-sensor nodes transmit, receive as well as wait for acknowledgment during T_{Active} period. For switching between sleep to active also consumes the energy. The E_{Active} is considered as energy consumption of fore mentioned actions during T_{Active} period and it is given in eq. (10)

$$E_{Active} = (2 \times E_S) + E_{TX} + E_{RX} + E_{TO} \quad (10)$$

where,

E_S=Switching energy

E_{TX}=Transmission energy

E_{TX}=Reception energy

E_{To}=Time-Out energy

IV. RESULTS

To evaluate and validate the proposed protocol we compared the energy efficiency with that of IEEE 802.15.4 protocol by deploying network with 10 bio-sensor nodes. To analyze the energy consumption of REA- MAC we employed Crossbow MICAZ transceiver features as simulation parameters are mentioned in Table I. We employed priority guaranteed superframe structure for MAC packet format as given in Fig.4. Time frame size used in simulations is T_{Frame} = 1 Second with drop rate of 1 to 2 percent. Fig. 8 shows the performance comparison of IEEE 802.15.4 and proposed protocol in terms of energy (mJ) and Pocket Error Rate (PER) (%).

Table 1. Simulation parameters

Parameter	Value
T^F	1 Sec.
Operating Voltage	3V
Transmit Mode Current	17.4mA
Receive Mode Current	19.7mA
Idle Mode Current	20mA
Sleep Mode Current	1μA
Number of Cycles(N)	1000
Bio-sensor Nodes	10

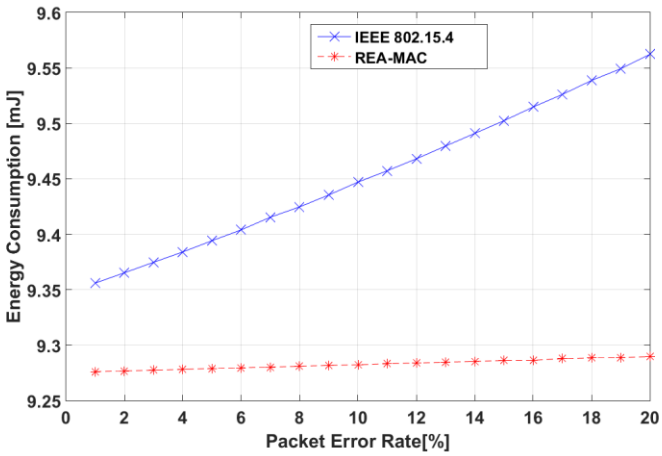

Fig. 8. Performance comparision of IEEE 802.15.4 Vs proposed protocol for N = 1000

To compute the energy consumption of both these networks, we employed eq. (7) with number of cycles are 1000. In Fig. 8 the graph of IEEE 802.15.4 increases as PER probability increases. This increase is mainly due to CSMA/CA operation in IEEE 802.15.4, which requires extra energy. But the graph of REA-MAC increases with a minor variation as compared with IEEE 802.15.4, due its adaptive guard band mechanism and adaptive time allocation. Further, to overcome the packet collision and overhearing, the REA-MAC allocates GTSs to every bio-sensor node for communication.

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V. CONCLUSION

A new MAC protocol for WBBSNs is presented in this paper i.e., REE-MAC. This protocol allocates guaranteed time slots in adaptive manner and provides reliable communication by introducing adaptive guard band to avoid collisions. Synchronization is attained by introducing a smart mechanism to balance the drift of bio-sensor nodes clock. From the simulation results, the performance of REE-MAC improved as compared with that of IEEE 802.15.4 in terms of energy consumption by 20 percent. Simulation results show superior performance.

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