A Reliable, Energy Aware and Stable Topology for Bio-sensors in Health-care Applications

Ch. Rajendra Prasad[1,2] and Polaiah Bojja[3]
[1] Research Scholar, Koneru Lakshmaiah Education Foundation (KLEF), Guntur, India.
[2] Department of ECE, S R Engineering College, Warangal, India.
[3] Department of ECE, Koneru Lakshmaiah Education Foundation (KLEF), Guntur, India.
Email: rajendra_prasad_ch@srecwarangal.ac.in; paulraj.bojja@gmail.com

Abstract —Advancements in Wireless and Micro-Electro-Mechanical Systems (MEMS) devices empowered a vast variety of wearable wireless sensors to be used for Wireless Body Sensor Networks (WBSNs). With technological changes WBANs are most capable approaches for allowing remote patient monitoring, improving the quality life and other Medicare applications. In this paper a Reliable, Energy Aware and Stable Topology (REAST) is proposed for WBSNs. For deployment of heterogeneous bio-sensors on patient body this topology is employed. We used direct and indirect communication for real-time and normal data delivery respectively. With indirect communication, any node can be elected as forwarder node, which can gather information from bio-sensors and then aggregating it for further transmission to the sink. Temperature and cost function of the bio-sensor node is considered for selection of node as a forwarder. The proposed algorithm to be simulated by considering parameters such as network lifetime, path loss and packet delivery. These parameters of the proposed network are compared with ATTEMT.

Index Terms—WBSNs, bio-sensors, stable topology, cost function, radio model, forwarding node

I. Introduction

WBSN is an emergent field of wireless senor networks that enables autonomous bio- sensor nodes to provide real-time healthcare of patients and human body conditions monitoring in no-medical applications [1]. Fig. 1 shows architecture of WBSN topology with wearable bio-sensors and three communication tires in the topology [2].In WBSN, bio- sensors are entrenched inside the body or wearable to monitor changes in body conditions such as body temperature, heat rate, blood pressure, glucose level etc. The real-time condition information of patient body is sending to central sever and doctor will enhance the treatment and Medicare of patients. This proves economical and is widely used in healthcare centres for patients' health monitoring. But, energy constraints are present on bio-sensor nodes and there is a research scope to minimize power consumption.

The main problem that arises in WBSN topology is battery recharging cycle and it is also not feasible to detach batteries from body parts for charging them from time to time. Since each bio- sensor nodes continuously transmit their information to central device which is done at the cost of their energy level consumption. Which results in stability of network and network lifetime is reduced. Hence, the energy distribution among the nodes is major factor for designing the WBSN. By concentrating on this factor, we propose REAST for WBAN. In this proposed topology two Bio-sensors are deployed near the sink to collect the emergency information of patient with low attenuation, these sensors continuously transmit their information to sink. Other sensors follow indirect communication to transmit their information via forwarder node which is elected by cost function defined in this protocol. It minimizes the energy of nodes and enhances the stability of network.

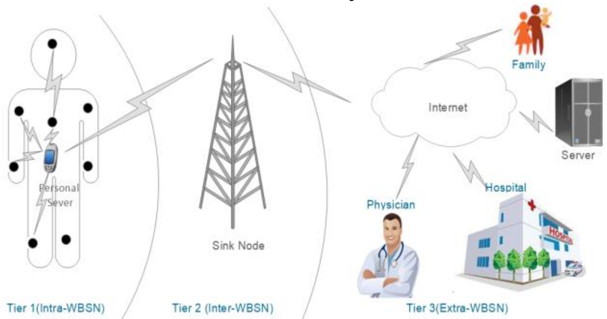

Fig. 1. WBSNs architecture [2]

II. Related Work

From last decade, changes in lifestyle of people have been takes place and our expectations are increased, the prevalence of long-term diseases has been increased. These physiological disorders often need a real-time monitoring of their vital signs. The portable health care system can provide opportunities and act as valuable support instrument for both patients and doctors [3].

In [4], authors presented a system in which the direct communication may raise the temperature of the sensor nodes which affect human body tissues. So, they used indirect communication for communication from root nodes to sink. But these authors' also present storage and congestion delay increase overall delay in indirect

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Corresponding author email: rajendra_prasad_ch@srecwarangal.ac.in
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communication. Hence communication is not best choice for emergency data. Previous established links disconnect due to versatility of our body. In setup of a new connection, it takes time and causes delay. Energy management is presented in routing protocol to outlay the problem of disconnection and to minimize the delay.

In [5] the authors proposed iM-SIMPLE, a routing protocol for WBANs. Indirect transmission is used to optimize the energy consumption and employed higher cost function node as forwarded node. This will further improve the pocket delivery and reduce path loss.

An ESR energy aware routing protocol [6] is considered for medical applications and hospitals. Due to Change in network topology batteries will deplete, consequently destroys efficiency of the network. Uniform load distribution plays an important role while designing a routing protocol, such that energy consumption at every iteration must be even. Direct transmission leads to more load on distant nodes and indirect communication rapidly deplete battery energy of nearer nodes quickly.

Authors in [7] used single-hop transmission to send data from nodes to sink. This technique is effective to beat delay; however, far away nodes consumes more energy. In [8] authors highlighted the indirect transmission between nodes and sink. But, delay and consumption of energy are major concerns in route selection. In [9] authors proposed EAR scheme which uses both direct and indirect transmissions in between nodes and sink. However, indirect transmission is not reliable for emergency data, because it results in delayed delivery of data. Authors in [10] employed priority-oriented tree structured protocol for WBASNs. They used specific channels for critical data and when critical data is successfully delivered; normal data is put forward for transmission. However, frequent loss of accessible resources takes place due to dedicated channels. Authors in [11] proposed adaptive route selection based on remaining energy at the node. Dynamic route selection assurances results in even load distribution on the nodes and extend lifetime of the network.

The network topology design issues for WBANs are presented in [12], [13]. The first issue is that number of forwarder nodes in the topology and it must be predetermined. The second issue is related with placement of forwarder node in architecture of WBAN. In addition, total network establishment expenditure is depends on relay nodes, because they attentend network lifetime issues.

III. Radio Model

Several number of radio models are presented in the literature. We used basic 1st order radio model in this paper. In this model, d is the distance from sender to the receiver and d^2 is energy loss from the channel. The 1st order radio model is characterized in (1) and (2) are given as.

$$E_T(p,d) = E_{T-elec}(p) + E_{T-amp}(p,d)$$

$$E_T(p,d) = E_{elec} \times (p) + E_{amp} \times (p)(d)^2 \quad (1)$$

$$E_R(k) = E_{R-elec}(k) E_{Rx}(k) = E_{elec} \times (p)$$

$$E_R(p) = E_{R-elec}(p) E_R(p) = E_{elec} \times (p)$$

$$E_R(p) = E_{elec} \times (p) \quad (2)$$

where E_T is the transmitter energy consumption, E_R is the receiver energy consumption, E_{T-elec} is the transmitter electronic circuit energy and E_{R-elec} is the receiver electronic circuit energy, E_{amp} is the required energy for amplifier circuit and p is the size of packet. In WBSN, human body is the communication channel which leads to attenuation of radio signal. So, we add path loss co-efficient (n) parameter in radio model of transmitter can be rewritten as in (3).

$$E_T(p,d) = E_{elec} \times p + E_{amp} \times p \times d^n \quad (3)$$

In Equation (3) based on the hardware, the energy parameters may be varied. We considered two most frequently available hardware transceivers in WBSN. The energy parameters for two commonly used transceivers are given in Table I and their frequency of operation is 2.4 GHz.

TABLE I: RADIO PARAMETERS

Parameters	nRF 2401A	CC2420
DC Current (Tx)	10.5 mA	17.4 mA
DC Current (Rx)	18 mA	19.7 mA
Supply Voltage(min)	1.9V	2.1V
Etx−elec	16.7 nJ/bit	96.9 nJ/bit
Erx−elec	36.1 nJ/bit	172.8 nJ/bit
Eamp	1.97e-9 j/b	2.71e-7 j/b

In this topology design, we consider a WBAN scenario in which eight sensor nodes are placed on the human body. The deployment of nodes is pre-determined and fixed. Let N is the set of nodes, *f* is the forwarder node and S is sink node. C_i is the capacity of the wireless link. The data generated by sensor is denoted by d_{is}, which is routed to sink by sensor node i. According to placement, we define the following connectivity parameters in (4) and (5).

$$A_{if} = \begin{cases} 1, & if \;\; i \;\; establishes \;\; a\, link \\ 0, & otherwise \end{cases} \quad (4)$$

$$A_{fs} = \begin{cases} 1, & if \;\; f \;\; establishes \;\; a\, link \\ 0, & otherwise \end{cases} \quad (5)$$

A_{if} represents the connectivity between i and *f*. similarly A_{fs} is the connectivity between *f* and S. Fs if is the data flow node i to forwarder. F_t^{fs} is the total data flow routed from forwarder node to the sink. We employed optimized energy dissipation model and given in (6) which shows energy utilized by sensor nodes to transmit data to *f* and to total energy utilized by the forwarder node(E_f) to transmitted and received at a packets.

$$\min \sum_{i\in N} E_t = \sum_{i\in N} E_t + E_f \tag{6}$$

where,

$$\sum_{i\in N} E_i(T_x) = \sum_{i\in N} d_{if} A_{if} (E_{T-elec} + E_{amp} \times n \times D^n)$$
$$\sum_{i\in N} E_i(R_x) = \sum_{f\in N} d_{if} A_{if} (E_{R-elec})$$
$$\sum_{f\in N} E_f(T_x) = \sum_{f\in N} f_{fs}^t (E_{T-elec} + E_{amp} \times n \times D^n \times E_{da}$$
$$\sum_{f\in N} E_f(R_x) = \sum_{f\in N} d_{if} A_{if} (E_{T-elec})$$

Subjected to:

$$\sum_{i\in N} d_{is} A_{if} (E_{T-elec} + E_{amp} \times n \times D^n) \le E \tag{7}$$

$$\sum_{f\in N} F_{fs}^t \le C_i \tag{8}$$

$$\sum_{i\in N} F_{if}^s - \sum_{f\in N} F_{fs}^t = 0 \tag{9}$$

$$A_{if} = 1 \qquad \forall_{i,j\in N} \tag{10}$$

$$A_{fs} = 1 \qquad \forall_{f\in N} \tag{11}$$

$$F_{fs}^t \le d_{is} A_{if} \tag{12}$$

$$A_{fs} A_{if} \in [0,1] \qquad i, f \in N \tag{13}$$

In equation (7) E is the limitation on the available energy for each sensor node. It represents the energy capacity constraint on sensor nodes. All sensors have finite energy constraints. Constraint in (8) is the capacity constraint on wireless link. C_i is the link capacity and the data routed on wireless link has not to exceed link capacity. Equation (9) shows the flow balance constraint. Data flow from sensors to sink, however, the converse cannot be true. Constraints in (10) and (11) are coverage parameters and guarantee overall coverage of the sensor network. If forwarder node is not connected with sink, then constraint in (12) ensures zero flow data on the link from forwarder to the sink. Constraints in (13) are the binary decision variables.

This section is discussed on throughput maximization model for WBANs. The minimum energy d of sensor nodes is another issue with high throughput requirement. The forwarder node gathers information from its neighbor nodes and transmits data to sink in this protocol. A forwarder node with large data rate is required to maximize throughput. The parameter r_i represents current data rate. A Sensor node transmits to sink when its residual energy and data rates are greater than the E_{min} and R_{min}, respectively. The physical link that carries data from node i to node j is characterized by $L_{i,j}$ and the wireless channel capacity by C_i.

Let Z_i is a 0 to 1 integer which represents nodes with residual energy greater than E_{min} and E_i is the sum of available energy. If the residual energy of nodes decreases below E_{min}, the nodes stop sending data. We formulate maximum throughput problem. The optimized model for maximum throughput is given as follows

$$\max \sum_{i\in N} d_{is}^t \tag{14}$$

$$\sum_{j\in N} y_{ij} = 0 \qquad \forall_{i\in S} \tag{15}$$

$$E_i \le E_{\min} \tag{16}$$

$$y_{i,j} \le y_{i,j} \qquad \forall_{i,j\in N} \tag{17}$$

$$\sum_{i,j\in N} y_{i,j} \le C_i \qquad \forall_{i,j\in N} \tag{18}$$

$$Z_i \ge r_i \qquad \forall_{i\in N} \tag{19}$$

$$\sum_{i,j\in N} y_{i,j} - \sum_{i,j\in E} y_{i,j} = 0 \tag{20}$$

$$A_{if} = 1 \qquad \forall_{i,j\in N} \tag{21}$$

$$A_{fs} = 1 \qquad \forall_{f\in N} \tag{22}$$

$$A_{fs} A_{if} \in [0,1] \qquad i, f \in N \tag{23}$$

The objective function in (14) represents the successful data transfer from i^{th} node to sink, through this we optimize throughput of network. The constraint in (15) presents that; there is no uplink traffic after the sink in the network. The constraint in (16) represents that, if the residual energy of a node decreases below minimum residual energy level E_{min}, the node is considered offline and it stops forwarding data to sink. The constraint (17) shows that the amount of data transfer on any link is bounded by physical link capacity. Similarly, constraint in (18) provides upper bound on the nodes, and it ensures that the traffic flow in the network is always less than the channel capacity. Constraints in (19) ensure that data rate is assigned to nodes with residual energy equal to or greater than E_{min}. Constraint in (20) is the flow conservation on the outgoing and incoming data of i^{th} node. Every node will send data to the sink but it does not receive any data from the sink, hence all data transmitted from the sensors must reach the sink. Constraints in (21) and (22) are the link parameters. In order to achieve high throughput, all nodes must have good communication link. Finally, constraint in (23) is the binary decision value.

IV. Proposed Work

In this proposed algorithm eight sensors and one sink are placed on the human body. The positioning of bio-sensor nodes and sink on patient body is shown in Fig. 2(a). Two paths are commonly used for communication between bio-sensor nodes and the sink.

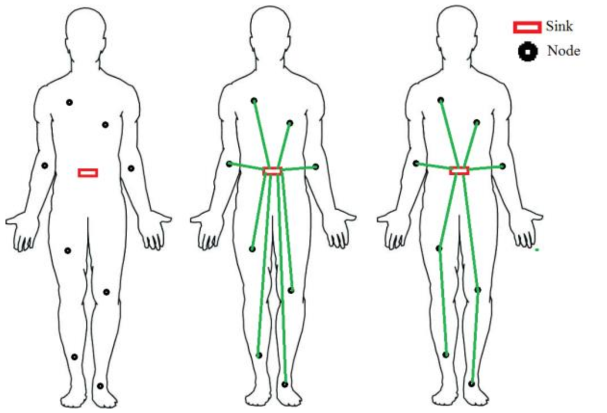

Fig. 2. a) Node deployment b) Direct communication c) Multi-hop communication.

Direct (Single-hop) communication: In this communication every sensor directly transmits the information to sink and is shown in Fig. 2(b). This communication is used for emergency (ECG and heart rate) data. For emergency data this protocol follows the direct communication between bio-sensor node and the sink.

Indirect (Multi-hop) communication: this type of communication is shown in Fig. 2(c), in which the data is transmitted via a path with less number of nodes. Two sensors already used for critical data and remaining six sensors uses this communication. Direct communication results in increased load on far away nodes and indirect communication leads nearer nodes quickly consume their battery energy. These problems have been handled by ATTEMPT protocol I [14]. But sill ATTEMPT is having drawbacks, these are presented in [15]. To minimize the mentioned difficulties in this paper we presented protocol II. This protocol is self-explanatory and extends the network lifetime, residual energy and reduces path loss of overall network.

Protocol I: ATTEMPT

```
Forwarder selection
In each round
For each node
Calculate Hop_count
For (i=0; i<=n; i++)
if (Hop_Count(i) <Hop_Count(i+1))
   select node(i) =forwarder node
 else
        if(S(i).E>S(i+1).E
          select node(i) =forwarder node
        else
          i=i+1
         select node(i) =forwarder
    endif
   endif
```

Protocol II: REAST

```
 Forwarder selection
In each round
For each node
Calculate Cost function(i)=1/(S(i).E^2 * distance(i)
For (i=0; i<=n; i++)
if (Cost function(i) >min Val &&S(i).E>Threshold Energy)
     select node(i) =forwarder node
else
      Directtransmission to sink
endif
```

V. Results

The performance evaluation of proposed REAST is compared with ATTEMPT protocol with the help of MATLAB simulations. We considered 6 × 2.5 feet network area for deployment of network topology, where wearable bio-sensor nodes are deployed at immobile places with initially energized with 0.4J and sink is deployed at centre of the human body. The radio parameters shown in Table I are employed in simulation by considering of collision-free channel. We observe the simulation results for 10^4 rounds or iterations on logarithm scale and represented with "r". The number of iterations required for first node death after establishment of network is known as Network stability period. Here span is presented in terms of iterations and in single iteration the protocol operation is completed once. First node death occurs at $0.21\text{x}10^4$ iterations, while for REAST $0.53\text{x}10^4$ iterations. Similarly, initialization of the network to the death of all nodes is the network lifetime is shown in figure (3).

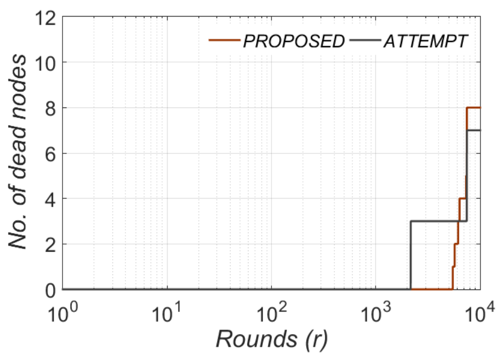

Fig. 3. Comparison of stability periods

Network lifetime of ATTEMPT is 10^4iteration and that for REAST is about $0.8\text{x}10^4$ iterations. Here network lifetime for ATTEMPT is more compared with our protocol but in WBANs we normally considered the half of the network life. The half the network lifetime period is same in both the protocols. Figure4shows of packets received at sink is extremely improved in REAST as related with ATTEMPT protocol. The improvement is achieved by selecting the forwarded node based on the cost function defined in REACT protocol. This somewhat reduces the multi-hop communication, if any node is which not satisfying the threshold conditions defined in REAST protocol. Numerically, the number of packets received in ATTEMT is 1.5×10^4 while that of REAST is about 4×10^4 respectively. This basically achieved by proper scheduling, which makes REAST is more reliable in terms of successful packet delivery in comparison with the ATTEMPT protocol.

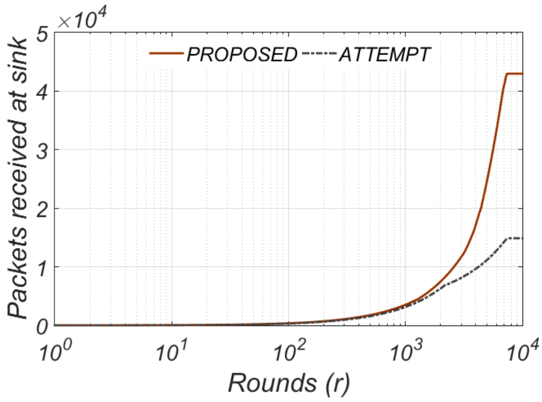

Fig. 4. Comparison of packets received at sink

The non-uniform of energy distribution in ATTEMPT may results from forwarder nodes consume more energy and unnecessary multi-hopping of data is avoided in REAST, hence it is having uniform energy distribution. Numerically, up to half of the network lifetime the residual energy in REAST double compared with ATTEMT. The comparison of residual energy for ATTEMT and REAST protocols are depicted in Fig. 5.

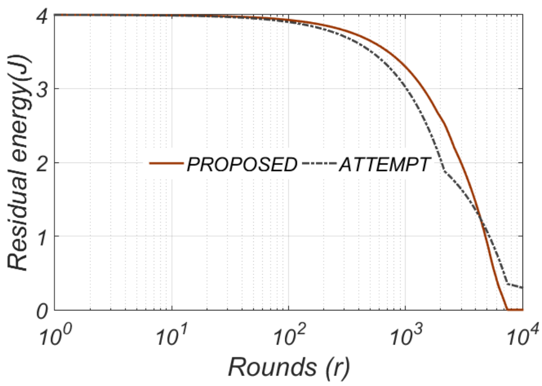

Fig. 5. Comparison of residual energy

The path loss is a function of frequency and distance. Path loss of each bio-sensor node is computed form its distance to sink with constant wavelength. Human body path loss co-efficient is also 3.38 and 4.1 for standard deviation ( ). Proposed protocol is having stable and less path loss as comparison with the ATTEMT protocol and is shown in Fig. 6.

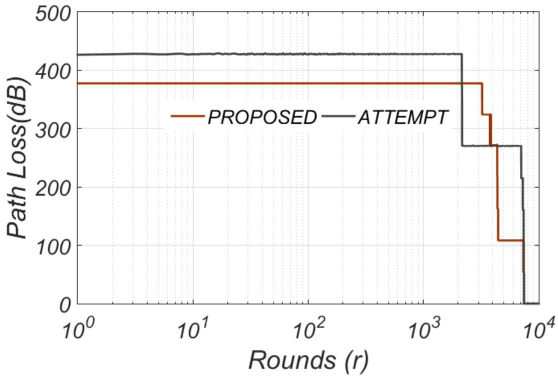

Fig. 6. Comparison of Path loss

VI. Conclusions

For heterogeneous WBSNs, we presented a reliable energy aware and stable topology. In this topology we deployed eight sensors for monitoring patient health conditions and one sink for collecting the data from these sensors. Out of these eight sensors, two are for demand data transmission and remaining six sensors for normal data transfer. For communication between sink and sensor nodes, we used direct and indirect communications. In indirect communication the forwarder node selection decides the energy consumption and the network stability. In this paper we presented new approach for selection of forwarder node. In this approach we considered new cost function and residual energy of the node to elect a as forwarder. This makes transmission to be successful by optimizing the energy consumption of overall network. The improvement in performance of network which is computed based parameters such as dead nodes, residual energy, packets received at sink and path loss. The MATLAB simulation results shows the improvement of the network performance by 30% as compared with ATTEMPT. Still there will be a scope for research to improve the network performance by considering mobility and hot-spot detection of nodes

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Ch. Rajendra Prasad Assistant. Professor, Department of Electronics and Communication Engineering, S R Engineering College, Warangal, Telangana, India. He is pursuing Ph.D. from Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India. He published 15 international journals and attended the 6 International Conferences. He is working as Co-investigator for DST project titled "Development of Adhesive Tactile Walking Surface Indicator for Elderly and Visually Impaired People". He has ISTE and IETE Life Member ships. His areas of interests are embedded systems, Wireless sensor networks and signal processing.

Polaiah Bojja, Professor, Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation, Guntur, Andhra Pradesh, India He is having more than 12 years of 3experience in teaching and Research from prestigious Institutes like NBKRIST, Vidyanagar, ASCET, Gudur, SVEC, Tirupati., He published 28 papers in reputed with highest index, SCI and Scopus journals and presented the 32 papers in International and National Conferences. He also completed one AICTE Project as Chief Investigator and having experience with reputed Govt. R&D departments as a consultant or developer as part of the prestigious projects."